Elastic mudflow regulating barrage and methodology for its calculation

G.V. Gavardashvili[1,2], E.G. Kukhalashvili[1], Sh.G. Kupreishvili[1,2], N.G. Gavardashvili[2]

[1]*Tsotne Mirtskhulava Water Management Institute of Georgian Technical University, Tbilisi, Georgia, givi_gava@yahoo.com, e.kukhalashvili@agruni.edu.ge, shorena_12@mail.ru*

[2]*Ecocenter for Environmental Protection, Tbilisi, Georgia, n.gavardashvili@gmail.com*

Abstract. The Elastic Debris Flow-Regulating Barrage is a longitudinal structure placed across the bed of a debris flow channel. As the heights of the prisms are increasing, the structure has a springboard shape directed opposite the current, while damping of the debris flow energy is attained by means of pockets formed with elastic ropes between the upper faces of the prisms. With the purpose of designing an elastic debris flow -regulating barrage, computational models were developed and a laboratory model was made based on them (with sizes: length – 0,60 m, width – 0,36 m and height – 0,25 m; the gradient of a springboard-type model is 0.25) to test it at the hydraulic laboratory. The methodology for calculating the design of Elastic Debris Flow-Regulating Barrage is presented.

Key words: *debris flow, elastic barrage, springboard, regulation*

Cite this article: Gavardashvili G.V., Kukhalashvili E.G., Kupreishvili Sh.G., Gavardashvili N.G. Elastic mudflow regulating barrage and methodology for its calculation. In: Chernomorets S.S., Viskhadzhieva K.S. (eds.) Debris Flows: Disasters, Risk, Forecast, Protection. Proceedings of the 6th International Conference (Dushanbe–Khorog, Tajikistan). Volume 1. Dushanbe: “Promotion” LLC, 2020, p. 88–96.

Селерегулирующий эластичный барраж и методология его расчета

Г.В. Гавардашвили[1,2], Э.Г. Кухалашвили[1], Ш.Г. Купреишвили[1,2], Н.Г. Гавардашвили[2]

[1]*Институт водного хозяйства им. Ц. Мирцхулава Грузинского технического университета, Тбилиси, Грузия*

[2]*Экоцентр охраны окружающей среды, Тбилиси, Грузия, givi_gava@yahoo.com, e.kukhalashvili@agruni.edu.ge, n.gavardashvili@gmail.com, shorena_12@mail.ru*

Аннотация. Противоселевой эластичный барраж представляет собой упругую конструкцию, устанавливаемую в селеносном русле поперек направления потока. По мере увеличения высоты призм конструкция имеет форму трамплина, направленного против течения, а демпфирование энергии селевого потока достигается с помощью карманов, образованных эластичными канатами между верхними гранями призм. С целью проектирования эластичного противоселевого барража были разработаны расчетные модели и на их основе изготовлена лабораторная модель (размеры: длина - 0,60 м, ширина - 0,36 м и высота - 0,25 м; уклон трамплина - 0,25) для испытаний в гидравлической лаборатории. В статье представлена методология расчета при проектировании противоселевого эластичного барража.

Ключевые слова: *селевые потоки, эластичный барраж, трамплин, регулирование*

Ссылка для цитирования: Гавардашвили Г.В., Кухалашвили Э.Г., Купреишвили Ш.Г., Гавардашвили Н.Г. Селерегулирующий эластичный барраж и методология его расчета. В сб.: Селевые потоки: катастрофы, риск, прогноз, защита. Труды 6-й Международной конференции (Душанбе–Хорог, Таджикистан). Том 1. – Отв. ред. С.С. Черноморец, К.С. Висхаджиева. – Душанбе: ООО «Промоушн», 2020, с. 88–96.

Introduction

The fund of the major fertile soils on the Earth, settled areas, agricultural and industrial facilities and a certain proportion of motor roads and railway lines are located in the riverbank zones or on the alluvial fans of solid sediment and are subject to an impact of such natural disasters as mudflow processes.

Due to an unexpected nature and great destruction force, these currents drastically change the existing environment and inflict great damage to the people's economy. Due to the activation of mudflow processes, the scientists were forced to study the physics of their formation and develop engineering measures on its basis to combat them [*Assessment of hazard mapping system in Georgia and recommended actions (Road Map), 2018*].

At present, in order to protect the buildings, premises and territories from mudflows, mudflow-arresters, mudflow-guide, and stabilizing, mudflow-avoiding and organized technical-engineering measures are used. They are as follows:

- Mudflow-arresting concrete, reinforced concrete rip-rap and ground dams: the mudflow currents are retained by forming mudflow-reserves in the surfaces;
- Mudflow-conducting channels, mudflow-diversion structures: they conduct mudflows across or by bypassing the object;
- Mudflow-guide and guard dams and heels: a current is directed to a mudflow-conducting bed;
- A cascade of dikes, retaining walls, slope terraces, agrotechnical melioration: the movement of mudflow currents are stopped or the dynamic properties of mudflow currents are diminished;
- Mudflow-avoiding structures, mudflow regulation dams, mudflow-diverters: mudflows are prevented;
- Organizing organizational-technical supervisory and reporting services: the occurrence of mudflow currents is predicted.

It should be noted that the first works to regulate mountain currents were accomplished in 323 c. BC in Japan. Since then, till the end of the XIX century, the scientists had to study the essence of mudflow origination and make conclusions in order to select the right measures to combat mudflows and to use them as a basis to classify the combating measures into the following groups:

- **European:** the European approach is based on the French school and prioritizes forest melioration as a measure to combat mudflows and recommends the construction of hydraulic structures, barrages, mass flood beds and weirs to regulate the tributaries of the second and third ranges of a hydrographic network. As per the recommendations of the European approach of recent year, open-end filtering barrages are expedient to use.
- **African:** the measures of the African approach, aiming at protecting the soil from erosion, use slope terracing and growing forest reserves and recently, have been using barrages as transverse hydraulic structures to regulate the watercourses.
- **American:** the American approach means regulating the mudflows by using the complexes of large hydraulic structures and mudflow-retaining dikes. Recently, the given measures have been actively using forest melioration, barraging, weirs, etc.
- **Asian**: the Asian approach uses a combination of European and African methods to combat mudflows. Recently, it has been widely using different kinds of transverse open-end structures.

Due to the abnormality, the peculiarity of impact of the mudflows on the structures is directly associated with structural solutions. The work proposes the copyrighted engineering solutions, which are totally different from the existing ones.

Georgia, as a mountainous country, with its territory of 69 700 km^2 and with 25 074 small and big rivers with the total length of 54 768 km, has over 3000 water catch basins with active erosive-denudation processes developed in them [*Gavardashvili*, *2011*].

In the South Caucasus (see Fig. 1), the major scientific-classical studies of erosive-mudflow processes started in 1776 when in Georgia, a strong glacial mudflow was formed as a result of the movement of the icy mass in the process of formation of Devdorak Glacier in the Tergi River basin, which blocked the Tergi River bed and inflicted a great damage to the territory of Russia, after accumulated water mass outburst through the temporary dam.

Fig. 1. Map of South Caucasus

Thus, the scientific studies of the erosive-mudflow processes in South Caucasus has an over 200-year-long history in the history of studies with Tsotne Mirtskhulava Water Management Institute of Georgian Technical University (GTU) (former Scientific-Research Institute of Hydraulic Engineering and Reclamation of Georgia (ГрузНИИГиМ)) actively participating in it since 1929.

It should also be noted that in the 1950-1990s, in the former Soviet Union, the Scientific-Research Institute of Hydraulic Engineering and Reclamation of Georgia was a coordinator of scientific forecasts of mudflow processes and fight against them.

Fig. 2 shows the risk of mudflow hazard in different Municipalities of Georgia. The blue line denotes a mudflow watercourse. Each Municipality is given in a different color by showing hazard risk coefficients, which are calculated by dividing the total length of the mudflow-forming watercourses to the total length of the network of rivers in the basin [*Natural Hazards in Georgia*. *SENN*, *Tbilisi*, *2011*].

By using this methodology, the map shows the least damaged municipalities in a grey color (Ninotsminda, Akhalkalaki, Dmanisi and the cities of Poti, Batumi and Kutaisi); the blue color denotes more damaged Municipalities (Adigeni, Kharagauli, Khashuri, Kareli, etc.) and the brown color denotes the Municipalities with the highest risk of hazard of the development of mudflow processes (Kazbegi, Dusheti, Telavi, Kvareli, Gurjaani, Oni, Mestia, Lentekhi, Tianeti etc.) [*Guide for adaptation to the climate change. Tbilisi*, *2016*].

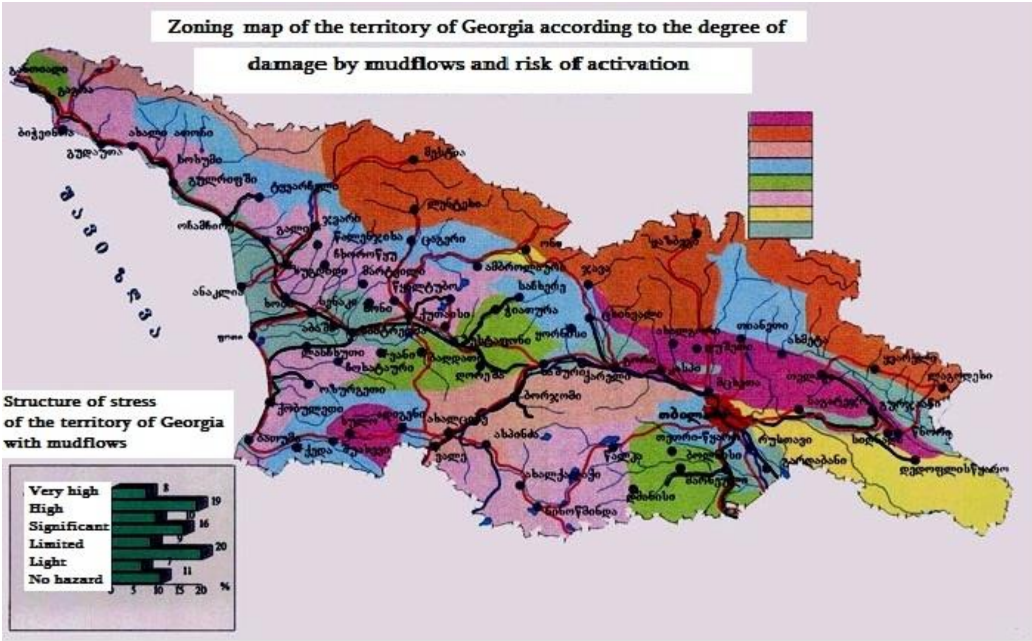


Fig. 2. Map of risks of mudflow hazard in Georgia

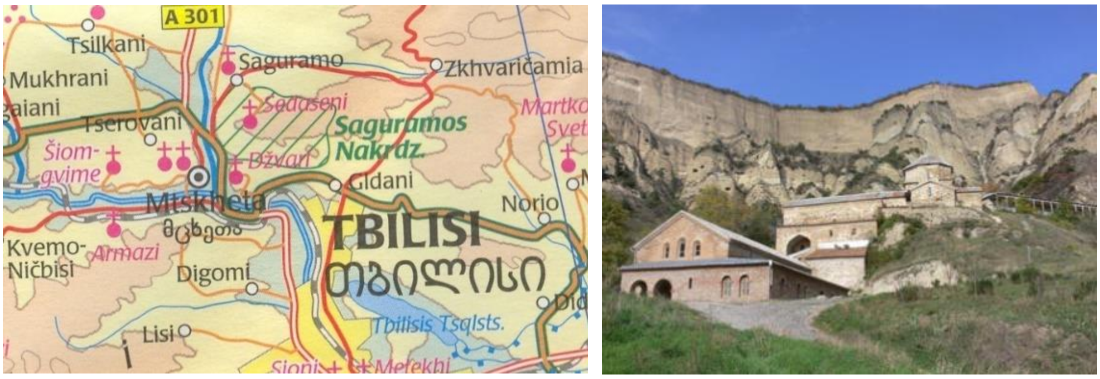
Study Object

On February 19, 2020, at the session of Technical Council of the Patriarchate of Georgia headed by episcope David, Mr. Givi Gavardashvili delivered a speech. The topic of his report was the presentation of Grant Project #AR-18-1244: “Elastic mudflow-regulating barrage” of Shota Rustaveli National Science Foundation and selection of the territory to build the facility. The Technical Council of the Patriarchate of Georgia made a decision to develop an elastic mudflow-regulating barrage project and provide the facility in the Samonastro Khevi River to protect the Shio-Mgvime Monastic Complex, a monument of the VI century, from mudflows [*Gavardashvili et al., 2013*].

The object of the study is the Shio-Mgvime Monastery located on the left bank of the Mtkvari River (see Fig. 3a), on the southern slope of Sarkine (Akhaltba) Ridge. The Monastery was founded by monk Shio, who came to Georgia from Syria. He spent the last two years of his life in a dark cave dug into the ground in the central part of the Monastery and was buried there. The ancient building of the Monastic Complex is the John the Baptist Church built in 560-570s, in the life of Shio, with its lower part built out of the rock cut on purpose. The Church is of a “Free Cross” type and is built with crushed stone (see Fig. 3b).

Geology of the area: the territory of the Shio-Mgvime Monastery is located at 600-650 m above sea level and the descending plane of the mountain slope is at the altitude of 750-760 m. In a geological respect, the territory is located in the central part of a big avalanche-type landslide, which is it main block.

Horizontally located thick strata of the Miopliocene conglomerates are clearly seen all along the height of a tear-off wall of the said landslide. The role of the cohesive ground of the conglomerates is played by clays, loamy soils and sometimes, sandy loams, resulting in weak cementing ability of the given rocks. Following the above-mentioned, under the impact of the surface waters, virtually loose non-cohesive ground has been converted into easily erodible material, with its strength, as per the visual assessment, exceeding several tens of meters.



a b

Fig. 3. a) Geographical location of the Shio-Mgvime Monastery. b) General view of the Shio-Mgvime Monastery

Soils and landscape: There are mainly alluvial, meadow alluvial and brown meadow soils spread on the territory adjacent to the Shio-Mgvime Monastery. These soils are gullied at some locations. At some locations, there are averagely or intensely washed-down dark, humus-sulphate (gazh) and dark brown soils subject to wind and water erosion and dissected with watercourses and active gullies, where the cases of freshets and mudflow passages have already been registered to date. Mostly, cliff xerophytes and light forests are identified on the territory of the Shio-Mgvime Monastery. As for the landscape, mostly forest plantations grow on meadow alluvial carbonate or brown soils in the environs of the Shio-Mgvime Monastery.

Climate: The territory of the Shio-Mgvime Monastery has a moderately humid climate, with moderately cold winter and hot summer, with two precipitation minimums a year: average 500-550 mm during the warm season of the year and 150 mm in the cold season of the year. An average value of absolute annual minimums of air temperature is 14° and an average value of absolute annual maximums is +38°; annual amplitude of air temperature is 24°. The number of days with a snow cover in winter is 30 a year, with an instable snow cover; the date of snow cover melting is 1-11 March. The duration of a stable snow cover does not exceed 50 days. Average annual evaporation on the territory of the Shio-Mgvime Monastery does not exceed 900 mm.

Goal of the study: The goal of the scientific study is to provide a structural design of an innovative mudflow-regulating barrage to protect the Shio-Mgvime Monastery against erosive-mudflow processes, to test it at the laboratory, develop the methodology to design the facility and build it in the River Samonastro Khevi to protect the Shio-Mgvime Monastery from mudflows. The given works are accomplished under the financial support of Grant Project #AR-18-1244 of Shota Rustaveli National Science Foundation.

Elastic mudflow-regulating barrage

With the aim to protect the Shio-Mgvime Monastery against mudflows, by considering the topographic, geological, hydrological and hydraulic properties of the River Samonastro Khevi, an innovative design of a mudflow-regulating barrage was developed at Tsotne Mirtskhulava Water Management Institute of Georgian Technical University (GTU), whose scientific and technical priority was approved in 2020 by Georgian Patent License [*Gavardashvili et al., 2019*].

The mudflow-regulating facility is made up of a surface of bank trusses (3), supports (4), trusses (5) and beams giving it additional stability (7), which are located in a manner as to form triangular prisms, with their bases with the holes to hold the ropes (8) are a support of the pockets of a semi-cylindrical shape formed with the ropes to be fixed (hung) in the body of the triangle bass along the current (1) and laterally (2).

Sizes of the mudflow-regulating facility: by considering the expected mudflow and site topography, the main impact force of a current passage strikes the mudflow-retaining pocket provided on the initial steps of the facility, while the subsequent quenching of energy is attained gradually on the springboard surface at the expense of an elastic cylindrical surface. The sizes of the through force are directly associated with the diameter of the micro-transported stones of the expected mudflow. Owing to its elasticity, the designed facility is capable of receiving multiple impacts of the mudflow. The technical-economic advantage of the facility is that it is possible to use it for many times by untying the ropes and cleaning the facility. In addition, the construction elements with less complex shapes are used in the facility design that reduces the cost of construction [*Kukhalashvili et al., 2019*].

The innovative aspects of the elastic mudflow-regulating barrage are that the barrage is reliable and has long service life; it is stable and elastic to the impact force of the current and comes with better elasticity and reduced rigidity.

The design of the elastic mudflow-regulating barrage (Fig. 4) uses the construction structures of simple shapes and secondary resources reducing the construction costs drastically, while the multiple use of the barrage results in its high technical-economic value.

Hydrological and hydraulic calculation of the Samonastro Khevi River to regulate

The natural factors contributing to the erosive-mudflow processes on the Samonastro Khevi River and its tributaries are: 1) the geology of the territory: great thicknesses of loose non-cohesive rocks playing a role of hearths of solid mudflow material, 2) the type of precipitations: short, but intense downpours are typical to the given Region (Mtskheta Region), 3) peculiarities of the relief: a big water catch basin, well-developed erosive network with dense branches and symmetrical location and steep slopes of the gorge and slopes, and 4) poor vegetation cover on the vertical tear-off wall (virtually, without grass cover).

The 1% liquid flow in the Samonastro Khevi River was calculated with the dependence of Prof. G. Rostomov [*Gavardashvili et al., 2013*], which is as follows:

$$Q_{\max} = R\left[\frac{F^{0,66}\cdot K^{1,35}\cdot \tau^{0,38}\cdot I^{0,125}}{(L+10)^{0,44}}\right]\cdot S\sigma\lambda \text{ (m}^3\text{/sec)}, \quad (1)$$

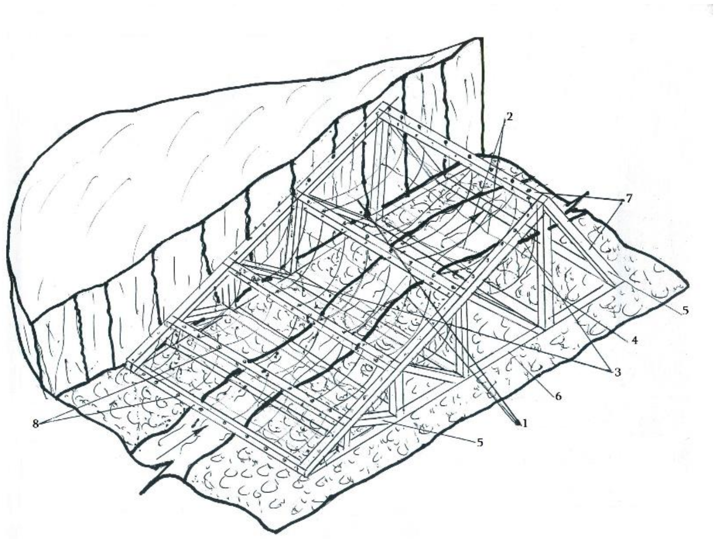
where: R is the regional coefficient and is 1,15 for the water catch basin of the Mtkvari River; F is the area of the water catch basin of the Samonastro Khevi River (F = =0,0156 (km^2)), K is the climatic coefficient (K = 5,5); τ is the reoccurrence in years (τ = 100 years); I is the average gradient of the watercourse (I = 0,181); L is the length of the watercourse (L = 0,375 km); S is the soil index (S = 0,82); σ is the shape coefficient of the water catch basin (σ =1,14), λ is the basin forestation coefficient (λ = 0,893). By inserting the data of the Samonastro Khevi River in dependence (1), we will gain:

$$Q_{\max} = 1{,}15\left[\frac{0{,}064\cdot 9{,}988\cdot 5{,}754\cdot 0{,}807}{2{,}80}\right]\cdot 0{,}835 = 1{,}33 \text{ (m}^3\text{/sec)}. \quad (2)$$

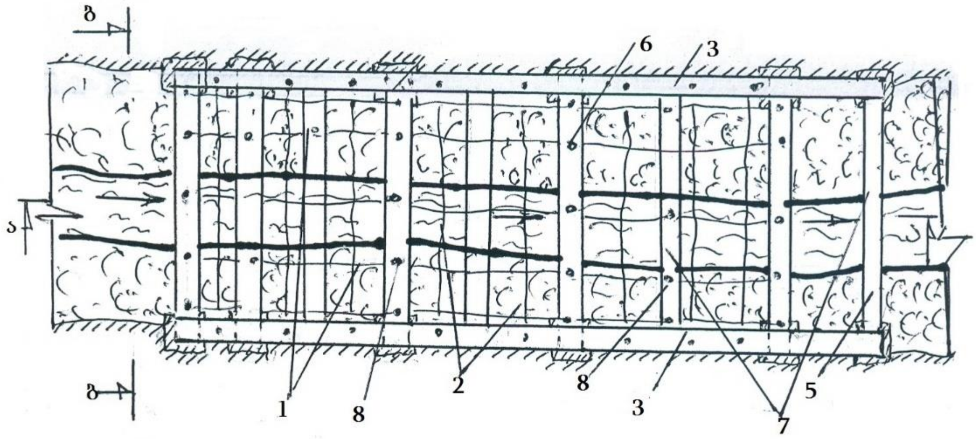
The density of turbulent mudflow (ρ) is calculated with the following dependence:

$$\rho = \frac{\gamma_m - \gamma_w}{\gamma_s - \gamma_w}, \quad (3)$$

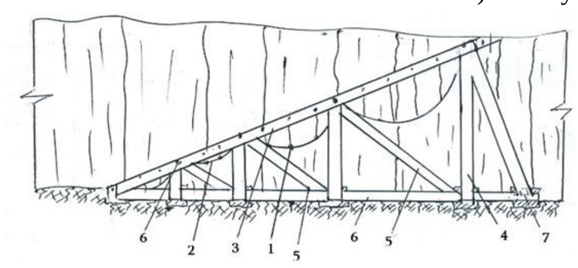
where: γ_m is the volume weight of the turbulent mudflow (γ_m = 1,8), γ_w is the water volumetric weight (γ_w = 1,0), γ_s is the volumetric weight of a stone (γ_s = 2,65). By considering the given values, by using dependence (3), we calculate the mudflow density, which is ρ = 0,48.



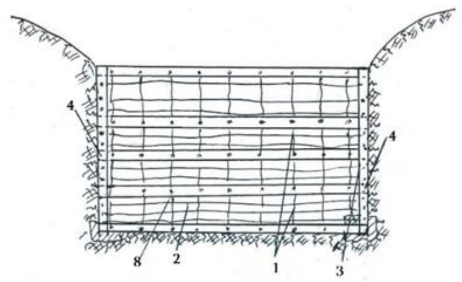
a) Elastic barrage in axonometry



b) Facility plan



c) Longitudinal section of the barrage



d) Cross section

Fig. 4. Elastic mudflow-regulating barrage

By using the given values, we calculate peak discharge of the turbulent mudflow with the following formula [*Натишвили, Гавардашвили, 2018*]:

$$Q_m = \frac{\gamma_w \cdot Q_w + \gamma_s \cdot \rho \cdot Q_w}{\gamma_m} = \frac{1{,}0 \cdot 1{,}33 + 2{,}65 \cdot 0{,}48 \cdot 1{,}0}{1{,}8} = 1{,}45. \quad (4)$$

As a result of the expedition studies accomplished in the Samonastro Khevi River in 2000-2019, it was determined that the mudflow passage mainly occurs from May to July, with the depth of H=1,0 m; the average diameter of solid fractions transported by the mudflow is 10-15 cm and their maximum diameter is 20-30 cm. However, in some cases, stone admixtures with the diameter of 40-50 cm were fixed in the bed of the Samonastro Khevi River.

In case of a peak discharge of the turbulent mudflow formed in the Samonastro Khevi River, the relevant velocity is calculated with the following dependence [*Натишвили, Гавардашвили, 2018*]:

$$V = \frac{6{,}5 \cdot H^{0,66} \cdot I^{0,25}}{\sqrt{\frac{\gamma_m(\gamma_s - 1)}{\gamma_s - \gamma_m}}} = \frac{6{,}5 \cdot 1{,}0^{0,66} \cdot 0{,}19^{0,25}}{\sqrt{\frac{1{,}8(2{,}65-1)}{2{,}65-1{,}8}}} = 2{,}29 \qquad (5)$$

Thus, by knowing the main hydrological and hydraulic characteristics of the turbulent mudflow, at the next stage, we may consider the design engineering plans of an elastic mudflow-regulating barrage to protect the Shio-Mgvime Monastic Complex against the natural calamities.

Laboratory modeling of the elastic mudflow-regulating barrage

In order to provide a laboratory model of the elastic mudflow-regulating barrage, a hydraulic channel was selected at the hydraulic laboratory of Tsotne Mirtskhulava Water Management Institute with the following sizes: width – 0,36 m, height – 0,29 m, channel gradient variation – 0,01-0,06.

As for the model of the elastic mudflow-regulating barrage itself, its sizes are as follows by considering the parameters of the hydraulic channel: length of the model barrage – 0,60 m, width – 0,36 m, maximum height of the barrage is 0,15 m, number of steps is 3, length of the step base is 0,20 m, the sizes of the through network holes to provide in the elastic pockets are 5-7 mm in the first case, 4-5 mm in the second case and 203 mm in the third case (see Fig. 5).

a b

Fig. 5. Elastic mudflow-regulating barrage: a) laboratory model of the barrage; b) barrage in experiment

The test experiments on the laboratory model of the elastic mudflow-regulating barrage will be provided in terms of movement of the currents loaded with sediment through the hydraulic channel, where the following parameters of modeling similarity will be observed: the laboratory experiments will be done in terms of movement of the currents loaded with sediment through the hydraulic channel when dynamic similarity ($Fr = ident$), geometrical similarity (bed gradient $i = ident$), sediment movement ($V_{water} / V_{sediments} = ident$), bed resistance coefficient (Chezy's coefficient $C = ident$). At present, the experiment planning methodology is being specified with the aim to continue the works at the laboratory.

Conclusion

With the aim to efficiently regulate the mudflows, an innovative design of the elastic mudflow-regulating barrage was developed at Tsotne Mirtskhulava Water Management Institute of Georgian Technical University (GTU) and the priority of its scientific-technical novelty was approved by Georgian Patent License (GE P 2020 7068);

Based on the available scientific literature and field and experimental studies, the geographical, climatic and geological conditions of the Samonastro Khevi River were evaluated and the principal hydrological and hydraulic parameters of the turbulent mudflow formed in the given River were calculated.

Aiming at developing the model of the elastic mudflow-regulating barrage, the design plans of the facility were developed, a laboratory model was prepared by using it and relevant scientific studies were accomplished at the hydraulic laboratory of Tsotne Mirtskhulava Water Management Institute of Georgian Technical University (GTU).

The results of the primary scientific studies are satisfactory what allows continuing the laboratory studies in the future.

Acknowledgments

The scientific studies are accomplished under the financial support of Grant Project #AR-18-1244 “Elastic mudflow-regulating barrage” of Shota Rustaveli National Science Foundation.

References

Assessment of hazard mapping system in Georgia and recommended actions (Road Map). (2018). Tbilisi, Georgia, 64 p.

Gavardashvili G. (2011). Measures for the Safety of Mountain Landscapes During Natural and Tehnogenic Disasters. Tbilisi, Universal, 273 p. (in Georgian).

Gavardashvili G.G., Chakhaia G.G., Tsulukidze L.N., Okriashvili O.K. (2013) Designing The Engineering-Environmental Measures To Protect The Shiomghvime Monastery Against Erosive And Mudflow Processes. // Proceedings of the 5th International Conference on Contemporary Problems in Architecture and Construction. June, 24-27, Saint-Petersburg, p. 7-12.

Gavardashvili G., Kukhalashvili E, Kupreishvili Sh., Gavardashvili N. (2019). Elastic debris flow-regulating barrage. Georgian Patent #AP 2019 14656 A. Official, Bulletin of the Industrial Patent #15(523), SAKPATENTI, 12/08/2019, Tbilisi, p. 6.

Guide for adaptation to the climate change. Tbilisi, 2016, p. 266.

Kukhalashvili E.G., Gavardashvili G.V., Kupreishvil Sh., Gavardashvil N.G. (2019) - Designing and evaluating elastic debris flow-regulating barrage for efficient debris flow regulation. XIII International Conference on Environmental, Biological, Ecological Sciences and Engineering.

WASET, Rome, Italy, December, 12-13, pp. 759- 762.

Natural Hazards in Georgia. SENN, Tbilisi (2011), 65 p. http://drm.cenn.org/paper_atlas/RA-part-3. pdf

Натишвили О.Г., Гавардашвили Г.В. (2018). Гидравлический расчет противоселевого сооружения с донной решеткой для гашения кинетической энергии несвязного селевого потока с целью трансформации его в обыкновенный наносонесущий поток. // Селевые потоки: катастрофы, риск, прогноз, защита. Труды 5-й Международной конференции Тбилиси, Грузия, 1-5 октября, с. 500 – 505