Ecological and engineering solutions for the reconstruction of anti-mudflow hydraulic structures of the Crimea

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Abstract. The article studies the territorial features of the formation of a dangerous process - mudflows. The factors of mudflow hazard formation are described, the classification and characteristics of mudflows formed in the Crimea are given. The methods of studying mudflows are considered, the parameters of the mudflow are calculated on the example of the Shelen River, on the basis of which options for the reconstruction of existing mudflow protection structures are proposed. The purpose of the article is to substantiate environmental engineering solutions for the reconstruction of anti-mudflow hydraulic structures in mudflow-prone Crimean river basins. The object of research is the basin of the Shelen River typical for the South-Eastern rural area. The purpose of the research is to substantiate technical solutions for the reconstruction of anti-mudflow structures in the Shelen River basin. Research objectives: to study the conditions for the formation of Crimean mudflows, the history of research and classification; consider existing methods for studying mudflow hazard and calculation methods for determining the parameters of mudflows; to characterize the current state of anti-mudflow structures on the example of the Shelen river basin; justify decisions on the reconstruction of anti-mudflow structures and develop recommendations for their restoration. In the article, on the basis of field studies, hydrological flood flow rates, annual runoff volumes, water flow rates and volumes in years of different water content and average monthly water flow rates using the Shelen River basin as an example, the mudflow parameters are calculated. Anti-mudflow structures were identified and their condition was analyzed. Based on the results of the study, proposals and environmental engineering technical solutions for the reconstruction of existing anti-mudflow structures were developed

1 Introduction

The article studies the territorial features of the formation of a dangerous process - mudflows. The factors of mudflow hazard formation are described, the classification and characteristics of mudflows formed in the Crimea are given. The methods of studying mudflows are considered, the parameters of the mudflow are calculated on the example of

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the Shelen River, on the basis of which options for the reconstruction of existing mudflow protection structures are proposed. The purpose of the article is to substantiate environmental engineering solutions for the reconstruction of anti-mudflow hydraulic structures in mudflow-prone Crimean river basins. The object of research is the basin of the Shelen River typical for the South-Eastern rural area. The purpose of the research is to substantiate technical solutions for the reconstruction of anti-mudflow structures in the Shelen River basin. Research objectives: to study the conditions for the formation of Crimean mudflows, the history of research and classification; consider existing methods for studying mudflow hazard and calculation methods for determining the parameters of mudflows; to characterize the current state of anti-mudflow structures on the example of the Shelen river basin; justify decisions on the reconstruction of anti-mudflow structures and develop recommendations for their restoration. In the article, on the basis of field studies, hydrological flood flow rates, annual runoff volumes, water flow rates and volumes in years of different water content and average monthly water flow rates using the Shelen River basin as an example, the mudflow parameters are calculated. Anti-mudflow structures were identified and their condition was analyzed. Based on the results of the study, proposals and environmental engineering technical solutions for the reconstruction of existing anti-mudflow structures were developed.

When conducting a survey of the territory accepted for study, it was revealed that the situation has changed, in the basins and channels of watercourses over the past 30 years, almost all mudflow protection structures have been destroyed - retaining walls have been washed away and displaced, terraces are partially covered with loose material (the solid component of mudflows), unregulated cutting down of protective plantings has led to to slope deformations. The importance of mudflow studies is indicated by the results of the analysis of floods and the level of implementation of measures for anti-mudflow protection in the mountainous part of Crimea. Based on the materials of Lushchik A.V. [1] the last powerful mudflow in the region under study passed along the river. Raven in 1998. In the results of the survey, it was found that it was quite characteristic. As a result of the passage of the mudflow flood, the water metering post was destroyed, since the flow rate of the flood reached 70 m^3/s. A feature of the past mudflow was a variable qualitative component of sediments, since the mudflow was either a water flood or a mudflow. The state of mudflow protection structures, difficulties in predicting the occurrence of mudflows due to a large number of factors to be taken into account, and the uneven frequency of passage and destructiveness determine the relevance of concretizing projects for the reconstruction of mudflow protection structures in Crimea. Therefore, an assessment of the state of mudflow protection structures is necessary to establish the feasibility of using structures of a certain type.

2 Materials and methods

Studies of the reasons for the formation of mudflows, their characteristics and the construction of mudflow protection structures in the Crimea have been systematically started since 1955 and are described in the works of B.M. Goldina, A.N. Oliferov and B.I. Ivanova and others. It has been proved that for the territory of the Crimean peninsula, the anti-erosion properties of forest plantations are important, since the lack of vegetation provokes the formation of mudflows. Since 1963, taking into account the features of the formation of mudflows in Crimea has been implemented in government decisions to create a system of stationary posts for mudflow formation, and made it possible to compile a cadastre of mudflows, engineering-geological maps of the forecast of mudflows in Crimea until 2000.

During this period, anti-mudflow measures were also developed and implemented: upstream mudflow trapping dams and ponds were created in the upper reaches of the rivers, terraces and a system of shrub plantings were created on the slopes of the mountains.

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Modern studies of mudflows and mudflow hazard on the territory of the mountainous part of the Crimean peninsula are divided into two components: comparison of quantitative and qualitative regional characteristics of mudflows with other areas of their formation in Eurasia and assessment of dynamic characteristics (intensity, strength and impact on socio-economic objects (destructiveness) in time.

3 Results

The ongoing research made it possible to detail the natural and technogenic factors that form destructive mudflows - natural (geological-geomorphological, tectonic, climatic, hydrological-hydrogeological) and technogenic - a decrease in forest cover, intensive agricultural activity (grazing and plowing slopes with depleted vegetation, construction).

Mudflows passing through the territory of the Crimea, according to their hydraulic characteristics, belong to the category of fluid, turbulent. The mudflow velocity reaches 1.2–4 m/s, which is comparable to the velocity of the water flow.

Taking into account the mineralogical and mechanical composition of the solid component of mudflows and the models used for the movement of mudflows, they can be divided into connected (structural) and disconnected (turbulent).

Mudflows in the Crimea are classified as water-stone, which contain a small amount of sandy and clayey fractions, which allows us to conclude that the transparency is average in comparison with mudflows, and a significant mass and volume of coarse clastic fraction in the mudflow.

According to A.N. Oliferov [10], mudflows occurring in the mountainous part of the Crimea do not exceed 1700 kg/m^3 in density. With an observed average density of about 1,100 kg/m^3, water flows-floods are transformed into mudflow processes, in which there is a destruction of the channel, saturation with coarse clastic material, transportation of fragments of different sizes over a considerable distance along the entire length of the channel, the formation of mudflow cones at the mouths of gullies and rivers . Most of the passing mudflows in the Crimea are characterized as disconnected nanowater.

The studies carried out by the authors confirm that mudflows in terms of physical and mechanical characteristics represent an intermediate state between a mudflow and a flood. The reduced density of mudflows in the conditions of a dissected relief and a large amount of loose clastic material leads to an increase in their destructiveness - erosion and destruction of valuable agricultural land - vineyards, orchards, fields, etc.

On the other hand, the low density of mudflows and saturation with detrital material increases the impact force of the mudflow, which leads not only to the destruction, but also to the drift of vineyards, orchards, the filling of gaps in bridges, their subsequent destruction, drifting of roads, and deformation of the banks. In the conditions of active development of such processes on the southern slope of the mountain range of the Crimean Peninsula, they pose a threat to recreational facilities and previously were the causes of death.

The results of generalization and classification of data on the mudflow hazard of the main basins of rivers and watercourses are presented in Figure 1.

To substantiate the choice of types of anti-mudflow protection structures for reconstruction, on the example of the Shelen River, the main characteristics of the mudflow

were calculated. The obtained data are compared with the actual data of past mudflows. The main parameters of the mudflow were calculated taking into account ODM 218.2.052-2015 [11].

For the Shelen River, hydrological and hydrographic characteristics were calculated, among which the most important is the maximum flood discharge of 1% probability. It is equal to Qi1%= 11m/s.

For subsequent comparison with the flow rate of the observed mudflow, hydrological characteristics were calculated, which are shown in Table 1.

Conducted field studies and calculation of the characteristics of mudflows indicate that mudflows are formed in the study area of medium size with a frequency of manifestation of 3-4 years.

The results of field studies showed that the most common type of anti-mudflow hydraulic structures within the boundaries of the study area are mudflow diversion channels, which were used at the mouths of mudflow-prone gullies and tributaries to protect vineyards and orchards. Mudflow-retaining dams were used in the upper reaches of mudflow-prone gullies (for example, on the tributaries of the Ai-Serez River).

Characteristics of debris flows

Indicators	Messengers	Disconnected
Types of rocks in the areas of formation	Clays, clayey shales, siltstones, marls, loesses, loess-like loams	Granitoids, effusives, glacial deposits of coarse clastic composition
Mineralogical composition of the solid component of mudflow	Montmorillonite and hydromicas	Hydromicas and kaolinite
The ratio of solid and liquid component	Solid material 80–90%, water 10–20% by weight	Solid material 20–30%, water 70–80% by weight
Volumetric weight of mudflow mixture, kg/m3	1700-2500	1100–1800
Transport medium	Conglomerate of mud-stone mass	Debris suspension
The nature of the movement	Slip; moves like a plastic quasi-solid body; no internal mixing	Flow; characteristic turbulent mode of motion with active mixing of mudflow mixture
Speed, m/s	Up to 2–4	Up to 10–15
Impact on the channel	Smooths out irregularities, "plasters" the bottom and sides	Active deep and lateral erosion
Mudflow behavior in the accumulation zone	The structure of the mixture is completely preserved, there is no sorting according to the size of the fragments	Characterized by partial sorting of the mixture according to the size of the fragments
Spreading	Limited (local); determined by the composition of the mountain rocks in the foci of origin	Ubiquitous (dominant)

Fig. 1. Main characteristics of mudflow types.

The collected data on the south-eastern region of the Crimean Peninsula allow us to conclude that various combinations of anti-mudflow structures were used in the region - in the upper reaches of mudflow-prone gullies - ponds with soil dams, in the channels of mudflow-prone rivers - retaining walls and strengthening bottoms and slopes to prevent the impact of bottom and lateral erosion; mudflow channels. The structures identified in the region under study were damaged, destroyed as a result of recent floods, filled with coarse-grained material, and currently do not fulfill their functions.

Table 1. The main characteristics of the mudflow of the Shelen River.

Characte-ristic	Mudflow flow average velocity, Vnc, m/s	Maximum debris flow velocity, Vmax, m/s	Mudflow flow rate Qs, m^3/s	Mudflow volume Vc, m^3	Sel by volume
Meaning	2.07	3.7	14.3	42000 (calculated) 38402 (according to observations)	average

The authors conducted field studies in the southeastern part of the mountainous Crimea. When examining the Shelen River basin, the existing anti-mudflow structures were identified - preserved fragments of retaining walls, which are in extremely poor condition. The following destructions were revealed in the existing structures: destruction of the foundation as a result of undermining the base; loss of stability and rollover; loss of strength leading to the destruction of part of the structure and its washout. The identified structures were used to protect agricultural land (mainly vineyards), to protect roads and rural settlements.

The obtained results of the mudflow flow rate according to [16] were compared and confirm the correspondence with the water flow rate during a flood of 1% probability for the Shelen River, they are confirmed by the results of field studies of mudflows that have taken place in this basin for 30 years and can be used to justify the loads on the proposed mudflow protection structures.

Promising are proposals for the use of through reinforced concrete prefabricated lattice anti-mudflow structures. For the Crimea, I. I. Kherkheulidze (1976) developed a lightweight model of a through barrage. There are options for creating barrages from used tires (Gabibov, 1991).

Mudflow control structures are accepted as the most expedient for reconstruction, since they will pass the mudflow without obstructing the removal of the solid component, which will replenish the beaches with stone material to preserve their recreational opportunities.

3 Discussion

Previously, for the southeastern region of Crimea, calculations of anti-mudflow structures were not carried out. Mudflows were studied as a natural process. Researchers were most often interested in the causes of formation, classification, liquid and solid components of mudflows. The structures that were erected in the riverbeds had a complex purpose, but were most often used to strengthen slopes located near highways.

During the survey of the riverbed of the Shelen River, the authors identified preserved fragments of retaining walls of three types:

- Thin-walled gravity (corner) cantilever retaining wall. The walls are made of monolithic reinforced concrete on a natural base. Length 1.5 m, width 0.25 m, height 2.5 m (Figure 2).
- Retaining wall of rock fragments and bonding material. The shape of the wall is stepped, consisting of three rises. The width of the steps is 0.4 m. The width of the wall is 1.2 m, the height is 2.2 m (Figure 3).
- Retaining wall made of blocks fastened with mortar. The blocks were set on a foundation, which was made of stone and mortar. Block parameters: length 0.6 m, width 0.2 m, height 0.2 m (Figure 4).

Fig. 2. The current state of the cantilever retaining wall p. Gromovka.

Based on the studies and calculations carried out, options for technical solutions for the reconstruction of anti-mudflow structures in the Shelen River basin are proposed.

For the reconstruction of areas where disturbed retaining walls are located, it is proposed to build penetrating retaining walls from gabions - a metal or composite mesh filled with rubble, as more cost-effective due to high load resistance, flexibility and stability, simplicity of design and construction. The advantage of anti-mudflow penetrating structures is associated with the possibility of free outflow of water.

Fig. 3. Retaining wall made of rock fragments of the Shelen River.

Fig. 4. Block retaining wall on the banks of the Shelen River.

The route of the mudflow facility will start at a distance of 350 m above the village of Gromovka and will run along the riverbed. The length of the structure will be about 1 km. The slope of the channel will be equal to the slope of the riverbed in the village. Gromovka and will be 0.08.

The shape of the channel was adopted as trapezoidal, based on the shape of the riverbed. The width of the channel along the bottom is 4 m, the slope factor is 1.

Schemes of engineering solutions for the reconstruction of destroyed anti-mudflow structures are shown in Figures 5 and 6.

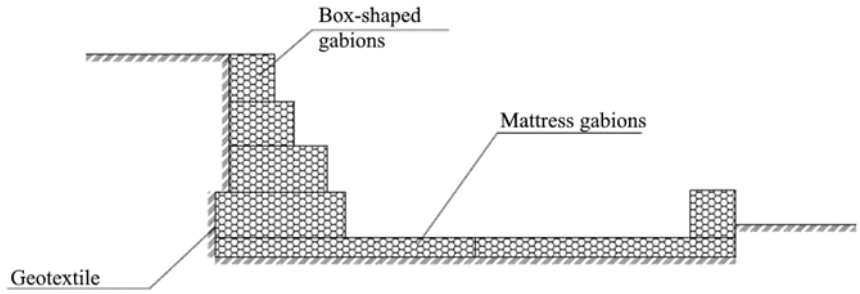

Fig. 5. Reconstruction of destroyed retaining walls with gabion walls.

The end section of the mudflow passage channel will be brought to the section where the accumulation of mudflows will not cause damage. The cladding is adopted taking into account the resistance to abrasion, therefore, the slopes are fastened with riprap or reinforced concrete slabs. The riprap fastening consists of a return filter made of sand, crushed stone, gravel and a layer of stone located on it. The thickness of the outline can be 1-2 m.

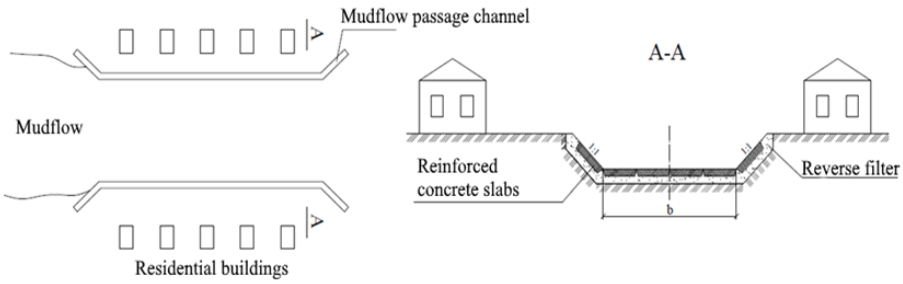

Fig. 6. Scheme of the mudflow channel on the Shelen River near the village of Gromovka.

At this site, a channel made of reinforced concrete slabs is proposed to prevent flooding of the adjacent territory and to prevent erosion of areas where gardens and vineyards are located. Reinforced concrete slabs are also placed on a layer of gravel or crushed stone, laid according to the reverse filter principle. This is necessary to prevent washing out of the soil from the base and subsidence of the slabs. The thickness of the cladding is taken depending on the flow rate - at a flow rate of 3 - 4 m/s, the thickness should be equal to 0.25 - 0.3 m.

5 Conclusion

The conditions for the formation of mudflows in the Crimea were studied, which made it possible to clarify their classification and factors for the formation of mudflow hazard, the location, climatic conditions, geological, geomorphological and hydrological conditions for the formation of mudflows were described using the example of the Shelen River basin. In Crimea, four areas of mudflow hazard have been identified. The most active of the identified areas is the southeastern one. The Uskut, Arpat, Shelen, Voron and Ai-Serez rivers are among the most mudflow-prone rivers in the region.

In order to estimate the maximum possible flow rates of floods that form a mudflow in the Shelen River basin, hydrological calculations were performed, the following were determined: the annual flow rate, the flow rate and volume of water in years of different

water content, and the average monthly water flow rates. Also presented are the indicators of sediment runoff during mudflows, the granulometric composition of suspended and bottom sediments along the Uskut analogue river.

The calculation of the main parameters of the mudflow of the Shelen River was carried out in accordance with the current standards, namely, the flow rate, speed and volume of the mudflow. As a result, according to the classification by volume, it was determined that the calculated mudflow refers to the average. The resulting mudflow flow is necessary to justify the correct choice of the parameters of the proposed structures, by comparing it with the capacity of the structures.

Variants of technical solutions for the reconstruction of anti-mudflow structures are proposed. Due to the fact that the beaches of the Crimea are a promising recreational resource and for its conservation there is a need to replenish with stone material, it was decided that it is not advisable to prevent the removal of the solid component. In the channel of the Shelen River, which passes through the territory of the settlement of the village of Gromovka, we offer the construction of a mudflow channel with a lining of reinforced concrete slabs. The implementation of the proposed solutions will make it possible to secure land and residential buildings, improve the ecological state of the territory as a whole.

Acknowledgments

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References

1. A.V. Lushchik, M.A. Lushchik, T.A. Ivanenko, Economics of construction and nature management, **62,** 50-56 (2017)
2. V. Perov, S. Chernomorets, O. Budarina, Nat Hazards, **88**, **1**, 199–235 (2017)
3. M. Dongtao, T. Jianjun, C. Peng, J. Mt. sci., **1,** 143-154 (2004)
4. M.C. Zalikhanov, N.V. Kondratieva, A. Adzhiev, 2016 KA, Dokl. Earth Science, **470,** 965–967 (2016)
5. B.M. Krestin, I.V. Mal'neva, Water Resources**, 43,** 974–981 (2016)
6. L.V. Volgina, S.A. Sergeev, A.A. Romanova, Power Technol Eng**, 52,** 675–679 (2019)
7. V.L. Baburin, S.A. Gavrilova, P.Koltermann, Yu.G. Seliverstov, S.A. Sokratov, A.L. Shnyparkov, Geography, environment, sustainability, **7**, **3**, 108-122 (2014)
8. K.I. Shevchenko, Hydrotechnical Construction, **30,** 676–680 (1996)
9. G.S. Ermakova, O.V. Gorelits, K.K. Zhbakov, Water Resourse**, 49,** 616–629 (2022)
10. A.N. Oliferov, *Study of mudflows in the Crimean and Carpathian regions. Mudflows: catastrophes, risks, forecast, protection*, Faculty of Geography of Moscow State University, Moscow, 127 (2012)
11. *Guidelines for the design and construction of anti-mudflow structures for the protection of highways*, Rosavtodor, Moscow, 79