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Engineering protection of recreational facilities

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Abstract. Based on empirical evidence from field surveys, morphometric parameters of debris flows were determined. In laboratory conditions, data on the geological structure of slopes, physical and mechanical properties of soils, etc. were obtained. On the site, three debris flow basins were identified, which in case of prolonged heavy rainfall and snowmelt form debris flows causing damage to various-purpose structures, including the ropeway, ski track No.1, engineering protection facilities, haul road, antenna-mast structure No. 2, and pedestrian crossing. Based on field surveys, it was established that the existing debris flow protection structures were insufficient to ensure full safety of the existing facilities and adjacent structures. Based on these calculations, the following measures were recommended to stabilise the situation, namely along the Sulimovsky Creek: installation of flexible anti-debris flow barriers, arrangement of a network of drainage ditches, and erosion control. Thus, the structure type recommended for Section Line No. 3 was unsupported debris flow barrier 5–6 m high and 15 m wide. The structure type for Section Line No. 4 was unsupported debris flow barrier 4–5 m high and up to 15 m wide.

Key words: *debris flow protection structures, debris flow, load on protective barrier, hydraulic engineering, morphometric parameters*

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Инженерная защита объектов рекреации

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Аннотация. На основе эмпирических данных полевых исследований определены морфометрические параметры селей. В лабораторных условиях получены данные о геологическом строении склонов, физико-механических свойствах грунтов и др. На участке выделены три селевых бассейна, в которых при длительных ливневых дождях и снеготаянии формируются сели, наносящие ущерб сооружениям различного назначения: канатной дороге, горнолыжной трассе № 1, объектам инженерной защиты, автодороге, антенно-мачтовому сооружению № 2, пешеходному переходу. По результатам натурных обследований было установлено, что существующие селезащитные сооружения недостаточны для обеспечения полной безопасности существующих объектов и прилегающих к ним конструкций. На основании проведенных расчетов были рекомендованы следующие мероприятия по стабилизации ситуации, в частности, вдоль Сулимовского ручья: установка гибких противоселевых барьеров, устройство сети водоотводных канав, противоэрозионная защита. Так, для участка № 3 был рекомендован тип сооружения – безопорный селезащитный барьер высотой 5–6 м и шириной 15 м. Для участка № 4 – безопорное селезащитное сооружение высотой 4–5 м и шириной до 15 м.

Ключевые слова: *селезащитные сооружения, селевой поток, нагрузка на защитный барьер, гидротехническое строительство, морфометрические параметры*

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Introduction

Debris flows are widespread throughout the Russian Federation [*Shvarev, 2021*]. In order to protect buildings and structures from debris flows, anti-debris flow facilities and structures are erected, with preliminary calculations of the debris flow load on the barrier and the capacity of the debris flow-retaining structure [*Bandurin, 2022*]. The analysis of debris flow risk for the territory of the North-West Caucasus, which included probability of the event and its possible consequences, has shown that the highest value of debris flow risk of the territory (R) is found in the Central region (R = 78%), followed by the Southern region (R = 56%), then the Maritime and Eastern regions, respectively (R = 36% and R = 29%) [*Baljyan, 2020*]. Our research object is located within the boundaries of the Maritime District of the North-West Caucasus.

Brief overview of the issue

Over a half of the area within the boundaries of the studied site is covered by forests with evergreen species. There is a widespread undergrowth of Caucasian rhododendron (*Rhododendron caucasicum*) throughout the area, which prevents debris flows, but dense vegetation does not provide complete protection from debris flows (Fig. 1) [*Bogdanov, 2020*]. Debris flow control structures belong to engineering protection structures, which should ensure reliability and the possibility of systematic observations [*Geobrugg, 2024*]. For debris flow-directing and debris flow-preventing structures, the structure category is determined depending on the type of the soils and their height: debris flow-directing and debris flow-preventing structures located in unpopulated areas are assigned class IV; those located in populated areas are assigned class III. Stabilising structures are assigned class IV. Thus, the channels of watercourses contain coarse clastic material of wood origin, as well as various fractions of geological elements.

The aim of this research was to substantiate the need to take measures to stabilise the situation regarding possible debris flows at the site, and to select optimal engineering protection structures.

Materials and methods

In the course of the debris flow hazard assessment process, debris flow basins were identified within the alpine resort's recreational complex. During the field surveys, the boundaries of debris flow basins and their parameters were clarified, and erosion and debris flow activity at the site was examined.

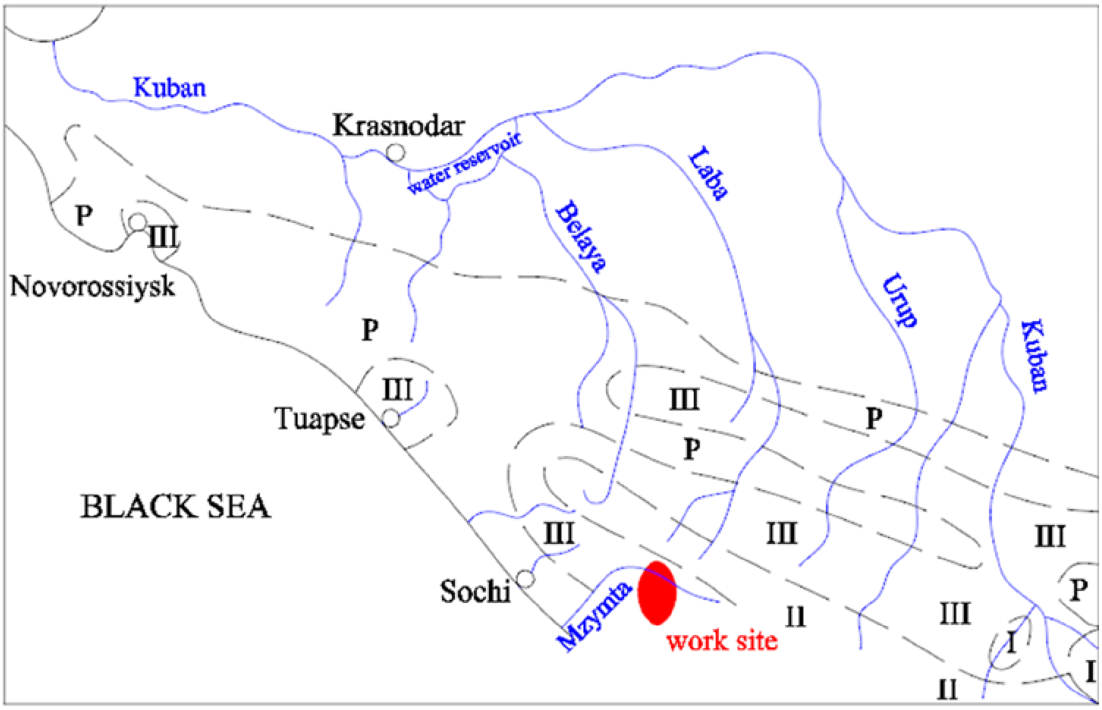
The site is located on the left slope of the Mzymta River valley near the village of Esto-Sadok. Sixty-five debris flow channels were identified in the basin of the Mzymta River. The area affected by debris flows is 510 km^2 [*Ghetto, 2021*]. When assessing the debris flow potential of an area, one of the factors was the lithological composition of the rocks as the source of the solid component of debris flows. The area under study lies within the evolution of rocks of the Jurassic and Cretaceous age. The northern half of the area is represented by the Lower and Middle Jurassic clay shale, siltstones, mudstones, and their interbedding packages, i.e. rocks of low anti-denudation stability, which form a large amount of clayey matter. The main basins of the right tributaries of the Mzymta River are located within the limits of these rocks. Dense limestone, dolomites, marls of the Middle and Upper Jurassic eras are known to be resistant to degradative agents. These rocks form the rocky Achishkho Ridge and the Aibga Ridge, from where the Mzymta's left tributaries originate. The valleys of these watercourses have the form of gorges, with channel gradients up to 400 ppm. According to archival data, among the Quaternary formations are landslide and deluvial-landslide deposits over 10 m in thickness, and alluvial fan deposits up to 20 m in thickness. The various-age alluvial fan deposits are represented by pebbly-rubbly, grussy-gravelly masses with inclusion of boulders with loamy filler. The alluvium of the Mzymta River terraces is composed by 80% gravel, pebbles and boulders and 20% sandy-clayey rock. The presence of thick friable (soft) deposits on the slopes of the site determines favourable conditions for debris flow formation in the middle and lower parts of the slope.

Fig. 1. The Rzhanoi Creek course with boulders and fragmental material (debris)

The North-West Caucasus is characterised by poorly developed debris flow processes and a low level of knowledge about them. The debris flow processes emerged after deforestation [*Ghetto, 2020*] (Fig. 2). In the region, rainfall is the main factor of soil erosion, leading to the splitting of the Mzymta River into a system of deep basins, which are leftovers of millennia-old depressions before turning into an elongated marshy depression [*Ghetto, 2022*, *Golosov, 2020*]. The study site is located in the Krasnodar Territory, the village of Estosadok (Russia).

Thus, 3 permanent watercourses and 13 temporary water catch basins were identified in the area of survey, the latter of which were becoming more active during incessant rainfall.

Based on the results of field surveys of the area, the following morphometric characteristics of the debris flow basins of the Rzhanoi, Shumikhinsky and Sulimovsky Creeks were computed: channel length, water catchment area, and general slopes; the data are presented below in Table 1. The length of temporary watercourses varied from 0.11 km to 4.58 km.



Laba – river and it's name
– coastline
- - - - - - - - – border of mudflow hazardous area
Sochi – town and its name
I – the first category of mudflow hazard*
II – second category of mudflow hazard*
II – third category of mudflow hazard*
P – potentially mudflow hazardous area

* Note: Category I areas are characterized by the presence of medium-sized mudflows and medium-active runoff-forming surfaces;
In areas of category II, small mudflows and weakly active runoff-forming surfaces are noted;
Category III areas are characterized by rare or absent mudslides, but due to environmental changes they may occur

Fig. 2. Location of the work site combined with the map of debris flow-prone areas

Table 1. Morphometric parameters of debris flow basins of alpine resorts

Watercourses	Mean watercourse slope, ‰	Weighted average channel slope angle, ‰	Water catch area, km^2	Channel length, km
Rzhanoi Creek, Ski piste No. 1	357	321	2.35	4.58
Shumikhinsky Creek, Ski piste No. 1	425	321	1.77	2.89
Water Intake No. 2, Shumikhinsky Creek	425	321	1.77	2.89
Water Intake No. 1, Sulimovsky Creek	405	398	1.18	2.07

The quantitative parameters of debris flows were identified in accordance with the instruction for determination of rain debris flow calculated characteristics and the debris flow study guide. Based on that, conclusions were made about the spread of debris flows and their hazard within the construction site and measures were proposed to reduce the debris flow hazard.

The existing debris flow protection structure protects the transformer box from debris flows at the Alpika-Service railway station. It is located in the basin of the Rzhanoi Creek. The debris flow protection structures serve to attenuate and detain possible debris flows in case of their passage along the streambed [*Kondratieva, 2015*]. Additionally, the channel is being reinforced downstream both sides of the barriers with gabion meshy products [*Panina, 2017*].

Results and discussion

According to Special Technical Specifications (VSN 03-76 «Instruction for Determination of Rain Debris flow Characteristics»), debris flow barriers should be calculated for the maximum debris flow volume with a 1% exceedance probability. The debris flow velocity ν, m/s, was determined for each gabion mesh (Table 2).

Table 2. Calculation of debris flow velocity of 1% probability

Section line	$Q_{1\%}$, m^3/sec.	I_y, ‰	$W_{1\%}$	ν, m/sec.
No. 2	4.1	299	0.053	2.28
No. 3	6.6	298	0.175	3.18
No. 4	6.5	298	0.175	3.17

The debris flow load calculation was performed using “DEBFLOW” design software for flexible debris flow protection systems. “DEBFLOW” software provides design solutions for debris flow protection structures. The debris flow load calculation for Barrier I in the Sulimovsky Creek is shown in Table 3.

The load calculations for Section Lines Nos. 3 and 4 were carried out similarly.

According to the calculation of debris flow retention volume, the total volume was 1866 m^3, the required volume was 1600 m^3; hence the reserve was 266 m^3.

Table 3. Debris flow load calculation for Barrier I (Section Line No. 2)

Parameter	Identifier	Value	Measurement unit
Debris flow type and density			
Type of debris flow	Typ	typical	–
Density of debris flow mass	ρ	2300	kg/m^3
Weight of debris flow mass	γ	22.6	kN/m^3
Liquid phase content	ω	0.21	–
Debris flow volume and number of debris flow waves			
Aggregate debris flow volume (water included)	V_{tot}	1600	m^3
Number of waves	H	3	–
Average wave volume	V_H	533	m^3
First wave volume	V_{N1}	800	m^3
Peak discharge			
Peak discharge	Q_p	7	m^3/sec.
Reliability factor			
General reliability factor	SF	1.5	

According to point 2.16.8 of Special Technical Specifications VSN 03-76, when determining the height of the structure, the equalising slope of debris flow deposits should be taken into account. For the site under consideration, this slope was 22°. When choosing the type of structures, the following were considered: calculations of retained material; calculations of debris flow velocity; debris flow load on debris flow protection structure. Once the initial data were entered, the optimal types of structures to protect alpine resort facilities from debris flows were determined (Table 4).

The choice of the type of structures required for structures Nos. 3 and 4 was done by analogy.

The construction type for Section Line No. 3 is an unsupported debris flow barrier 5–6 m high and up to 15 m wide. The construction type for Section Line No. 4 is an unsupported debris flow barrier 4–5 m high and up to 15 m wide. Unsupported structures are applicable for narrow valleys and streambeds of small mountain rivers [*Volosukhin, 2022*]. Thus, according to the calculation of the capacity of the debris flow retention structures: for Section Line No. 2: length of the retained material – 31.7; retained volume – 0.768 m^3; for Gate No. 3: length of the retained material – 31.7; retained volume – 0.725 m; for Section Line No. 4: length of the retained material – 20.0; retained volume 0.373 m.

Table 4. Construction type selection for Barrier I

Parameter	Identifier	Value	Measurement unit
Section line geometry			
System height	H0,1	5	m
Channel width at ground rope	bu,1	5	m
Channel width at head rope	bo,1	22	m
Distance to overlying barrier	L0,1	65	m
Channel slope and volume of retained material			
Height of filled system	H1,1	3.8	m
Average channel slope upstream barrier	lc.1	40	%
Surface slope of barrier-retained material	l'c.1	27	%
Angle between wire net and channel talweg	ξ	73.2	o
Length of barrier-retained material	L1	31.7	m
Volume retained	Vr.1	768	m^3
Front velocity and flow height			
Front velocity	Vstr	3.7	m/sec.
Impact velocity at barrier site	V1	2.3	m/sec.
Flow height	h	0.6	m
Maximum height of lower section line	hd.1	0.4	m

Construction type – debris flow barrier with support, height – 5–6 m, width – up to 25 m.

The total volume of debris flow retention facilities capacity is 1,866,000 m^3 for the total debris flow volume of 1,600,000 m^3.

Conclusions

According to the study, the most typical for the North-West Caucasus are debris debris flows of up to 10,000 m^3 in volume. In the process of debris flow surveys, the following facilities were found to be exposed to debris flow hazard:

Alpine ski track No. 1 at the points where it is crossed by the Shumikhinsky and Rzhanoi Creeks. To protect it, it is necessary to design debris flow protection nets in the narrow part of the valley of the Shumikhinsky Creek; strengthen the bottom and the banks of the Shumikhinskiy Creek upstream of the projected Water Intake No.1. Protection of the ski piste No. 1 from debris flows along the Rzhanoi Creek can be realised by construction of a debris flow-deflecting dam.

Structures of the main water intake located within the Shumikhinsky Creek impact area.

Formation of low-volume debris flows is possible in the Sulimovsky Creek, but it has debris flow protection.

Other facilities are not exposed to debris flows.

To reduce the level of debris flow hazard in the territory of the mountain resort, installation of debris flow barriers is planned as part of engineering protection, for which calculations have been made in this paper. According to their results, two barriers 5 metres high and one barrier 4 metres high are to be installed there. The total capacity of these barriers is sufficient to ensure the protection of the Olympic infrastructure from possible destructive debris flows.

In addition to engineering anti-debris flow measures, it is recommended to perform the following works on reducing the occurrence of debris flow processes in the study area: embankment of the beds of small streams, including temporary watercourses, to prevent the occurrence of erosion and debris flow processes, and reclamative afforestation – soil reclamation in areas with open soils, including along the routes of roads and ski trails. In addition, for forecasting purposes, it is necessary to organise constant monitoring of the state of the slopes and watercourse beds [*Zharashuev, 2021*].

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