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Ecology

Innovative Anti-Snow Avalanche Structure

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The paper presents and evaluates the mountainous and foothill landscapes of Georgia, which are in high risk areas of impact of snow avalanches. Particular attention is paid to the Kobi-Gudauri section of the Georgian military road, where snow avalanches occur almost every winter, there are frequent cases of snow blocking of the road and, unfortunately, human casualties are also frequent. The development of a methodology for designing an innovative anti-snow avalanche structure consists of secondary metal stands of various heights, attached to the slope, in which the metal elastic ropes, with the vehicle amortized tires on their top are placed into sections, and a metal crossbar is rigidly attached to the top of the stand, the distance of which from the soil is increasing in the direction of snow avalanche movement. The process of its operation is as follows: during the snow avalanche movement, the main impact force is received by the tip of the building, which divides the snow avalanche into two parts, and the avalanches losing the energy then move to the permeable sections of the building, where their energy is completely extinguished. During the avalanche movement its volume gradually increases in the direction of movement, and in the presented structure the distance from the soil of the building crossbar also increases in the direction of avalanche movement, which allows the building to retain a large amount of snow avalanche. Innovative anti-snow avalanche structure was built in October-December 2021 on the mountain slope of the Kobi-Gudauri alpine zone of the Georgian military road at 2338 m above sea level, with 24^0 inclination angle, coordinates X = 456043,3; Y = 470559,6. *© 2022 Bull. Georg. Natl. Acad. Sci.*

snow avalanche, anti-avalanche structure, Kobi-Gudauri section, alpine zone

A large part of the territory of Georgia is occupied by high mountains, mountain passes and steep slopes, so snow avalanches are frequent, especially in the passages of Jvari, Roki and Surami. Road tunnels, snow avalanche retaining walls and other structures are built on these passages, but due to their lack, traffic is stopped for some time during heavy snowfall until the roads are cleared of collapsed avalanches. Road accidents are frequent in the valleys of the rivers Tergi, Aragvi and Dzirula [1,2]. Among the anomalies impacting the infrastructure in the mountainous regions of Georgia, snow avalanches are the most dangerous, which have special frequency in terms of the loss and has increased geometrically in the last ten years due to the climate change in the world [3,4].

There are 145 definitely expressed hotspots of avalanches on the Georgian military road and avalanches occur almost every year. Often the traffic is delayed due to the danger of avalanches. Due to the danger of avalanches during the winter, the Gudauri-Kobi section is limited and closed, where it is possible to move after the end of the avalanche period and clearing the road from avalanche cones [5,6].

During the winter holiday season this obviously causes inconvenience to both holidaygoers and the drivers those who carry cargo and have to spend many nights in trucks in the frost due to the danger of avalanches. However, the rescue service is successfully performing its function and the representatives of the local municipality and the population are alleviating their difficult conditions, providing drivers with drinking water and food. For example, on 6 January 2015, 3 avalanches with a length of 200 m and a cone height of more than 3 m fell on the Pasanauri-Mleta-Gudauri-Kobi section. In separate years, avalanches coming from avalanche catchment in Pasanauri and Stepantsminda resorts caused great damage to some settlements. Dozens of houses, auxiliary buildings, vehicles and mills were destroyed and damaged. In Pasanauri, in February 1954, an avalanche damaged the building of the meteorological station and the protective wall of the existing HPP, due to which the HPP did not function for 18 days [7]. On 10 January 1987, an avalanche destroyed a stone workshop and a mineral water bottling plant, damaged the building of a second plant in Pansheti village, Stepantsminda municipality, and in Arsha village in the same winter, 6 houses in the tourist center were demolished. Numerous people lost their lives in the avalanche and forests and orchards were damaged on tens of hectares [8] (Table 1).

Table 1. Material damage caused by avalanches on the Georgian military road in Stepantsminda

№	Year, month, day	Settlement/river valley	Number of casualties	Demolition		Cattle	
				House	Building	Black cattle	Small Cattle
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	4.02.1846	Khati village/Tergi	56	16	10	80	96
2	5.02.1846	Ereto/Tergi	7	7	6	49	60
3	1938;1987	Pansheti/Tergi	7	6	8	10	22
4	1932;1939 1954;1956	Karkucha/ Sno water	9	11	13	33	50
5	1956	Gaiboteni/Tergi	3	3	2	14	28
6	1987	Arsha/Tergi		6	5		
Total			**82**	**49**	**44**	**186**	**256**

Materials and Methods

Innovative anti-snow avalanche structure [9] consists of secondary metal stands of various heights (1) attached to the slope, in which the metal elastic ropes (3) with the vehicle amortized tires on their top (2) are placed into sections, and a metal crossbar (4) is rigidly attached to the top of the stand, the distance of which from the soil is increasing in the direction of snow avalanche movement. Fig. 1 shows a snow avalanche structure in axonometry (Georgian Patent # 278).

The snow avalanche structure has an anchor-like shape in the plan, with the tip pointing in the opposite direction of the avalanche movement. Green plants can be planted in the protected areas of the mountain slope.

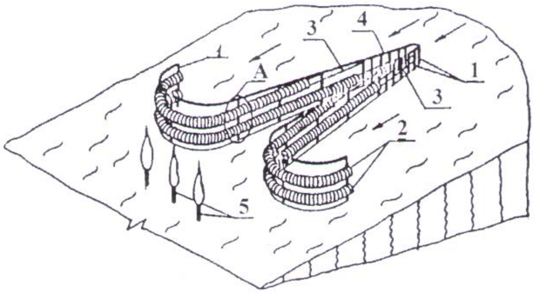

Fig. 1. Anti-snow avalanche structure. 1 – Secondary metal stands; 2 – Amortized vehicle tires; 3 – Metal elastic ropes; 4 - Metal crossbar; 5 – Green plants.

Depending on the location of the presented building on the slope of the mountain, based on the principle of operation, we can consider two options:

a) When the buildings are located on the whole massif of the mountain slope, the building is a structure working against the origin of snow avalanches.

b) When the topographic environment of the mountain slope does not allow us to place the presented structure on the whole area of the mountain slope, the building works as an anti-snow avalanche movement (avalanche-retaining) structure.

Snow avalanche pressure in case of enclosing the building is calculated by the following dependence [10,11]:

$$P_0 = G_d \left(\frac{\rho_{Ave} V_{Ave}^2}{2} \right) \; (Kg.P./m^2) \qquad (1)$$

$$P_0 = 1,5 \left(450 \cdot \frac{4.43^2}{2} \right) = 6623.4 \; (Kg.P./m^2), \qquad (2)$$

where, ρ_{Ave} is the snow avalanche stream density, which equals to ρ_{Ave} = 450 (kg/m^3). C_d is the Resistance coefficient of snow avalanche enclosing on the building, the numerical indicators of which are given in Table 2.

Table 2. Snow avalanche resistance coefficient in case of enclosing on the building

The shape of enclosing the building	Values of the coefficient of resistance C_d	
	If dry snow	If wet snow
Circle	1.5	3 - 5
Rectangle	2.0	4 - 6
Wedge-shaped	1.5	3 - 6

Snow avalanche stream velocity is calculated according to the following dependence:

$$V = (2gZ)^{0.5} (m/\sec) = (2 \cdot 9.81 \cdot 1.0)^{0.5} =$$
$$= 19.62^{0.5} = 4.43, (m/\sec), \qquad (3)$$

where,

$$Z = h_B - (H/L) l_B (m) \qquad (4)$$

$$L = 800 \cos 24^0 = 800 \cdot 0.91 = 728.0, (m). \qquad (5)$$

Snow mass sliding can occur at a slower pace and by interacting with the nets on the structure, a natural "wall" can be created, which will distribute the loads according to the "wall" area:

$$P = P_0 \cdot b_0 = 6.623 \cdot 1.9 = 11.86 (ton/m) \qquad (6)$$

The dynamic impact of a snow avalanche on a building is equal to:

$$F = K \rho \omega V^2 (kg.p/m^2) \qquad (7)$$

where: ρ – snow avalanche stream density; ρ = 450 *(kg.P/m*^{3}), ω – distribution area (m^2); V – avalanche stream velocity V = 4.43 (m/sec); k – coefficient, k =1.5.

Because the structure of the building is permeable, under the dynamic impact of a snow avalanche, part of the snow avalanche stream stops at the nets while the other part continues to move at a reduced velocity. Therefore, the dynamic load of snow is considered on the profile of the columns, column size Ø245 mm.

$$F = 1.5 \cdot 0.450 \cdot 0.245 \cdot 4.43^2 = 3.25, (t/m) \qquad (8)$$

According to the relevant conclusions obtained as a result of seismic zoning and engineering-geological surveys of the territory of Georgia, it is established that the construction site is located in a 9-point seismic hazard zone according to MSK 64 scale (A = 0.40); According to the calculation scheme of the carcass (frame) of the anti-snow avalanche building, the structure is calculated for horizontal (X, YY) seismic impacts. According to the current norm PN 01.01-09 applicable in Georgia, the calculated static loads are multiplied by the following coordination coefficients: constant 0.9; temporary 0.8; Initial data of seismic impact, according to PN 01.01-09; Soil Category II; Soil acceleration A = 0.40 (c); Category II, 9 points. K_0 = 1.0; Reinforced concrete frame. K_1 = 0.25; position 8. K_2 = 1.0; position 1. K_3 = 1.4; position 3. K_ψ=1.0;

Basic Designing Parameters of Anti-Avalanche Innovative Structure

An innovative anti-snow avalanche structure is presented for calculation. The avalanche restraint building has the anchor shape, with the tip directing in the opposite direction of the avalanche movement. The building is a structure of steel elements. The structure is designed to mitigate the action of bifurcated snow mass and minimize the risk of loss resulted from natural disaster. The calculation scheme is compiled on the basis of the requirements of the technical regulations and the data of the study material. The calculation should determine the bearing capacity of the load-bearing elements of the snow avalanche control structure [3]. Steel cymatiums (frame-connections system) are accepted as load-bearing elements, while snow restraint is provided by means of support nets made of steel nets and attached to the load-bearing elements. Spatial frame of load-bearing structures is compiled by the complex program Лира-САПР 2019 (license number #1/7165).

Arrangement of Innovative Anti-Avalanche Construction at the Site

The mountain slope in the Kobi-Gudauri alpine zone of the Georgian military road, in the territory of Kazbegi municipality, with coordinates X = = 456043,3; Y = 470559,6, length L = 800 m, slope inclination i = 24^0, absolute mark above sea level H = 2570 m was selected for the arrangement of the innovative snow avalanche structure at the site (Georgian Patent # 278).

Based on the schedule chart and the contract of the Applied Grant Project CARYS-19-305 of LEPL Shota Rustaveli National Science Foundation of Georgia – "Innovative Complex Measure Against Snow Avalanche" dated 31 July 2020, a foreign expert – Sergey Chernomorets, Associate Professor, Candidate of Geography Sciences, Senior Researcher of Laboratory of Snow Avalanches and Mudflows of Faculty of Geography of Lomonosov Moscow State University, was invited to Georgia from 15 October to 21 October 2021. During his business trip, 3D modelling of the mountain slope was carried out using a drone at the Kobi-Gudauri section of the Georgian military road, as well as the location for arrangement of an innovative snow avalanche structure was selected on the mountain slope.

On 8 November 2021, a reinforced concrete foundation was laid for the construction of an anti-avalanche structure on the Kobi-Gudauri alpine area of the Georgian military road (Kazbegi Municipality). On 9-12 November 2021, an innovative anti-snow avalanche structure was arranged (Fig. 2).

Fig. 2. General view of innovative anti-avalanche structure.

Conclusions

1. An innovative structural solution of an avalanche control building on a mountain slope in connection with the topography of the site is presented, the priority of scientific novelty of which is certified under a relevant Georgian patent certificate (Georgian Patent #278).

2. Based on the characterization of hydrological and hydraulic parameters of snow avalanche movement and analysis of their evaluation, snow avalanche movement schemes and the calculation dependencies of snow mass pressure and other key characteristics during impact on avalanche control buildings at different stream angles are presented;

3. Based on the field-reconnaissance surveys carried out at the Kobi-Gudauri section of the Georgian military road for the design of innovative anti-snow avalanche structure, modern equipments and technologies and licensed software Лира-САПР 2019 (license number #1/7165), the scientific methodologies are developed and the structure is designed on the mountain slope under survey (GPS coordinates: X = 456043,3; Y = 470559,6, length L = 800 m, slope inclination i = 24^0, absolute mark above sea level H = 2570 m) taking into account the dynamic and statistical loads of snow avalanches.

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ეკოლოგია

თოვლის ზვავის საწინააღმდეგო ინოვაციური კონსტრუქცია

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(წარმოდგენილია აკადემიის წევრის თ. შილაკაძის მიერ)

ნაშრომში წარმოდგენილი და შეფასებულია საქართველოს მთისა და მთისწინა ლანდშაფტების ის ტერიტორიები, რომლებიც განთავსებულია თოვლის ზვავის მოქმედების მაღალი რისკის ზონებში. განსაკუთრებით, ყურადღება გამახვილებულია საქართველოს სამხედრო გზის კობი-გუდაურის მონაკვეთზე, სადაც თითქმის ყოველი ზამთრის პერიოდში ადგილი აქვს თოვლის ზვავის მოქმედებას, ხშირია საავტომობილო გზის თოვლით გადაკეტვის შემთხვევები და, სამწუხაროდ, ხშირია ადამიანის მსხვერპლიც. ყოველივე ზემოთ აღნიშნულის გათვალისწინებით, განხილულია თოვლის ზვავის საწინააღმდეგო ინოვაციური კონსტრუქცია, რომელიც წარმოადგენს ფერდობზე ჩამაგრებული სხვადასხვა სიმაღლის მეორადი ლითონის დგარებს, რომლებშიც სექციებად გაყრილია ავტომანქანის ამორტიზებული საბურავჩამოცმული ლითონის ელასტიკური ბაგირები, ხოლო დგარების თავზე ხისტად დამაგრებულია ლითონის რიგელი, რომლის გრუნტიდან დაშორება იზრდება თოვლის ზვავის მოძრაობის მიმართულებით. თოვლის ზვავის მოძრაობისას ძირითადი დარტყმის ძალას იღებს ნაგებობის წვერი, რომელიც ზვავს ყოფს ორ ნაწილად, ხოლო ენერგიადაკარგული თოვლის ნაკადები შემდეგ მოძრაობენ ნაგებობის გამჭოლი სექციებისაკენ, სადაც ხდება მათი ენერგიის სრული ჩაქრობა. თოვლის ზვავის დინამიკიდან ცნობილია, რომ ზვავის მოძრაობის დროს მისი მოცულობა მოძრაობის მიმართულებით თანდათან იზრდება. ამიტომ წარმოდგენილ კონსტრუქციაში ნაგებობის რიგელის გრუნტიდან დაშორებაც თოვლის ნაკადის მოძრაობის მიმართულებით იზრდება, რაც ნაგებობის მიერ თოვლის ზვავის მოცულობის დიდი რაოდენობით შეკავების საშუალებას იძლევა. სტატიაში ასევე განხილულია ნაგებობის დაპროექტებისათვის გაანგარიშების მეთოდოლოგია და მისი გამოყენებით მუშა პროექტის მომზადება. თოვლის ზვავის საწინააღმდეგო ინოვაციური კონსტრუქცია 2021 წლის ოქტომბერ-დეკემბრის თვეებში აშენდა საქართველოს სამხედრო გზის კობი-გუდაურის ალპური ზონის მთის ფერდობზე ზღვის დონიდან 2338 მ. დახრის კუთხით 24^0, GPS კოორდინატებით X = 456043,3; Y = 470559,6.

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