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An innovative construction for regulating snow avalanches and developing a method for its design

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Abstract: The article discusses the sensitive areas of snow avalanches formed in the mountain landscapes of Georgia and presents their brief geographical, climatic-meteorological and hydrological assessments. By referring to global practices, the characteristics of different constructions of snow avalanche buildings and their reliability are presented. A constructive description of an innovative snow-avalanche-proof building, certified by a Georgian patent certificate, is presented. An innovative method for the design of the building was developed and the construction of the structure was carried out in the Kobi-Gudauri alpine zone of the Georgian military road at an altitude of 2238 m above sea level.

Keywords: snow avalanche, innovative snow avalanche construction

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Introduction

Among the hazards affecting infrastructure in mountainous regions of Georgia, snow avalanches are the one of most dangerous, in terms of consequences and damage incurred and the fact that avalanche frequency has increased in the last ten years due to climate change.

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The Mtskheta-Mtianeti region was taken as the survey target, it is located in the northern part of Eastern Georgia and it constitutes 8.3% of the total area of the country. The region has a significant strategic value for the country.

As scientific studies have shown, the most avalanche-prone regions in Georgia are Racha-Lechkhumi and Kvemo Svaneti (74%), followed by Mtskheta-Mtianeti and Adjara (26%). It is worth noting that Mtskheta-Mtianeti is the leader in high-risk avalanche sites, which is expected when taking into consideration the great absolute altitudes, slope inclinations, and forest cover, etc. (Fig. 1) (Salukvadze, 2018).

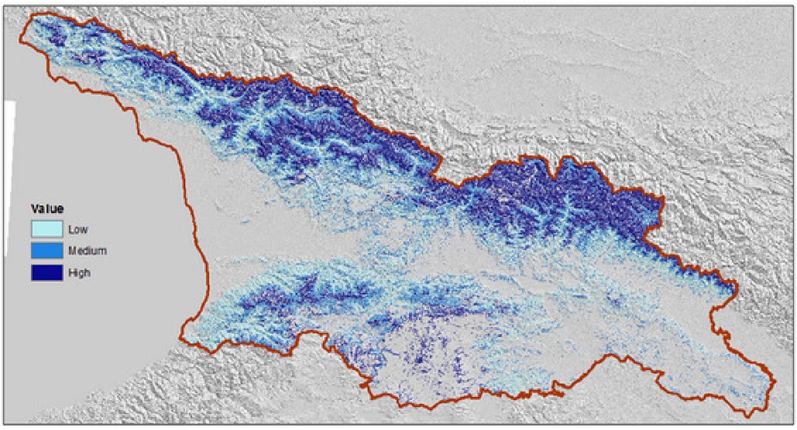

Fig. 1. Avalanche risk map of Georgia (scale 1:2 000 000) (Salukvadze, 2018)

According to data from the National Environment Agency, there are more than 5,000 identified avalanche catchment areas in Georgia. Constantly updated data, practically automates the changes in the environment to be quickly shown in the database, with the quick processing and mapping of thousands of avalanches (Sukhishvili & Megrelidze, 2011).

Due to the natural conditions of Georgia, it is very important to focus more attention on the study of snow avalanches and the use of modern technology in the process. Snow avalanches and their dangers isolate some municipalities of Georgia for up to ten months of the year, and given that these regions (Tusheti, Khevsureti--Arkhoti, River Arghuni gorge, Mighmakhevi, periodically Kazbegi Municipality) are border the Russian Federation, it becomes clear that this is the serious problem for the safety of the Georgian State. Figure 1 presents the risk map of snow avalanching sites in Georgia according to relevant classifications (Abdushelishvili et al., 1979).

The accurate design of anti-snow avalanche buildings and the selection of topographic location is of great scientific and practical importance (Gavardashvili et al., 2020).

There are different types of anti-snow avalanche structures in the world, which are mainly divided into three groups: prophylactic (artificial), snow avalanche supporting structures and structures restraining snow mass on mountain slopes, which attempt to prevent the formation of snow avalanches. Figure 2 shows the traditional longitudinal profiles of snow avalanches, which provide a longitudinal profile of the formation of snow avalanches on a mountain slope, consisting of: the slope eyebrow, snow mass abruption line, snow mass transit area, transported snow mass volume and the snow avalanche abruption cone (https://www.researchgate).

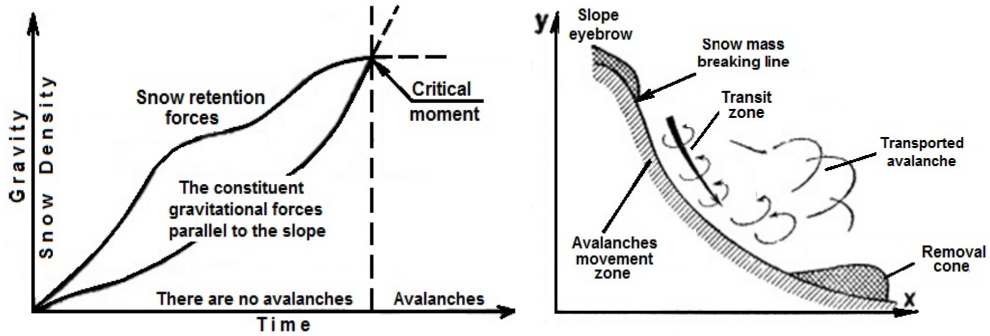

Fig. 2. Longitudinal profiles of snow avalanches (https://www.researchgate)

Figure 3 shows the different types of snow avalanche release on mountain slopes, namely: a) the snow mass on the mountain slope is broken in a pointed manner and b) when the snow mass is broken on the mountain slope along the entire width of the slope, within a certain area, causing a so called longitudinal release of snow mass.

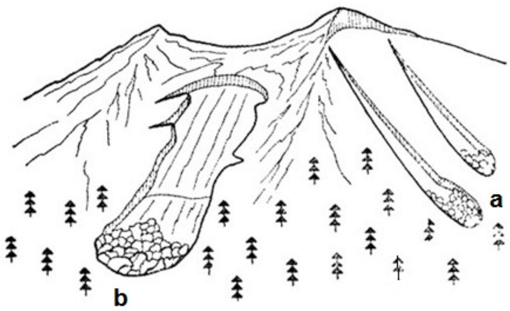

Fig. 3. Types of snow avalanche release on a mountain slope: a – pointed release of snow mass, b – longitudinal release of snow mass buildings (Kukhalashvi et al., 2018)

Taking into account all the above, let us consider the structural characteristics of traditional snow avalanche buildings (Kukhalashvil et al., 2018).

According to global practice, there are different systems to protect against snow avalanche. These are divided into three main types:

1. prophylactic (artificial descent, forecasting, zoning);
2. protection from snow avalanches (anti-snow avalanche structures, which protects the infrastructure, as well as prevents the movement of snow mass);
3. prevention of snow avalanches (various structures against the movement of snow masses on the mountain slope, as well as constructions that oppose the formation of snow avalanches, etc.).

1. A structural solution for an innovative mountain slope avalanche-regulating building in relation to location topography

Due to the wide-scale problem of snow avalanches, notwithstanding the existing models and control measures, it is not possible to avoid all catastrophic consequences. Snow avalanches are a terrifying phenomenon among natural disasters and the creation of innovative types of regulating buildings is linked to their genesis and dynamics.

The structural solution of regulated structures, used on the force-feed surface, often does not allow the transformation of the moving mass and the redistribution of the impact force. The innovation of avalanche-regulating buildings lies in the fact that they are reliable, durable and resistant to varying avalanche impact forces through increased elasticity and reduced rigidity.

The anti-avalanche building presented in the project (Georgian Patent # 278) consists of secondary metal stands of different heights (1) attached to the slope, in which the metal elastic ropes (3) with amortized vehicle tires on their top (2) are placed into sections, and a metal crossbar (4) is rigidly attached to the top of the stand, where the distance from the ground is increasing in the direction of snow avalanche movement. Figure 4 shows the snow avalanche building in axonometry (Gavardashvili et al., 1996).

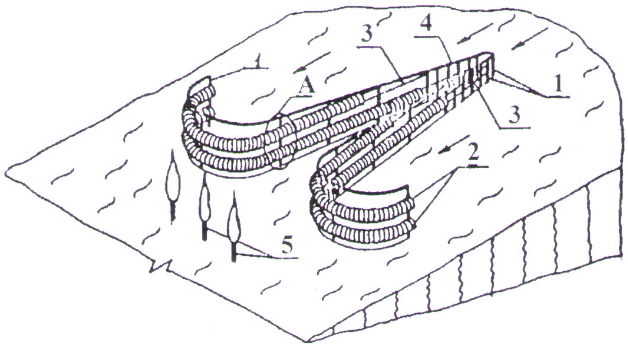

Fig. 4. Anti-snow avalanche building: 1 – secondary metal stands, 2 – vehicle amortized tires, 3 – metal elastic ropes, 4 – metal crossbar, 5 – green plants (Gavardashvili et al., 1996)

The anti-snow avalanche building has an anchor-like shape in the plan, with the tip directed in the opposite direction of the avalanche movement, green plants can be planted in the protected areas of the mountain slope. Depending on the location of the presented building on the slope and its intended use, we can consider two options:

- **When the buildings are located on the whole massif of the mountain slope, the building is a structure that prevents the formation of snow avalanches.**

The arrangement of the buildings on the mountain slope in chess-pattern or other optimal form, as well as the correct determination of the distances between them, ensures that the static balance of the snow cover is not disturbed and, if this happens, then due to the shape of the structure, the snow avalanche will have a small volume.

In addition to the above, green plants planted in the lines protected by a building on a mountain slope not only complement (restore) the mountain slope ecosystem, but also counteract the process of snow avalanche formation.

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

In particular circumstance, 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, therefore the avalanche loses energy, then moves to the permeable sections of the building, where the energy is completely extinguished. It is known from the study of avalanche dynamics that during the avalanche movement, its volume gradually increases in the direction of movement. Therefore, in the presented structure the distance from the ground of the building crossbar (4) also increases in the direction of avalanche movement, which allows the building to retain a large amount of the snow avalanche (Gavardashvili et al., 2012).

The presented structural solution of the building allows the planting of green plants (5) in the protected areas of the mountain slope, which is an urgently needed solution to the challenge of restoring the ecosystem of mountain slopes in the highlands.

2. The basic designing parameters of an innovative anti-avalanche structure

An innovative anti-snow avalanche structure is presented for calculation. The avalanche restraint building has an anchor shape, with the tip directing in the opposite direction of the avalanche movement. The building is constructed of steel elements.

The structure is designed to mitigate the action of a bifurcated snow mass and minimize the risk of loss resulting from the natural disaster (Salukvadze, 2018).

The calculation scheme is compiled from data of the requirements relating to the technical regulations and the data of the research material. The calculation should determine the bearing capacity of the load-bearing elements of the snow avalanche regulating structure (Gurgenidze et al., 2021).

Steel cymatiums (a frame-connection system) are used as load-bearing elements, while snow restraint is provided by means of support nets made of steel and attached to the load-bearing elements.

A spatial frame of load-bearing structures is compiled by the complex program Лира-САПР 2019 (license number # 1/7165).

3. Loads and impacts considered when calculating the structure

- **Constant load**
- ***Net weight of structures***

  The net weight of steel and reinforced concrete structures is generated automatically. Reset coefficient – for steel structures $\gamma = 1.05$ kgf/m^3; for reinforced concrete structures – $\gamma = 1.10$ kgf/m^3.
- ***Temporary load***

  Snow avalanche pressure in the event of it enclosing on a building is calculated according to the following dependence (Colbeck, 1980):

$$P_b = C_d\,(\rho_{av}\,V^2_{av}/2)\ \ [\text{kgf/m}^3] \tag{1}$$

$$P_b = 1.5 \cdot (450 \cdot 4.43^2/2) = 6623.4\ \text{kgf/m}^3 \tag{2}$$

where:

ρ_{av} – snow avalanche stream solidity and $\rho_{av} = 450$ kg/m^3;

C_d – resistance coefficient of snow avalanche enclosing on the building, the numerical indicators of which are given in Table 1.

Table 1. Snow avalanche resistance coefficient C_d in the case of enclosing on the building (*own research*)

The shape of enclosed building	Values of the coefficient of resistance C_d	
	Dry snow	Wet snow
Circle	1.5	3-5
Rectangle	2.0	4-6
Wedge-shaped	1.5	3-6

The snow avalanche stream velocity is calculated according to the following dependence (Gavardashvili et al., 2021a):

$$V = (2gZ)^{0.5}\ [\text{m/s}] = (2 \times 9.81 \times 1.0)^{0.5} = 19.62^{0.5} = 4.43\ \text{m/s} \tag{3}$$

where:

$$Z = h_B - (H/L)\,l_B\ \ [\text{m}] \tag{4}$$

$$L = 800 \times \cos 24° = 800 \times 0.91 = 728.0\ \text{m} \tag{5}$$

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:

$$P = P_b \cdot b_0 = 6.623 \cdot 1.9 = 11{,}86\ \text{t/m}^2 \tag{6}$$

- **Dynamic load of snow avalanche**

Determining the dynamic impact (F) of snow avalanches (Gavardashvili et al., 2021):

$$F = K\rho\omega V^2 \ [\text{kg.f/m}^2] \quad (7)$$

where:
ρ – snow avalanche stream solidity; $\rho = 450$ kgf/m^3;
ω – distribution area [m^2];
V – avalanche stream velocity; $V = 4.43$ m/s;
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).

$$F = 1{,}5 \cdot 0{,}450 \cdot 0{,}245 \cdot 4{,}43^2 = 3{,}25 \text{ t/m}^2 \quad (8)$$

- **Seismic load**

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 the MSK 64 scale ($A = 0.40$); the soil category is according to seismic properties – II.

According to the calculation scheme of the anti-snow avalanche building, the structure is calculated for horizontal and vertical seismic impacts. According to the current norm PN 01.01-09 applicable in Georgia for anti-snow avalanche building, the calculated static loads are multiplied by the following coordination coefficients (Gavardashvili et al., 2021b): constant – 0.9; temporary – 0.8; initial data of seismic impact, according to PN 01.01-09; Soil category II, Table 1; Soil acceleration $A = 0.40$ (c); Reinforced concrete frame. $K_1 = 0.25$; Position 8. $K_2 = 1.0$; Position 1. $K_3 = 1.4$; Position 3. $K_\psi = 1{,}0$. A special algorithm was developed and the structure was calculated using a finite-difference scheme with the help of a computer. The results of the report are given in Table 2.

Table 2. The calculation was performed by matching the forces (*own research*)

Load No	Name of the load	Type of the load	Variation of load signs	Mutual exclusion of the load	Reliability coefficient	Load duration share
1	Constant	Constant (C)	+		1.000	1.000
2	Short	Temporary (T)	+		1.000	0.350
3	Special	Special (S_s)	+		1.000	0.000
4	Seismolog. – X	Seismic (S_x)	+/–	1	1.000	1.000
5	Seismolog. – Y	Seismic (S_y)	+/–	1	1.000	1.000

After entering the initial data into the computer by means of an algorithm, the design dimensions of the innovative anti-avalanche structure are given in Figure 5.

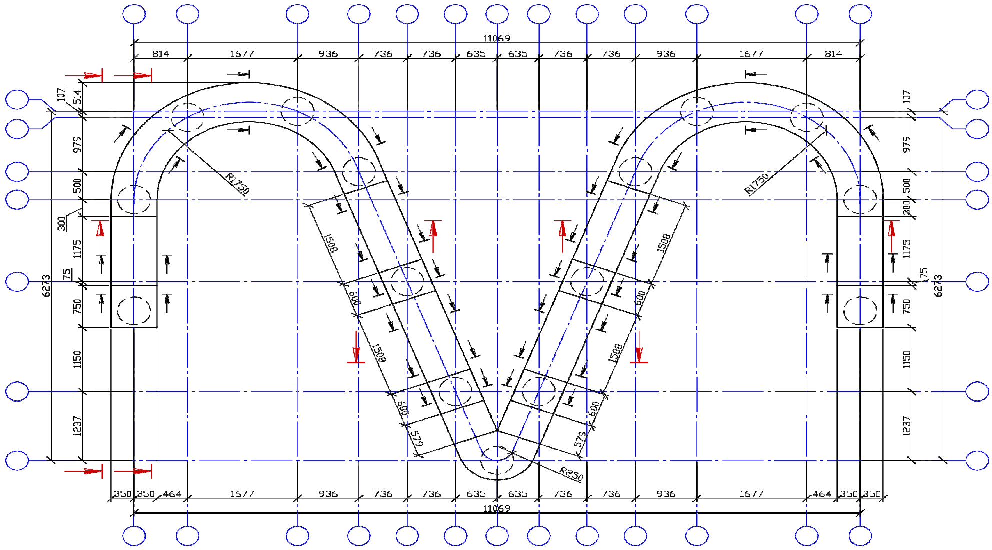

Fig. 5. Construction frostwork plan (*own research*)

An innovative snow avalanche structure on the Kobi-Gudauri alpine area of the Georgian military road at 2338 m above sea level has been calculated, designed and built in accordance with the presented recommendations, the general view of which is given in Figure 6.

Fig. 6. An overview of an innovative snow avalanche construction Georgian Military Road in Kobi-Gudauri alpine zone (2238 m above sea level) (*own foto*)

Conclusion

Field-reconnaissance surveys were conducted at the Kobi-Gudauri section of the Georgian military road to design an innovative snow avalanche design. A scientific method was developed and an innovative construction was designed on the mountain slope of the study area taking into account the dynamic and statistical loads of an avalanche.

In order to regulate snow avalanches, on November 17, 2021, an innovative snow avalanche construction was organized on the Kobi-Gudauri alpine section of the Georgian military road at an altitude of 2238 m above sea level.

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