

The Spread of Snow Avalanches at Transport Junctions in the Mountainous Regions of Georgia

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ABSTRACT

The snow avalanche has an insidious character, it can be repeated once in 100-200 years and cause great harm to the population of the mountainous region. There are many examples of damage caused by avalanches. In the 20th century, several thousand soldiers were died by avalanches in the Alps during the First World War, on the Austrian-Italian front. There are many examples of them not only in the Alps but also in the mountainous regions of Georgia. Frequently, snow avalanches block important transportation routes that connect people and countries.

In general, 56% of the territory of Georgia is covered with avalanche-prone slopes. Based on existing examples, it is important to record and study them, because snow avalanches are characterized by repetition. Examples of this are Svaneti, Racha and Mtianeti (regions of Georgia). It is worth noting the Mleta-Kazbegi section road (Georgia's military road), where there is a danger of avalanches every year, which is the subject of our research. The highway of Georgia is a transport hub of international importance. Therefore, observation of avalanches, study and carrying out various measures is a necessary prerequisite in order to avoid damage caused by avalanches.

Keywords: Mountainous regions, avalanche danger, climate, natural phenomena, transport infrastructure.

1. Introduction

Various natural events are frequent in the territory of Georgia, which prevent the operation of many facilities and international roads. Among natural events, snow avalanches are very important, which have always had a place in our country. The result of the snow avalanches is destroyed houses and roads. Sometimes even human victims. Snow avalanches have always attracted the attention of the world. There are many examples of them in Georgia as well.

A snow avalanche is a mass of snow of a certain volume and speed, detached from the slope under the influence of gravity. They call it "White Death" in Europe, "White Monster" in the Pamirs and Himalayas, and Professor Vasil Tsomaia called it White Trouble" in Georgia. As early as the 6th century, the word "avalanche" can be found in scientific treatises and various records.

Snow avalanches are formed by the mixing of crystals and air. From the point of view of mechanics, a snow avalanche occurs like a landslide. The grip forces of the snow overcome a certain limit, and gravity causes the snow masses to move down the mountain slope. Snow undergoes a kind of metamorphosis after falling. As the snow crystals grow, the pores of the snow mass decrease. At a certain depth, the change in crystallization from the

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surface of the snow can cause the snow to slide, and at this moment there is a big danger of an avalanche.

There are two types of snow avalanches: dusty and layered. Dusty is formed from a shapeless mixture of snow dust and layered by the principle of floating. It should be noted that the layered avalanche is faster.

Snow avalanches are also distinguished according to their arrival on the slope: snow avalanche, gully, and jumping: (Figure 1)

Snow avalanche	Grooved	Jumping
It slides over the entire surface of the slope without falling	It follows ravines and erosion beds	free fall from the step

Figure 1: Snow avalanches according to slope descent

The activation and arrival of avalanches are frequent in mountainous areas. It depends on the features of the terrain, climate, and vegetation. An important avalanche-generating factor is the relief, - in particular, the slope of the slopes. The slope depends on the possibility of an avalanche, the avalanche activity of the area, the distribution of avalanches, the frequency of avalanches, the duration of the avalanche period, the critical height of the snow cover, the morphometric characteristics of the avalanches, and the dynamic characteristics of the avalanches. An avalanche can descend from a slope of 150 and more (150-500).

Violation of the stability of the snow cover along the slope also leads to avalanches. The stability of fresh snow breaks down on steep sections where the actual snow depth exceeds a critical value.

Unlike the snow cover, which in most cases can be moved as a result of a thrust or integrity failure, the old snow layer begins to move gradually. At first, this layer moves slowly on the slope, and when a fault occurs in one area, the layer accelerates, the speed of movement increases, and because of this, the adhesion to the surface of the slope is broken, and the avalanche stops.

The influence of climatic conditions on the arrival and activation of avalanches is important. The climatic conditions determine the characteristics of the avalanche. For example, dry snow avalanches occur at negative temperatures, and wet snows occur where the moisture content is high, as well as watery snow. Added to this is the process of melting in the spring, which also contributes to the arrival of avalanches.

The abundance of atmospheric precipitation is important, which also determines the systematic arrival of avalanches. The circumstances are also important—whether the winter was snowless or not.

One of the factors contributing to the arrival of avalanches is the reduction of forest cover on the slopes. Deforestation contributes to the frequency of avalanches. Such examples are frequent in Georgia, which in itself causes the frequency of avalanches. Up to 40% of the territory is covered with forest. Forests occupy a large area in the mid-mountain zone.

16% of the territory is covered with broadleaved forest, 15% with mixed forest, and 7% with coniferous forest. The forest is preserved on the steep, hard-to-reach slopes, and there is practically no forest on the lower and more easily accessible slopes.

Therefore, we can say that 56% of Georgia's territory is located in avalanche-prone areas. Avalanches occur annually on 20% of the territory, and on 36% of the territory, both avalanches occur. They are distinguished by their destructive power, and human casualties are also associated with their arrival. It should be noted that the activity of avalanches was also used as a means of defense in the historical past.

Over the years, scientific staff of the Institute of Hydrometeorology (V. Tsomaia, L. Kaldani, M. Salukvadze) have visited many mountainous areas during field research on snow avalanches.

The aim of the study was to study the avalanche danger, fix the places of avalanches, and place them on the topographic maps, in order to calculate the morphometric (height of the beginning and end, length, focal area, slope of the surface) and dynamic characteristics of the avalanches (the maximum speed of the avalanche and the force of the impact, the volume of the avalanche cone, and the maximum height of the moving avalanche). On the basis of a forty-year research project, a cadaster of snow avalanches in Georgia was compiled, where all the above-mentioned parameters of 1108 avalanches are presented. 240 of the 1108 avalanches crossed the river valley, the road, and stopped on the opposite slope (Salukvadze M. 2018).

2. Previous research

Georgia is located in the middle of the Alpine-Himalayan mountain belt, at the junction of the European and Asian continents. It is surrounded by the Black Sea in the west, which has a great influence on its physical, geographical, and climatic conditions. (Geography of Georgia, 2000). Its area is 69,700 square kilometers, and the total length of the border is 1970 kilometers, of which 310 kilometers are maritime. (Figure 2)

The terrain of Georgia is diverse. Volcanic, glacial, and erosive terrain can be found here. denudation areas. The highest peak of the country is Shkhara (5203 m above sea level), and the lowest point is in the vicinity of Paliastomi Lake (city of Poti) (-2 m).

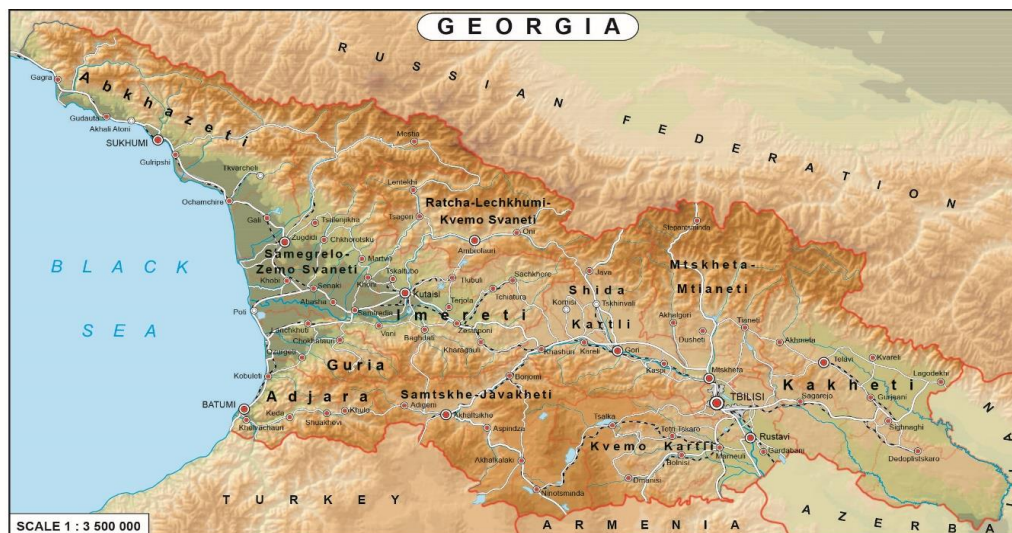


Figure 2. Physical map of Georgia

The climatic conditions of Georgia are diverse, which is due to the diversity of the terrain and the influence of the Black Sea. The Caucasus and Likh ridges are the main climatic barriers. The Caucasus prevents the invasion of cold masses from the north, and the Black Sea is one of the factors in the formation of atmospheric precipitation. The weather in eastern Georgia is dry, with harsh winters.

The coldest place on the territory of Georgia is the Kazbegi high-mountain weather station, where -430°C is recorded; the hottest places are Lata (Abkhazia) and Charnal (Adjara) at $+430^{\circ}\text{C}$. The driest is the Eldar Valley (Kakheti), where the amount of annual precipitation is only 375 mm, and the wettest is Mount Mtirala (Adjara), where the amount of annual precipitation reaches about 4500 mm.

There are many rivers and lakes in Georgia, as well as glaciers and mineral waters with healing properties. The longest river is Md. Alazani (390 km), and the largest lake in area is Faravan (37.5 km²); the most water-rich is Tabatzkuri (221 km³); the deepest lake is Ritsi (101 m), and the saltiest is Paliastom. The presence of glaciers, the largest of which is the Lekhzir glacier (length: 35.8 km², about 23 km²).

Our country is distinguished by the abundance of the living world. Here you can find both ancient endemic and relict plant and animal species, as well as adventive species. There are forest, alpine, and sub-alpine plants in the mountains; the forests are more diverse than the plains. (Salukvadze M. 2018).

Such diversity in Georgia determines the occurrence of natural events. Their active actions are related to both nature and human activities. Landslides, landslides, avalanches, floods, hail, winds, and drought are common in Georgia. However, these processes occur in different areas depending on the causative factors.

For example, hailstorms are common in eastern Georgia, and summer droughts are characteristic of the Intermountain West. Avalanches and disasters caused by glaciers are known in the highlands, and floods and landslides are frequent in the dry season.

We singled out avalanches from these natural events because they have been a danger every year for years and are still a danger to the mountain population of our country, as well as to roads and international roads and highways. These objects are distinguished by their strategic nature in terms of avalanche activity.

3. Data collection

Over the years, scientific staff at the Institute of Hydrometeorology (V. Tsomaia, L. Kaldani, M. Salukvadze) had to overcome many obstacles while conducting field research on snow avalanches. Research was conducted in all the mountainous regions of Georgia. The aim of the study was to study the avalanche danger, fix the places of avalanches, and place them on the topographic maps in order to calculate the morphometric (height of the beginning and end, length, focal area, slope of the surface) and dynamic characteristics of the avalanches (the maximum speed of the avalanche and the force of the impact, the volume of the avalanche cone, and the maximum height of the moving avalanche).

On the basis of a forty-year study, a cadastre of snow avalanches in Georgia was compiled, where all the above-mentioned parameters of 1108 avalanches are presented. In addition, for river valleys in mountainous regions, a specific place from which the avalanche descends is indicated, each parameter is calculated for several sections of the slope, the direct contact of the avalanche with the road, river valley, and residential houses, and the stopping place is indicated. 240 of the 1108 avalanches crossed the river valley, the road, and stopped on the opposite slope (Salukvadze M. 2018).

Snow avalanches can recur once every 100–200 years and cause great damage to the population of the mountainous region. Many examples can be given of damage caused by avalanches. However, historical facts stand out for their significance as a means of defense. There are many examples in the past of the activity and results of avalanches in war processes.

In Georgia, snow avalanches were used as a means of defending the territory of the mountainous part of the country.

Avalanches, both sporadic and systematic, are considered catastrophic when the latter goes beyond its usual limits. They are characterized by suddenness (sporadic avalanches) and rare destructive power (systematic avalanches). They cause great damage to the population, cause destruction, cause casualties, and destroy the forest in a large area. (Figure 3).

YEARS	LOCATION	CONTENT
As early as 218 BC	Carthaginian, Alps	The Roman historian Polybaeus describes: "This campaign lasted 33 days. Initially, the number of warriors was eighty thousand infantry, twelve thousand cavalry, and thirty-seven elephants. In northern Italy, in the valley of the river Po, after leaving the valley as a result of avalanches and snowstorms, the number of Carthaginians was twenty thousand infantry, six thousand cavalry, and one

		elephant" (Salukvadze M. 2018; Losev K.S. 1983; Флянг Вальтер, 1960).
November 1799	Alps	Reports of people killed in avalanches in the Alps are described in Walter Flig's book "Attention, Avalanches!" (Flyig Walter,1960). In, a significant part of the Russian army, led by A. Suvorov, was sacrificed to the arrival of avalanches.
1916-17	Alps, Austria	Among the avalanches that occurred in different years in the Alps, the "Black Thursday" of December 16. on this day, six people lost their lives due to snow avalanches. In 1916–17, more than ten thousand people died as a result of avalanches.
April 7, 2012	Pakistan's Himalayan	100 soldiers have died in an avalanche in Pakistan's Himalayan massif near the Indian border in Kashmir district.
May 31, 1970	Yungay, Peru	Approximately 20.000 victims when a huge avalanche swept down as a reaction to an earthquake just off the coast. (https://wepowder.com/en/forum/topic/210809)
1962	Plurs, Switzerland	It's quite a while ago, but an avalanche claimed 2427 lives in the village of Plurs. The avalanche destroyed the entire village. Only four inhabitants survived. Simply because they weren't there at the time of the avalanche. (https://wepowder.com/en/forum/topic/210809)
March 1910	Wellington (WA), USA	After a storm that lasted 9 days and dropped huge amounts of snow, an avalanche came down from the top of Windy Mountain, claiming the lives of 96 people. (https://wepowder.com/en/forum/topic/210809)

Figure 3: Examples of the avalanches

The southwestern part of Georgia was characterized by a lack of snow in February 1971, and in the northern part of Georgia, from Abkhazia to Tusheti, in January 1976 and 1987, avalanches came from almost all slopes and destroyed and damaged many houses, killing dozens of people.

From December 31, 1987, to January 31, 1988, in one month, avalanches destroyed and damaged 41 residential houses and various buildings in Khulo municipality, Citrus orchards were destroyed, and forestry suffered great losses.

Avalanches from 161 avalanche traps in mountainous Adjara threaten 92 settlements, and 32 avalanches are expected to arrive on the Khulo-Mlashe section of the Batumi-Akhalsikhe highway. (Salukvadze M. 2020)

A total of 99 avalanches occur on the Chokhatauri-Bakhmaro road and Kur Bakhmaro, including 32 avalanches in the territory of the Bakhmaro resort. Over the years, as a result of avalanches, 7 people have died, 47 houses have been destroyed or damaged, and 8.2 hectares of forest and orchards have been destroyed.

January 1976 was also snowless in Abkhazia, in particular in the Md, Lashipse, Kodori, Sakeni valleys, where avalanches damaged the Ritsa and Sgimar resorts. 104 avalanches are

possible on the Khaishi-Chuberi-Sakeni road, in the valleys of the Enguri, Nenskra, Darchi-Ormeleti and Saken rivers. whose action continues even today in snowless winters. The terrain of the territory of Zemo Svaneti is very difficult. The winters of 1875, 1932, 1976, and 1987 were characterized by a lack of snow. Out of 125 settlements in Svaneti, 61 are at risk of avalanches. As a result of avalanches over the years, 197 people have died, more than 200 houses, and various buildings have been destroyed. It poses a threat to the movement of transport. The Zugdidi-Mestia highway's Skormet-Jorkvali section is characterized by avalanche danger, where 46 avalanches have occurred, including Md. 34 avalanches from the right slope of Enguri, and 12 avalanches from both the right and left slopes of the Darchi-Ormeleti River. The Choluri-Mestia section from the Ughvir pass to Mestia is also at risk of avalanches, where 107 are expected. (Saluqvadze m. kobakhidze Z. 2011)

In snowless winters, especially snowless winters, the river is the left tributary of the Tshnisiskali river. Avalanches descend from many glaciers in the Jojora Valley. In January 1976 and 1987, avalanches damaged the populations of Racha-Lechkhumi and Kvemo Svaneti. In separate years, avalanches in Racha-Lechkhumi and Kvemo Svaneti have harmed the local population, As a result of the avalanches, 56 people died, 277 houses were destroyed or damaged, and roads were closed during that period. (Figure 4).

№	DISTRICT	QUANTITY		Destruction	Was destroyed
		Populates area	Victim	House and building	Forest, ha
1	Abkhazia	13	2	32	54
2	Upper Svaneti	61	197	216	11
3	Racha-Lechkhumi, Kvemo Svaneti	43	56	277	139
4	Guria, Bakhmaro resort	6	7	38	2.3
5	Highland Adjara	92	61	455	6.5
6	Georgian military road	13	82	93	-
7	Dushet	45	40	90	15.6
8	Shida Kartli	50	207	166	8
9	Tianeti, Mount Tusheti	4	3	17	2.7
10	Kvemo Kartli	2	-	-	-
11	Samtskhe-Javakheti	8	2	-	-
GEORGIA		337	647	1384	239.1

Figure 4. damage caused by avalanches

Mtskheta-Mletha-Gudauri-Stefantsminda-Larsi section of a 163 km long road, the so-called Military Road of Georgia, passing through Jvari Pass, st. It connects Tbilisi with St. Vladikavkaz. There are three main avalanche-prone sections on this road: Zhinvali-Mleta, Gudauri-Kobi and Almasian Darial valleys, of which the Gudauri-Kobi section is characterized by particularly strong avalanche danger, while the Zhinvali-Mleta and Almasian-Daryal sections are relatively weak in terms of avalanche danger.

There are 52 avalanche traps in the Zhinvali-Mleta section, and avalanche arrivals are expected during intense snowfall. Most of the avalanches cover the road only in snow-free

winter; there are three sporadic avalanches in this section that come out on the road especially in snow-free winter, and the volume of snow brought by the avalanches on the road is 1-100 thousand m³. The maximum volume was recorded in January 1987. On this road, seven avalanches descend in Fasanauri township.

There are 59 avalanche traps on the Kobi-Gudauri section, 41 of which descend to the road. And so far, the existing tunnels and galleries have protected parts of the road completely or partially from only 17 avalanches.

There are 27 avalanches on the Almasian-Daryal section, which completely block the road only in snowless winters, during intense snowfall. In January 1987, the volume of snow removed was 76 thousand m³.

Ten out of 47 settlements in Stepantsminda municipality are threatened and damaged almost every winter. The rescue service is always working and intensively cleaning the roads.

There are 145 designated avalanche hotspots on the Georgian military road, and avalanches occur almost every year. Due to the danger of avalanches, road traffic is often interrupted or completely closed, especially on the Gudauri-Kobi section, during the winter holiday season, which causes inconvenience to vacationers and drivers who transport transit cargo. (Figure 5)

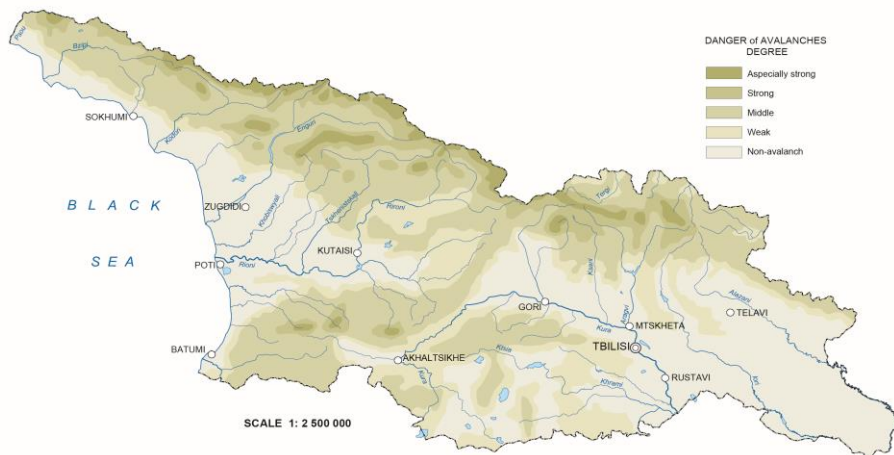


Figure 5. Danger of Avalanchs Degree map of Georgia (L. Kaldani, M. Salukvadze, S. gorgijanidze 2012)

4. Methodology

Avalanche forecasting methods were developed and implemented for the territory of Georgia in the Department of Water Resources and Hydroforecasting.

When predicting avalanches, it is necessary to consider:

- Speed of movement of the snow cover;
- determination of snow stability;

determining the size of the ice crystals or snowflake type that can set the snow mass in motion.

It is impossible to predict the arrival of avalanches over a large area with these methods, but for a local slope or a certain section of the road, it is possible to determine the time of arrival of an avalanche.

Avalanche forecasting methods are divided into two groups:

forecast of the avalanche danger period for individual avalanches or a small area;

Background forecasting methods for a large area.

At the Institute of Hydrometeorology, since the 1950s of the 20th century, the method of forecasting the arrival of avalanches of all genesis has been developed and has already been implemented. Forecasting of different types of avalanches is based on the following avalanche-generating elements of the climate: the amount of precipitation, the height of the snow cover, air temperature, wind speed, and blizzards. Changes in the listed elements affect the height of the snow cover.

Based on the analysis of stationary and expeditionary observation of the arrival of avalanches, it was established that 80% of the total number of avalanches in the territory of Georgia originates from newly arrived snow; 8% occur during spring snow melting; 6% occur during warming; 4% are caused by sublimation recrystallization; and 2% are caused by snowstorms.

Prediction of new snow avalanches by V. Tsomaia and K. It is calculated by the Abdushelishvili method with the following formulas: (3.11.1.-3.11.2) (Tsomaia V. 1985; Abdushelishvili K.L., Kaldani L.A. 1997).

$$X=55-1,8 \sqrt{h75} , \quad (3.11.1.)$$

$$h=55+0,9 h75 , \quad (3.11.2.)$$

where X is the sum of precipitation in mm necessary for the arrival of an avalanche of new snow; h is the maximum height of snow necessary for the arrival of an avalanche in cm; and h75 - the snow height of a stable transition at 75% of the average day-night relative air sinotype, cm.

According to K. Abdushelishvili, M. Salukvadze, and M. Kartashova's method of avalanche hazard prediction, the arrival time of the newly arrived snow avalanche is calculated by the formula (3.11.3) (Kaldani Lado, Salukvadze Manana, 2001).

$$T=27,8/i^{1,29} + 1 , \text{ when } i \geq 0,75 \text{ mm/h} \quad (3.11.3)$$

where T is the time in hours from the beginning of snow to the arrival of an avalanche, i is the intensity of precipitation, in mm/h.

During the massive arrival of catastrophic avalanches, the losses and human casualties are especially high. Includes both high and low mountain areas, when the precipitation intensity is equal to or exceeds 2 mm/h, then massive avalanches occur. The time from the beginning of snow to the arrival of avalanches is calculated by the formula (3.11.4.)

$$T=220/i^2 , \quad (3.11.4.)$$

Where T - is the time from the issuance of the forecast to the arrival of the avalanche, i - the intensity of the snowfall. The forecast is issued when the wind speed is less than 2 cm/h. That is, catastrophic avalanches occur when $I \geq 2$ cm/h.

Blizzard-induced avalanches, like fresh snow avalanches, are caused by snow accumulation and overloading of avalanche-prone slopes. The parameters are the duration of the blizzard (T_k) and the average wind speed during the blizzard (V). The relationship between these values indicates that the higher the air temperature during the blizzard, the more force it will need to trigger an avalanche. The arrival time in hours of an avalanche caused by a snowstorm is calculated by the formula (3.11.6):

$$T=1/v [(51,6(t)^{0,54}-54)/(t-1)], \quad (3.11.6)$$

where T is the time of the blizzard before the arrival of the avalanche, V - the average wind speed (m/s) during the blizzard in hours, and t - the air temperature in degrees.

Wet snow avalanches occur during the warming and melting of spring snow or rain, and if there is warming or heavy precipitation in the form of rain during the winter months, wet avalanches are also possible. The air temperature is decisive for such avalanches. To determine the arrival time of avalanches, we determine the intensity of the temperature rise. Using empirical formulas, the average day-night temperature is determined for each subsequent day, which determines the trend of its change. If the air temperature increases steadily, then we determine the day-night intensity of the temperature using the formula (3.11.9);

$$P_{i_t}=\Delta t/T, \text{ C/ a day} \quad (3.11.9)$$

Compilation of the operational forecast is not done if:

Already during the snowfall, a massive arrival of snow avalanches took place and the slopes are free of snow;

When the height of the snow cover is less than 30 cm;

When the air temperature decreases instead of increasing;

When the amount of precipitation does not exceed 6–10 mm.

The justification of all the predictions listed above is 80–87 percent; all these methods were introduced and used at the time (Kaldani Lado, Salukvadze Manana, 2001; Tsomaia V. 1985; Kaldani L.A. 1979; Tsomaia V, Gorgijanidze S, Gachechilaze G, Pkhakadze M. 2009, Salukvadze M. 2011; Kaldani L., Salukvadze M. 2011).

5. Conclusions

Based on the examples given and also due to the strategic location of our country, it is important to control avalanches on international roads and implement measures to prevent the damage caused by them.

Avalanche area, slope, maximum speed, avalanche impact force, cone volume, and moving avalanche height This data will help us avoid expected avalanches in strategic places in the future. The monograph also provides ways to prevent natural disasters, and, in the event

that they occur, measures that will help both the local population and the border points respond promptly.

One of the most effective anti-avalanche measures is to inform the municipalities and the population located in the avalanche zone about the time and place of avalanches; timely forecasting prevents human casualties.

The means of defense, which have been tested and established in different sub-glacial mountainous regions of the world, must also be implemented in Georgia. The first defensive structures were the terraces erected in the 19th century. Currently, there are various technical methods for avalanche protection, utilizing materials such as steel, aluminum, wood, wire, and concrete. These measures can be categorized as structural, planning, forestry, and temporary, depending on their purpose. Both engineering and non-engineering safeguards are installed, depending on the intensity of avalanche activity in the region. Understanding the starting zone of the avalanche, its projected path, and the vulnerable objects in its trajectory is crucial for effective management and prevention of dangerous situations. Additionally, controlled explosions using snow rakes can be employed. Snow catchment fences and snow nets are also viable options for installation. (Figure 6) By adopting these proven means of defense, Georgia can improve its avalanche protection capabilities, ensuring the safety of its inhabitants and minimizing potential risks in these hazardous mountainous areas.



Figure 6. TRUMER snowcatcher (<https://trumerschutzbauten.com/avalanche-fences/>)

The examples given, where the consequences of avalanches are well illustrated, clearly show the necessity of studying the nature of avalanches in all regions with heavy snowfall. Abundant, and especially abundant, snow is characteristic of mountainous regions. These

examples, as well as the data obtained from the ongoing works at the checkpoints, will lead to the implementation of new defensive measures in these areas. (Gorgijanidze S, Saluqvadze M, Gorgodze T. 2023.)

The given methodology allows for determining almost the same regularity of change of snow cover characteristics according to the absolute height of the place for each region. It is also necessary to note the determination of synoptic and meteorological conditions, which contribute to the recording of snowless winters in the mountainous regions of Georgia.

6. Acknowledgement

The research is done with the support of "Shota Rustaveli national scientist foundation" [Grant number - FR-21-1677].

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