Shota Rustaveli National Scientific Foundation of Georgia

World Bank

N(N)LE Ecocenter for Environmental Protection
Consultation Status Organization of the United Nations
Economic and Social Council (ECOSOC)

Innovative anti-snow avalanche structure

(Structure designing methodology, construction norms and rules)

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1. Preamble

Mountainous regions are essential for the sustainable development of the country, as mountain ecosystems play a crucial role in providing fresh water resources to a large part of the world's population (UNGA, 2012). 10% of the world's population is directly dependent on mountain resources. On the one hand, the mountain is an important source of water, energy, minerals, biodiversity, recreation, forest and agricultural products, on the other hand - it is a high-risk environment with vulnerable landscapes.

Mountainous regions are the most sensitive area to climate change. Most of them have limited resources (FAO, 2011), so the mountains are home to the world's poorest people. Mountain landscapes provide us with high quality and diverse resources, yet those of limited number and accessibility. Consequently, the use of nature and resources of mountainous regions requires a particularly careful approach.

Mountain population are known for their unique traditions and customs, thereby playing an important role in global ethnic, cultural, linguistic and religious diversity (FAO, 2011). It should also be noted that in traditional regions, natural landscapes are an integral part of local culture (UN, 1992).

More than two thirds of the territory of Georgia is mountainous areas, therefore, all the above-mentioned challenges are relevant here as well. Notwithstanding the small size of territory, there are many types of landscape found here, including highland alpine meadows and glacial landscapes (Nikolaishvili, et al., 2011). As in other regions of the world, the mountain in Georgia is a freshwater reservoir, "biodiversity reservoir" and a hearth of indigenous culture (FAO, 2011). Therefore, its protection and maintenance is one of the prioritized and, and at the same time, difficult tasks for the Georgian state, due to the economic challenges. It should be noted that development intervention is usually accompanied by environmental and social risks.

The protection of landscapes (ecosystems) is of the crucial importance within the concept of sustainable development of mountainous regions, as natural forests within mountain valleys are the most effective land cover in terms of regulating hydrological conditions (Hamilton & King, 1983). And mountain populations play a major role in preserving ecosystems so that they can provide the community with environmental/ecosystem/landscape services. It is important to strengthen the mountain population, to improve their life, for them to gain the strength to protect nature and to play the role of mountain rangers (FAO 2011).

A large part of the territory of Georgia is occupied by high mountains, passes and steep slopes. That is why snow avalanches are frequent in winter. Especially at Jvari, Roki and Surami passovers. Although road tunnels, avalanche retaining walls, galleries, and other buildings are built on these passovers, due to a lack of structures, traffic is often blocked for a while during heavy snowfall until the roads are cleared of fallen avalanches.

Traffic accident related to heavy snowfalls and snow avalanches are frequent in the catchment basins of the rivers Tergi, Aragvi and Dzirula, unfortunately, human casualties are also frequent. For example, in the winter of 1999, a bus moving from the Kobi village of the Kazbegi region to Vladikavkaz was hit by an avalanche, and the bus fell into the Tergi River, killing 42 people. In January 2000, a snow avalanche on the side of the Roki Tunnel struck a bus, killing 28 passengers.

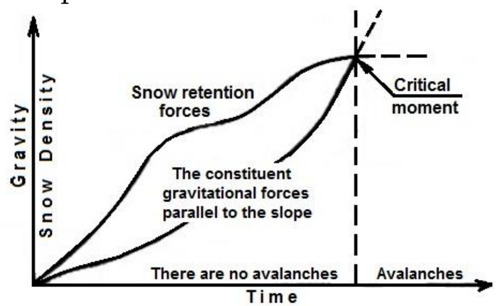
The statistics on the large number of casualties caused by avalanches worldwide are of particular note. In Karakum, for example, the Hassabad Glacier suddenly collapsed in 1905, killing 2,500 people and destroying thousands of homes and buildings. In 1906, the Carriheited Glacier collapsed from the Alaska Mountains, killing 3,500 people, destroying 28,000 homes, and so on.

On 4 January 2018, an avalanche fell in Svaneti, near the resort "Tetnuldi". According to the initial information, 4 foreign extreme sport-lover tourists who were in the resort "Tetnuldi", skidded in the unpathed snow, which caused an avalanche. Three of them managed to get to a safe place, and the fourth - buried in the snow and died.

2. Traditional anti-snow avalanche structures and their characterization

Accurate designing of anti-snow avalanche buildings and selection of topographic location is of great scientific-practical importance.

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 slope, which oppose the formation of snow avalanches. Figure 2.1 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: slope eyebrow, snow mass abruption line, snow mass transit area, transported snow mass volume and snow avalanche abruption cone.



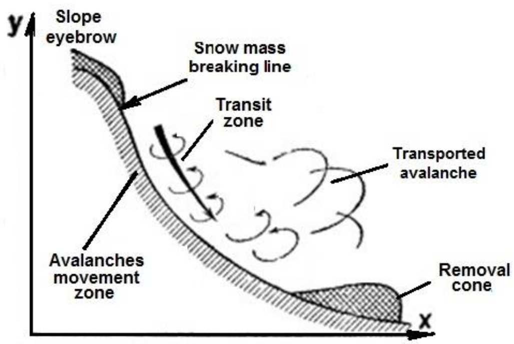


Fig. 2.1. Longitudinal profiles of snow avalanches

Figure 2.2 shows the different types of snow avalanche abruption on the mountain slope, namely a) the snow mass on the mountain slope is broken in pointed manner and b) when the snow mass is broken on the mountain slope along the entire width of the slope, with a certain area, so called longitudinal abruption of snow mass.

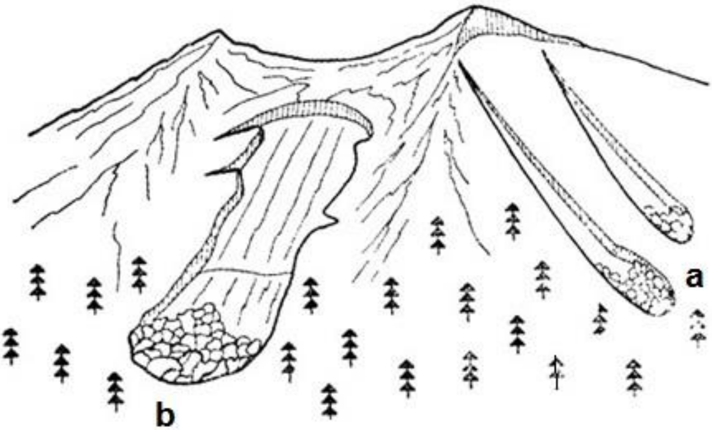


Fig. 2.2. Types of snow avalanche abruption on a mountain slope:
a) Pointed abruption of snow mass
b) Longitudinal abruption of snow mass

Taking into account all the foregoing, let us consider the structural characteristics of traditional snow avalanche buildings.

According to world practice, there are different systems for protection from snow avalanche, which 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 prevenst 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.).

Anti-snow avalanche structures are the most stable and effective type of protection, as they prevent the movement of snow masses on the slope, thus preventing the formation of snow avalanches. It is important for specialists to select the right place on the mountain slope for the arrangement of such types of buildings - these should be only the zones of avalanche origin, where the first movement of snow masses on the slope can take place. Considering the world practice, there are generalized types of such buildings - snow avalanche restraining fences, however, in Europe and the USA they classify these buildings in more detail and have extensive experience in terms of their application. Consider in more detail the various constructions of the following buildings (Fig. 2.3):

- Rigid structures (snow bridges, snow rakes);
- Flexible constructions (snow barriers, snow umbrellas).

A special role in the process of snow avalanche regulation is given to wind control structures (wind buckles, wind direction barrier constructions), which are also included in the group of anti-avalanche structures, although they are less sustainable, rarely used independently and will not be discussed in this paper.

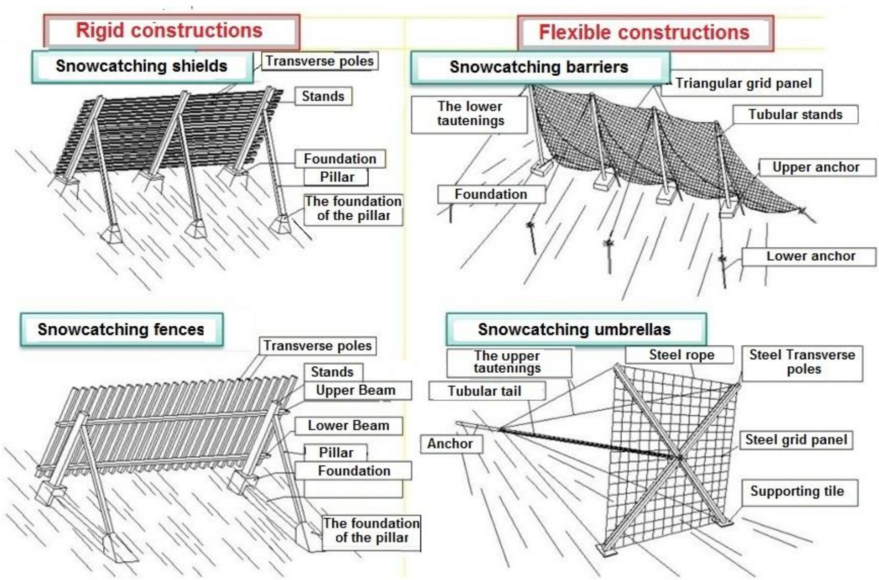


Fig. 2.3. Different types of snow avalanche restraining buildings

➢ **Snowcatching shields** - These are metal structures with horizontal lines, in the form of support panels, which are arranged on a mountain slope, usually on a concrete foundation. The bridges are arranged in the places of origin of the snow avalanche, where the height of the snow mass exceeds 4.5 m. The arrangement of bridges on a mountain slope also has a number of disadvantages: rather large weight (up to 200 kg/lm), which requires a stronger foundation compared to less heavy constructions, in addition, they stand out sharply against the background of the natural landscape (Fig. 2.3).

➢ **Snowcatching barriers** - The structure is made of wooden vertical poles, like support panels, and is located on a mountain slope from top to bottom. As the structure is made of wood, it is much cost saving - it can be made of local timber. In addition, this structure has a number of negative features, for example, the location of the connection to the foundation, the shorter useful life of the above-ground part (Fig. 2.3).

➢ **Snowcatching fences** - Flexible structure - Elastic snow nets are flexible steel structures that provide continuous, long-term resistance to static snow loads caused by the pressure of snow masses on a supporting permeable canvas. This type of structure is the lightest and has the least aesthetic impact on the landscape compared to other buildings. Because this building has support-related anchors, it can easily react to load changes during the entire snow mass pressure period, it adapts well to the slope morphology and can withstand large dynamic loads (rock-fall fragments and ice blocks). The only drawback of such buildings, compared to other types of buildings, may be the difficulty of installing the above-ground part (Fig. 2.3).

➢ **Snowcatching umbrellas** - Buildings that are made of steel elements and have cross-shaped steel balance bars that are attached to the panel by a "tail". The main advantage of this design is the ease of installation of both the above-ground part and the foundation, but their weight is about 100 kg long/meter, and the overall flexibility is significantly lower than snow barriers, although their characteristics are similar. The shortcomings of this building have been addressed by the Swiss Institute of Snow and Avalanches in Davos. However,

many experts believe that this is a matter of time, as the design is new and requires more practical field-scientific experiments (Fig. 2.3).
Based on the above description of the anti-snow avalanche structures and review of the structures given in Fig. 2.3, their constructive characterization is given in Table 2.1.

Table 2.1
Constructive characterization of snow avalanche

Structure type	Bridge	Fence	Barrier	Umbrella
Solidity	Rigid	Rigid	Flexible	Flexible
Material	Steel	Timber	Steel	Steel
Weight, kg.l.m.	≈200	≈100	≈70	≈100
Snow cover height	up to 4,5 m	up to 4,0 m	up to 4,3 m	up to 4,0 m
Dynamic load	Cannot withstand the load	Cannot withstand the load	Withstands load	Withstands load
Visual load on the mountain landscape	High	High	Low	Low
Above-ground part installation	Simple/ Difficult		Simple/ Difficult	Simple/ Difficult

Currently, in the EU, including the Caucasus, this type of structures is produced under the names of many brands, which is schematically given in Figure 2.4.

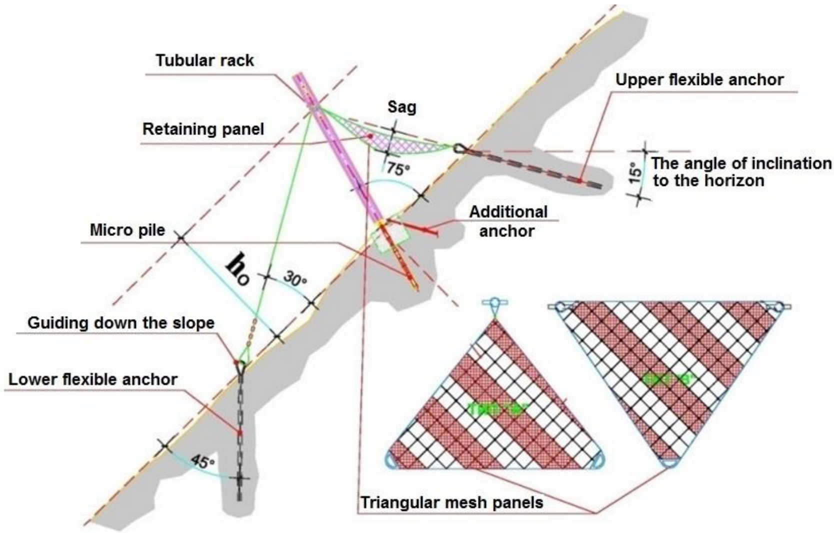


Fig. 2.4. Typical sections and key components of the snow avalanche barrier

Considering the topographic and configuration elements of the mountain slope, the snow avalanche barrier can be placed parallel to each other (Photo 2.1).

Photo 2.1. Flexible CTR-OM snow barrier rows in the Alps

Photo 2.2 shows snow barriers that are widely used in Europe and America, and practice has shown that such structures are reliable in protecting against snow avalanches.

Photo 2.2. CTR-OM system anti-snow avalanche barrier

Photo 2.3 shows the recommendation of the Italian firm Maccaferri to arrange Italian-made Erdox snow umbrellas to the former Soviet republics where there are problems with snow avalanche regulation.

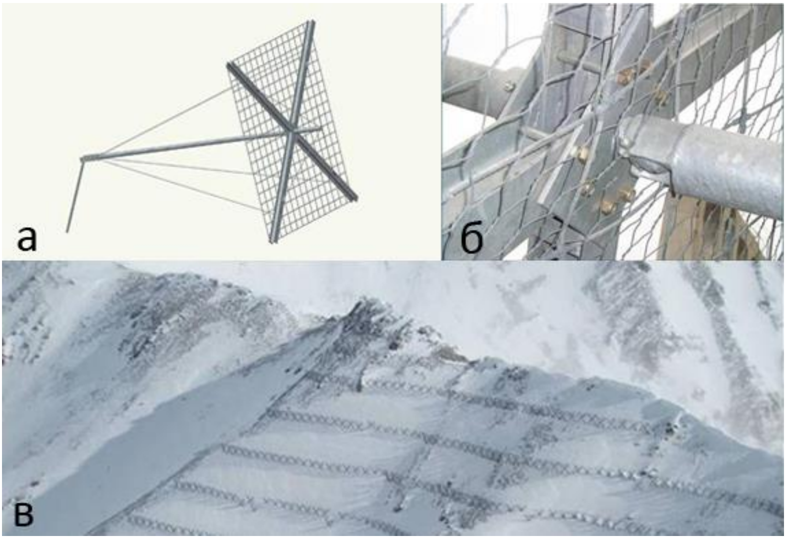


Photo 2.3. Erdox type snow support umbrellas
a) Scheme of the umbrella structure;
b) Hinged connection of the support panel to the "tail";
B) Rows of umbrellas in the avalanche zone

These snow barriers - umbrellas have shown in practice that they are very reliable to protect against snow avalanches, which guarantees the safety of the population and various facilities.

In the case of a large depth of snow cover on a mountain slope, when there is a likelihood of formation of snow avalanche, it is recommended that specialists work according to the scheme given in Fig. 2.5.

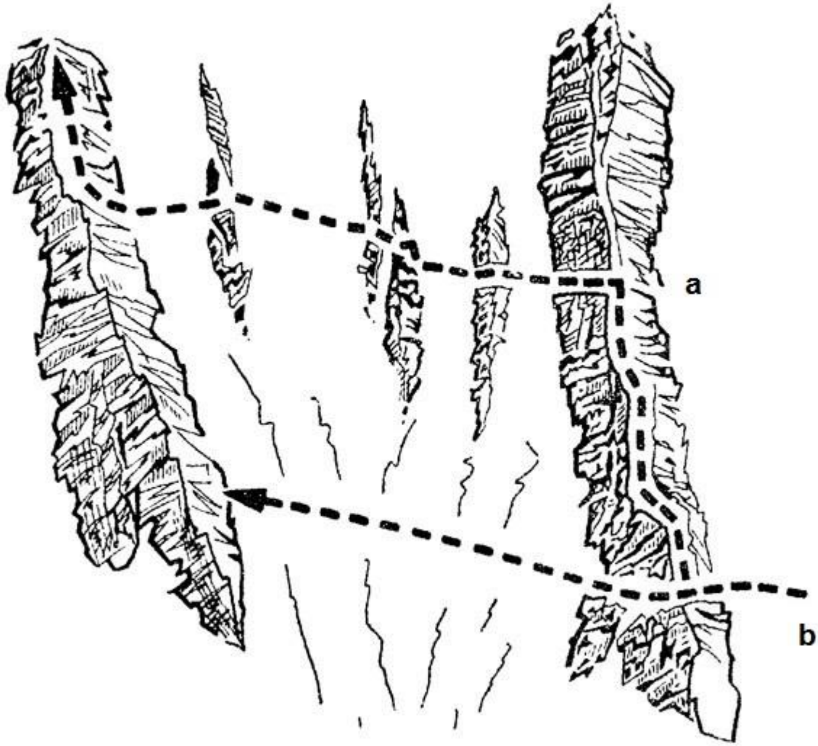


Fig. 2.5. Crossing an avalanche hazard slope
A) correct, b) incorrect

Thus, after characterizing the snow avalanche structures discussed and evaluated above, it is possible to recommend an innovative snow avalanche structure, which is characterized by reliability of operation and optimal technical-economic indicators.

3. Structural solution for an innovative mountain slope avalanche-regulating building in relation to location topography

3.1. Selection of structural features of innovative avalanche-regulating building (building shape, size, height) according to sensitive areas

Due to the wide-scale of snow avalanches, notwithstanding the existing models and control measures, it is not possible to avoid 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 the regulating structures used on it's 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 it is reliable, durable, resistant to flexible avalanche impact force, has 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 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 ground is increasing in the direction of snow avalanche movement. Figure 3.1 shows the snow avalanche building in axonometry, Figure 3.2 - the structure in the plan, and Figure 3.3 - the general view of the building A node.

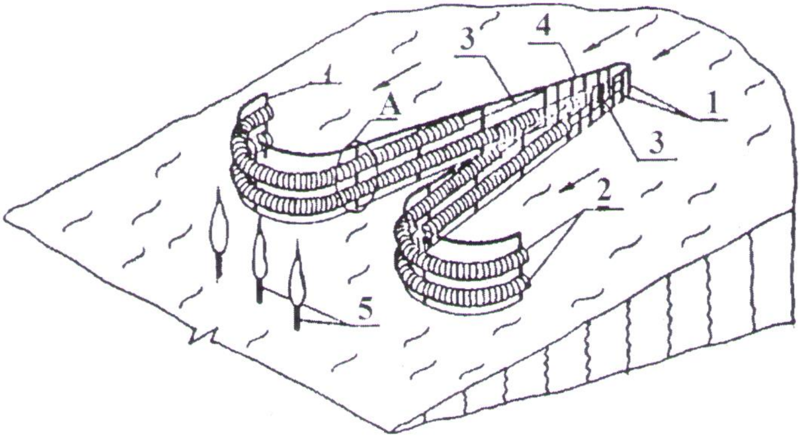


Fig. 3.1. Anti-snow Avalanche Building:
1 - Secondary metal stands; 2 -
Vehicle Amortized tires; 3 - Metal Elastic Ropes;
4 - Metal Crossbar; 5 - Green Plants

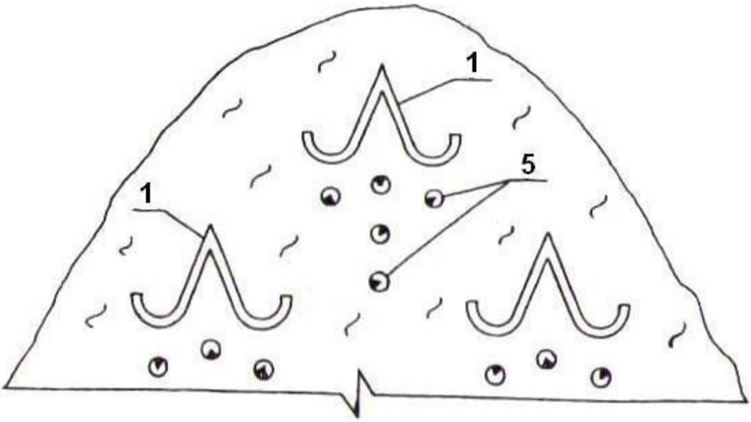


Fig. 3.2. Chess-pattern layout of buildings

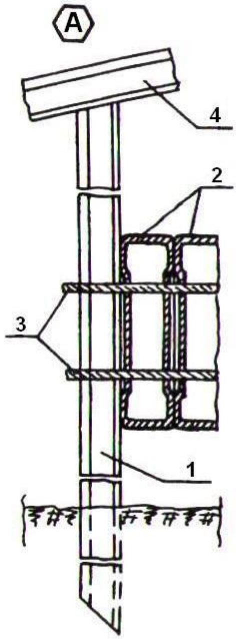


Fig. 3.3. Node A of the Anti-snow Avalanche Building

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 of the mountain, based on the principle of operation, we can consider two options:

- **When the buildings are located on the whole massif of the mountain slope, in this case the building is a structure working against the origin 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 us to place the presented structure on the whole area of the mountain slope, at this time the building works as an anti-snow avalanche movement (avalanche-retaining) structure.**

In particular, 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. It is known from the avalanche dynamics that during the avalanche movement its volume gradually increases in the direction of movement, so 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 snow avalanche.

The presented structural solution of the building allows the planting of green plants (5) in the protected areas of the mountain slope, which is currently such an urgent problem in terms of restoring the ecosystem of mountain slopes in the highlands.

3.2. Selection of number of buildings and layout scheme due to avalanche hazard in the study corridor according to the topographic characteristics of the mountain slope

In order to design anti-avalanche structures on the mountain slope, it is recommended to carry out the following types of field-scientific works:

- Engineering-geodesic survey of the territory;
- Engineering-geological research-survey of mountain slope;
- Engineering hydrometeorological research-survey;
- Engineering-ecological research-survey;

In the period of presence of snow cover in mountain landscapes, when we do not have statistical material to determine the period of snow avalanche origin, we use the indicators given in Table 3.1. (The table shows the hazard of snow avalanche origin N (days), which is determined by the maximum decadic average snow cover height of avalanche h_{av} (m) and the number of snow cover days N_{av} .)

Table 3.1

Statistical material on the origin of snow avalanches

h_{av} (m)	N (days) values of duration of snow avalanche origin and number of days of snow cover N_{av}							
	75	100	125	150	175	200	225	250
2,5	60	85	110	135	160	185	210	235
1,5	55	80	105	130	155	175	200	220
1,25	55	80	100	125	150	170	195	215
1,0	50	75	95	115	135	155	175	195
0,9	50	70	85	105	125	140	160	175
0,8	45	65	80	95	110	125	140	155
0,7	40	55	70	85	95	110	120	130
0,6	35	50	60	70	80	85	95	105
0,5	30	40	50	55	60	65	70	75
0,4	25	35	40	45	50	50	50	55

When we do not have statistics data in mountain landscapes the recurrence rates of snow avalanche origin are given in Table 3.2. The table below shows the recurrence values of the origin of snow avalanches with the decadic multi-year depth of snow avalanches and the temperature values for January.

Table 3.2

Recurrence rates of snow avalanche origin

The recurrence of snow avalanche origin averagely over 10 years	**Snow cover height h_{av} (m) and January temperature values ^{0}C**		
	from +4^{0}C to - 4^{0}C	**from 4^{0}C - to - 20^0 C**	**- 20^0 C and more**
Less than 1	To 1,0	0,4 – 0,7	0,3 - 0,5
From 1to -10	1,0 – 2,0	0,7 – 1,2	0,5 – 1,0
More than 10-	More than 2,0	More than 1,2	More than 1,0

If no engineering-hydrometeorological scientific studies have been carried out in the mountain landscapes to determine the height of the snow cover (h_{av}) at the avalanche origin sites, then the h_{av} with the appropriate provision is calculated according to the following dependence:

$$h_{Ave} = h_0\ (h_1/\ h_2) \qquad (m), \tag{3.1}$$

Where h_0 is the maximum height of snow cover with corresponding probability at the study site (m), h_1,h_2 - annual average and maximum depths of snow cover (m).

Practice has shown us that there are frequent cases when snow avalanches do not occur during the winter due to lack of snow cover. Table 3.3 shows the numerical values of snow avalanche origin with corresponding probability.

Table 3.3

Probability of snow avalanches in winter

Snow cover height h_{av}	From 0,1 to - 0,3	From 0,3 to - 0,5	From 0,5 to - 0,7	From 0,7 to - 1,0	From 1,0 to - 1,5	1,5 >
Probability	0,99	0,95	0,9	0,75	0,45	0,25

The height of a snow avalanche (h_0) in case of its formation in layers is calculated according to the following dependence:

$$h_0 = h_i \,.\, k_h \quad (m) \tag{3.2}$$

Where h_i is the variable value of snow cover height (m); k_h - average value of snow cover height (m).

The volume of snow avalanche torn on a mountain slope V is calculated according the following dependence:

$$V = h_0 [100\, tg10^0 + 30(L - 100)] \quad (m^3), \tag{3.3}$$

Where L is the horizontal projection (m) of the length of a snow avalanche on a mountain slope, and where L <100 m, the volume of a snow avalanche is calculated by the formula:

$$V = h_0 L\, tg10^0 \qquad (m^3), \tag{3.4}$$

The volume of a snow avalanche when a mass of snow falls over a certain area of a mountain slope is equal to:

$$V = h_0 k_F F \qquad (m^3), \tag{3.5}$$

Where F is the horizontal projection of the snow avalanche hearth (m^2); k_F - the average value share of an avalanche-forming hearth on a mountain slope that contributes to snow avalanches. The numerical values of its value are given in Table 3.4.

Table 3.4

Average values of the coefficient k_F

The height of the snow avalanche (h_0)	k_F - The average value of the mountain slope area									
	Dry snow avalanches					Wet snow avalanches				
	Areas of avalanche hearths (ha)									
	< 5	5-10	10-20	20-40	40 >	< 5	5-10	10-20	20-40	40 >
<0,2	0,15	0,12	0,10	0,07	0,05	0,15	0,12	0,10	0,07	0,05
0,2 - 0,04	0,30	0,25	0,20	0,15	0,10	0,30	0,25	0,20	0,15	0,10
0,4 - 0,6	0,40	0,35	0,30	0,20	0,15	0,40	0,35	0,30	0,17	0,12
0,6 – 1,0	0,60	0,50	0,40	0,30	0,20	0,50	0,40	0,30	0,20	0,15
1,0 – 1,5	0,70	0,60	0,50	0,40	0,30	0,60	0,50	0,40	0,30	0,20

Figure 3.3 shows the graph - diagram, which determines the distance of snow avalanche movement taking into account the topographic, hydrological and hydraulic parameters of the mountain slope.

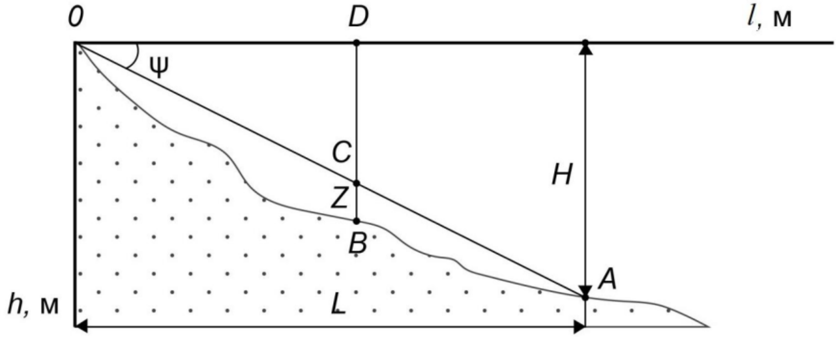


Fig. 3.3. Snow avalanche movement diagram.
L - horizontal projection of snow avalanche movement (m), H - height of relative fall of snow avalanche (m);
□ - Snow avalanche abruption angle from point O to point A, Z - distance from OA inclination line and point B, auxiliary points needed for calculation of C and D

At point **B,** the avalanche velocity V is calculated by the following formula:

$$V = (2gZ)^{0,5} \quad (m/s) \tag{3.6}$$

where,
$$Z = h_B - (H/L)\, l_B \quad (m) \tag{3.7}$$

Where g is the free-fall acceleration (g = 9.81 m/s²), Z is the distance from the inclination line OA to point B, l_B is the distance from the avalanche fall point O to the crossing D point, and h_B is the vertical distance from point B to the coordinate of line l. ,

Scientific-field studies have confirmed that when no scientific studies are carried out in mountain landscapes, the height of the snow avalanche front is calculated according to the following dependence:

• In case of dry snow avalanche:

$$H_f = (0,081\, gV - 0,10)\; V^{(0,74+0,121\, lgv)} \tag{3.8}$$

- In case of wet snow avalanche:

$$H_f = 0,25\; V^{0,3} \tag{3.9}$$

In case of snow avalanche movement (Fig. 3.4) the corresponding pressure on the surface of the parallel mountain slope is calculated according to the following dependence :

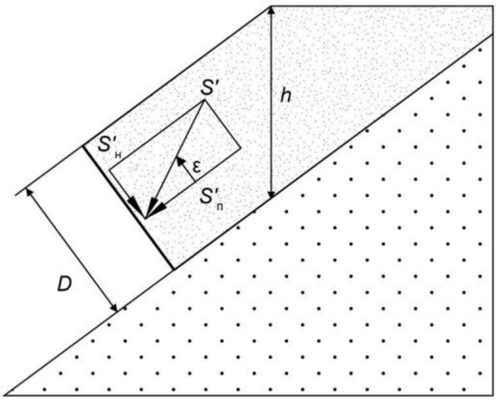


Fig. 3.4. Snow pressure calculation scheme on mountain slope during snow avalanche movement

$$S_n = \rho g\, (h^2/2)\, KN\ , \tag{3.10}$$

Where ρ is the natural snow solidity on the mountain slope (kg / m^3), K - the snow slip coefficient on the mountain slope, which is calculated by the formula or taken according to Table 3.5.

Table 3.5

Relationship between snow avalanche sliding coefficient on a mountain slope (K), snow avalanche solidity (ρ) and mountain slope slide angle

Snow solidity ρ (kg/m³)	200	300	400	500	600
K/sin²β	0,7	0,76	0,83	0,92	1,05

We here consider the impact of snow avalanches on a mountain slope on hydrotechnical buildings located in different ways.

a) Building located perpendicularly to snow avalanche (Fig. 3.5)

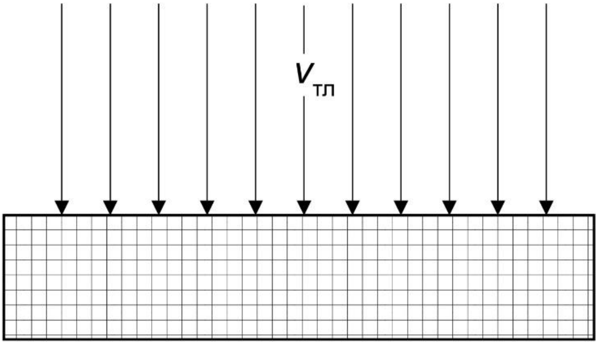


Fig. 3.5. Calculation scheme

In this case, the avalanche pressure on the building is calculated by the following formula:

$$P_{av} = \rho_{av} V_{av} \qquad \textit{(Pascal)} \qquad (3.11)$$

Where $\rho_{av.}$ Is the solidity of a moving snow avalanche which equals to 300 kg/m³ in the case of dry snow and - 400 kg/m³ in the case of wet snow. $V_{av.}$ - Snow avalanche velocity (m / s).

In case of snow avalanche movement, the pressure of the primary frontal impact on the building (P_{fr}) is calculated by the following formula:

$$P_{fr} = 3\,P_{av} \qquad \textit{(Pascal)} \qquad (3.12)$$

b) Building located at an angle of inclination to the snow avalanche (Fig. 3.6)

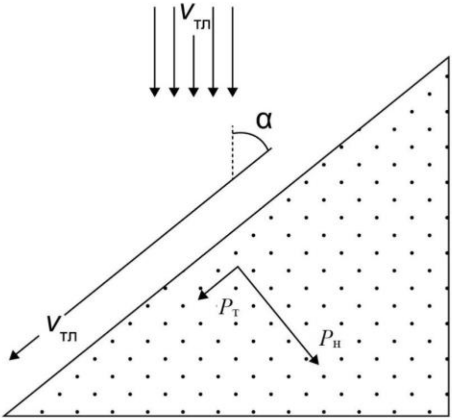


Fig. 3.6. Calculation scheme

In this case the normal P_n and tangent (tangential) P_t voltages impacting on the building are calculated according to the following dependence:

$$P_n = \rho_{av} V^2_{av} \sin^2 \boldsymbol{\alpha} \qquad (Pascal) \qquad (3.13)$$

$$P_t = \mu P_n \qquad (Pascal) \qquad (3.14)$$

Where **α** - is the angle between the direction of the snow avalanche and the building element, μ - the coefficient of friction during the movement of snow mass between the snow layers and between the snow and the ground, which is taken as equal to 0.30, and in the case of snow and coarse ground or rock thickness it is taken as equal to 0.40.

c) The movement of the snow avalanche mass in case of failure to enclosing the building (Fig. 3.7).

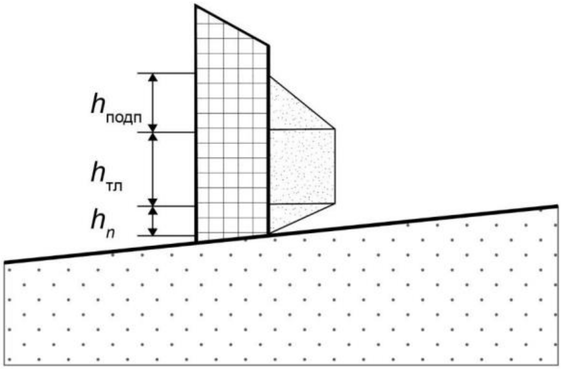


Fig. 3.7. Calculation scheme

In case of the snow avalanche's failure of enclosing on the building, the avalanche pressure (H_p) on the building is calculated according to the following dependence:

$$H_p = V^2_{av} / 2g\,\lambda \qquad (3.15)$$

Where $V_{av.}$ is the velocity of snow avalanche (m/s), λ - energy characteristic of snow avalanche, which: for dry snow avalanches is equal to λ = 1,5, and for wet - its value varies within the limits λ = 2 ÷ 3.

d) Movement of snow avalanche mass in case of enclosing on the building with area A (Fig. 3.8).

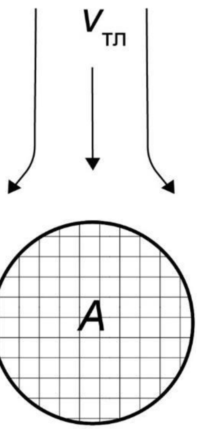


Fig. 3.8. Calculation scheme

Snow avalanche pressure in case of enclosing the building *(P_b)* is calculated by the following formula:

$$P_b = C_d\,(\rho_{av}\,V^2_{av}/2)\quad ,\quad (Pascal) \qquad (3.16)$$

Where C_d is the coefficient of resistance taken according to Table 3.6.

Table 3.6
Snow Avalanche Resistance Coefficient Cd
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

e) Movement of snow avalanche mass in case of rectangular enclosing on the building (Fig. 3.9).

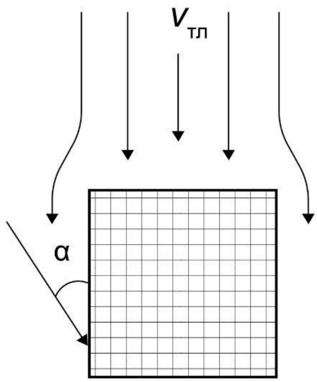


Fig. 3.9. Calculation scheme

The height of snow avalanche pressure in the case of enclosing a rectangular building is calculated according to the following dependence:

$$H_p = (V^2_{av}/2\,g\,\lambda)\,f \quad (m) \qquad (3.17)$$

Where f is the coefficient determined by the width of the enclosing the building, by the height of the snow avalanche front - h_B. The values of the coefficient f are taken from Table 3.7. The value of angle α is taken to be equal to 20^0.

Table 3.7

The values of the coefficient f according to relative values **(b / h_B.)**

(b / h_B)	0,1	0,5	1,0	2,0	≥ 3,0
f	0,1	0,4	0,7	0,9	1,0

f) In case of overflow at an angle of inclination to the snow avalanche gallery (Fig. 3.10).

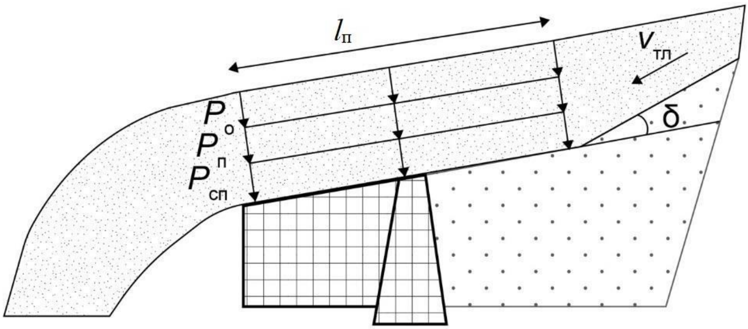


Fig. 3.10. Calculation scheme

The load by the snow avalanche on the roof of the gallery is calculated by the following formula:

$$P_p = (\rho_{av} h_{fr} V^2_{av} \sin\delta\,)\,/\,l_п, \quad (Pascal) \qquad (3.18)$$

Where δ is the angle of intersection of the avalanche with gallery (degrees), $l_п$ - the length of the intersection of the avalanche with gallery (m).

The load caused by the snow avalanche on the roof of the building when the avalanche crosses the gallery is calculated by the formula:

$$P_0 = (h_{av} - h_{st})\, \rho_0 g, \quad (m) \qquad (3.19)$$

Where h_{st} is the height of the building (gallery), ρ_0 - snow avalanche solidity which equals to 500 kg/m^3.

Thus, we have considered and evaluated the reporting dependences of loads while enclosing different types of buildings and of the pressure and load of the snow avalanche in case of avalanche movement.

4. 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 data of the requirements of 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.

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).

- Calculation schemes of innovative anti- avalanche structure

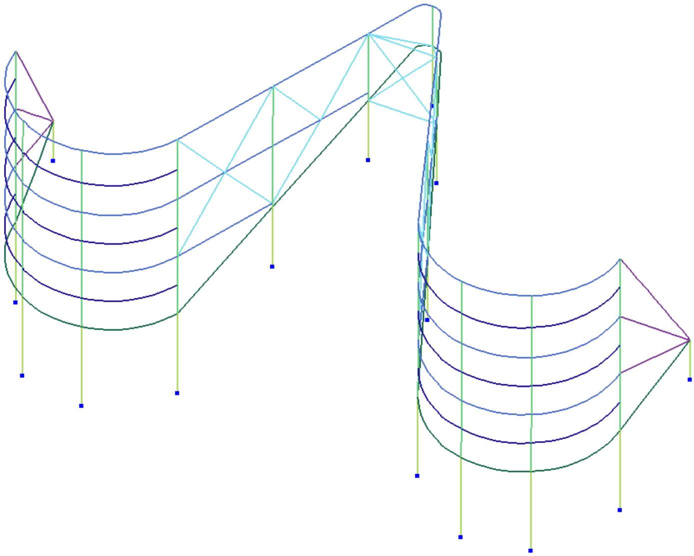


Fig. 4.1. Calculation scheme #1

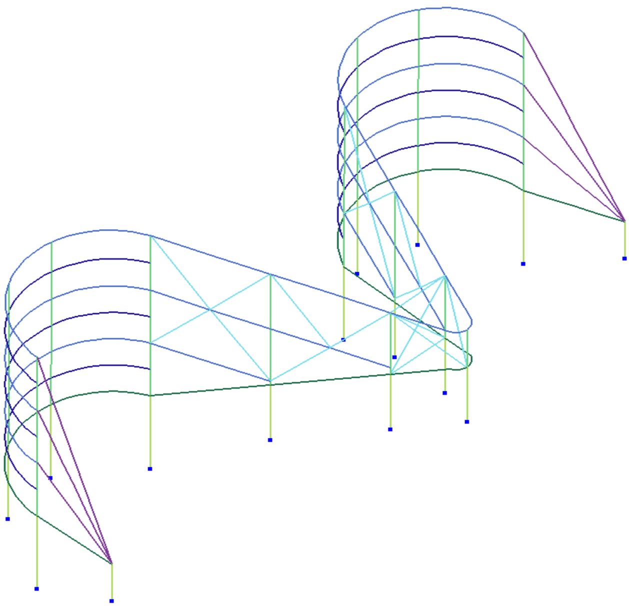


Fig. 4.2. Calculation scheme #2

- General views of innovative anti- avalanche structure

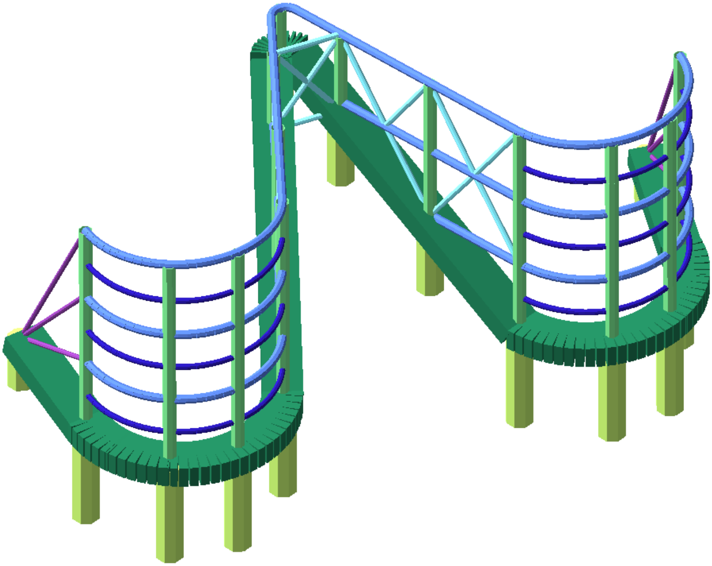


Fig. 4.3. View of the innovative avalanche structure from the down stream

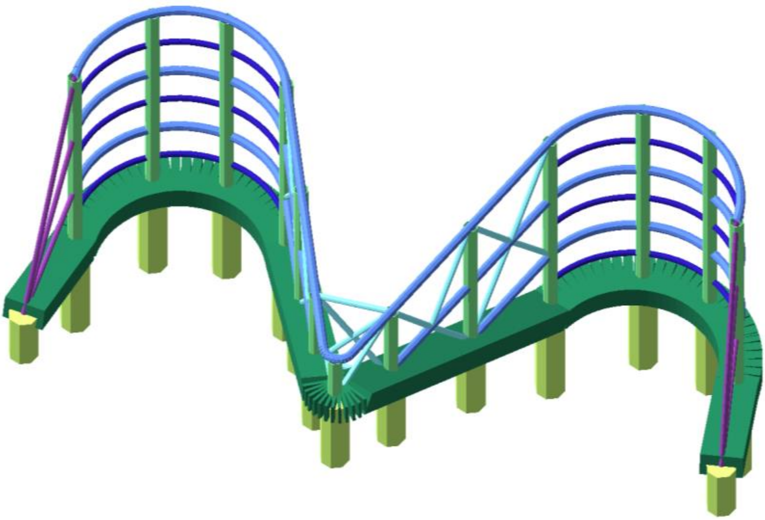


Fig. 4.4. View of the innovative avalanche structure from the upper stream

4.1. 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 $\gamma = 1.05$ (kg.f/m^3); For reinforced concrete structures - $\gamma = 1.10$ (kg.f / m^3).

- ***Temporary load***

Snow avalanche pressure in the event of a enclosing on a building is calculated according to the following dependence:

$$P_b = C_d\,(\rho_{av} V^2_{av} /2), \qquad (kg.f/m^3) \tag{4.1}$$

$$P_b = 1{,}5 \cdot (450 \cdot 4{,}43^2 / 2) = 6623{,}4 \quad (kg.f/m^3) \tag{4.2}$$

Where ρ_{av} - snow avalanche stream solidity and $\rho_{av} = 450$ (kg / m3), C_d – resistance coefficient of snow avalanche enclosing on the building, the numerical indicators of which are given in Table 3.6.
Snow avalanche stream velocity is calculated according to the following dependence:

$$V = (2gZ)^{0,5}\ (m/s) = (2 \times 9{,}81 \times 1{,}0)^{0,5} = 19{,}62^{\,0,5} = 4{,}43\ (m/s); \tag{4.3}$$

where,

$$Z = h_B - (H/L)\, l_B \quad (m) \tag{4.4}$$

$$L = 800 \times \cos 24^0 = 800 \times 0{,}91 = 728{,}0\ (m) \tag{4.5}$$

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:

$$P = P_b \cdot b_0 = 6{,}623 \cdot 1{,}9 = 11{,}86 \quad (t/m^2) \tag{4.6}$$

- **Dynamic load of snow avalanche**

Determining the dynamic impact (F) of snow avalanches:

$$F = K\rho\omega V^2 \quad (kg.f/m^2), \tag{4.7}$$

where: ρ – Snow avalanche stream solidity; $\rho = 450$ (kg.f/m^3); ω – Distribution area (m2); 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).

$$F = 1{,}5 \cdot 0{,}450 \cdot 0{,}245 \cdot 4{,}43^2 = 3{,}25 \ (t/m^2) \tag{4.8}$$

- **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 MSK 64 scale (A = 0.40); Soil category according to seismic properties - II. (Fig. 4.5).

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 (paragraph 4.1):

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) Appendix 1;

Fig. 4.5. Seismic hazard graph

Table 4.1, 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. $K_\psi = 1{,}0$.

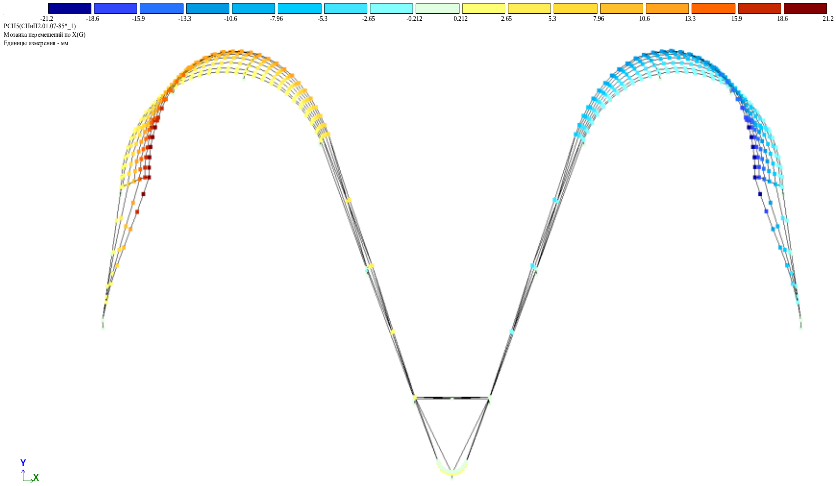
A special algorithm was developed and the structure was calculated using a finite-difference scheme with the help of a computer. The results of the report are given in Table 4.1.

Table 4.1

The calculation was performed by matching the forces

LoadNº	**Name of the l oad**	**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 **(Ss)**	+		1,000	0,000
4	Seismolog. - X	Seismic **(Sx)**	+/-	1	1,000	1,000
5	Seismolog. - Y	Seismic **(Sy)**	+/-	1	1,000	1,000

- # Analysis of the results obtained by calculation



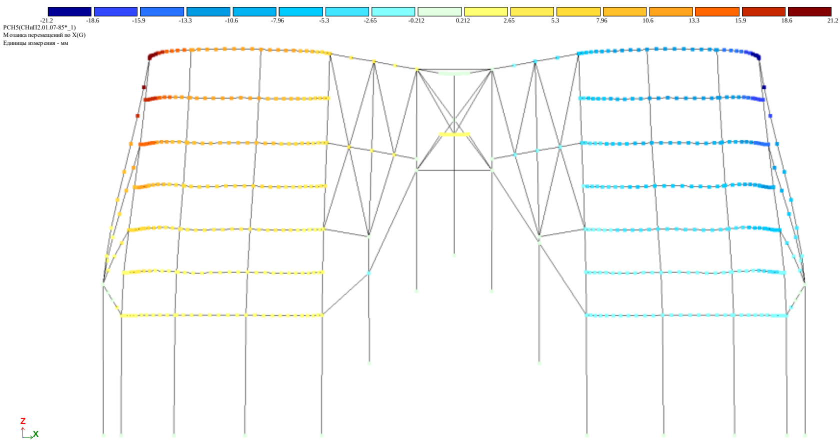


Fig. 4.6. In case of snow avalanche pressure

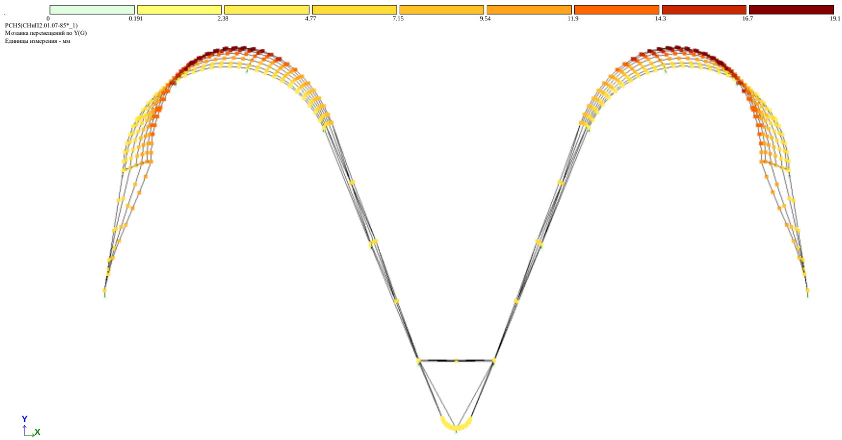


Fig. 4.7. In case of snow avalanche pressure
move in the direction of the X axis

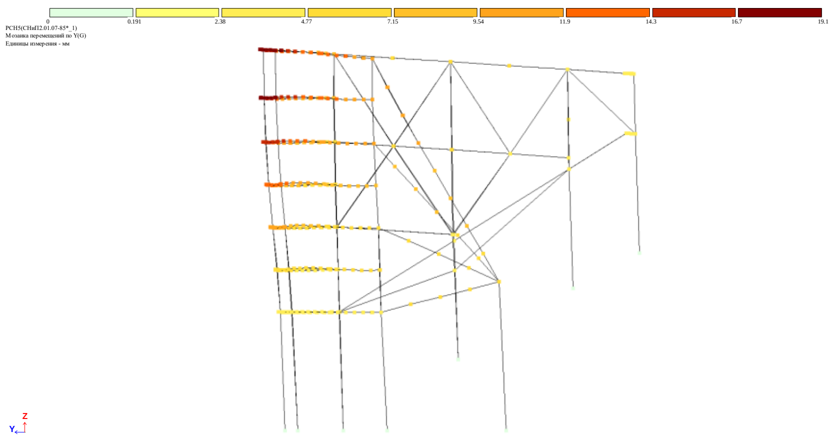


Fig. 4.7. In case of snow avalanche pressure
move in the direction of the X axis

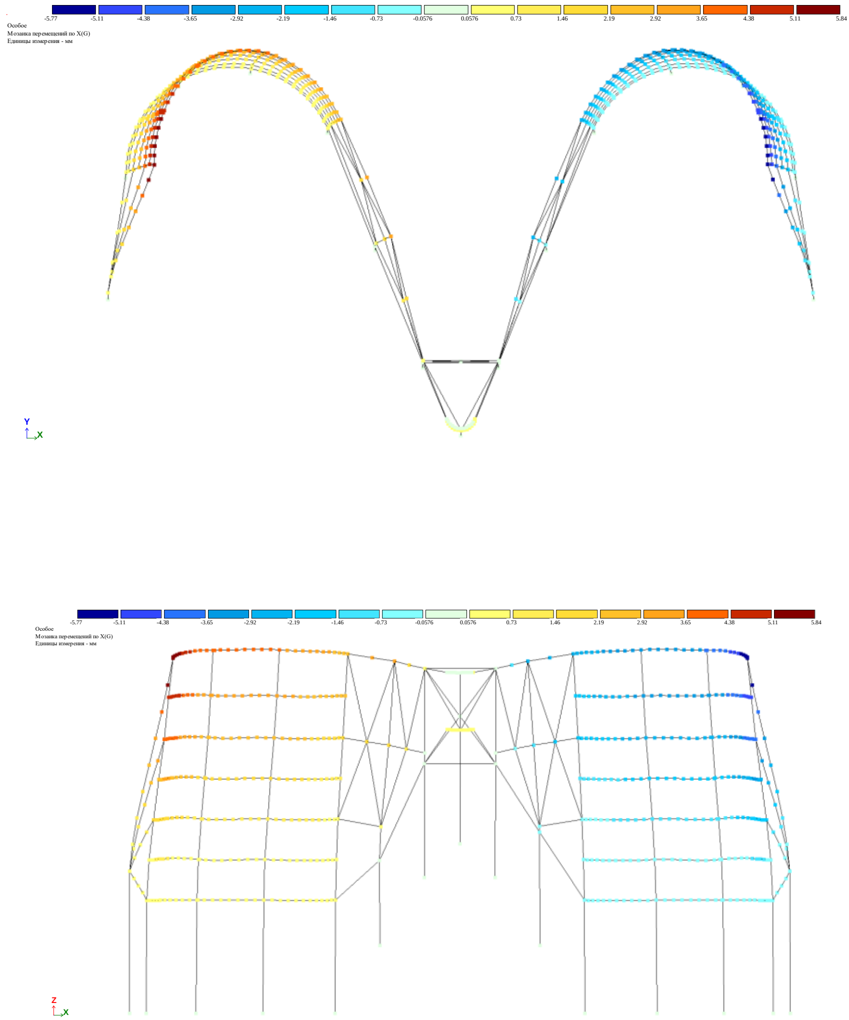


Fig. 4.7. With dynamic impact of snow avalanche
move in the direction of the X axis

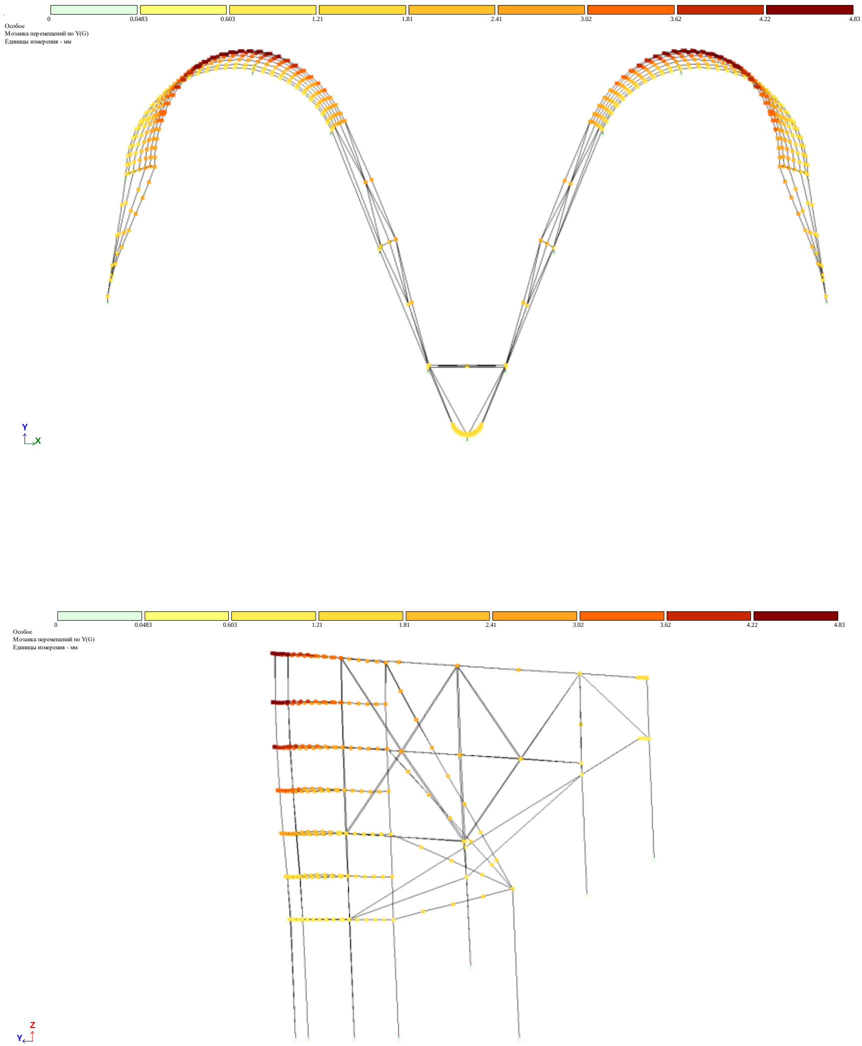


Fig. 4. 8. With dynamic impact of snow avalanche move in the direction of the Y axis

➢ Results of seismic impact

- **I - Form**

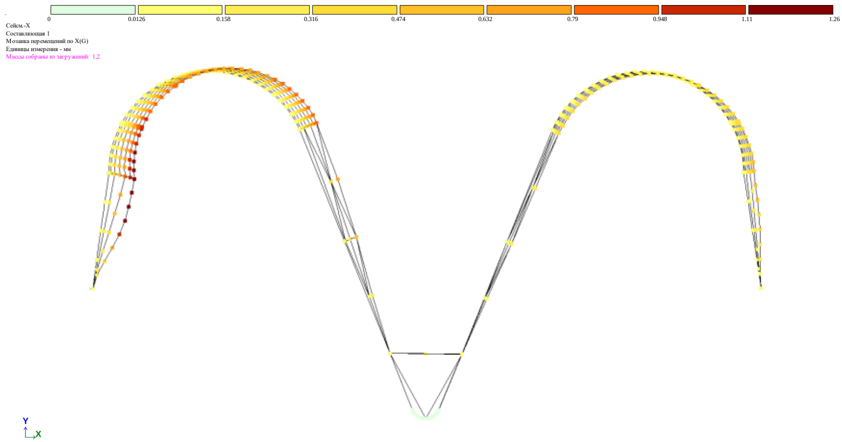


Fig. 4.9. Move in the direction of the X axis

- **IV - Form**

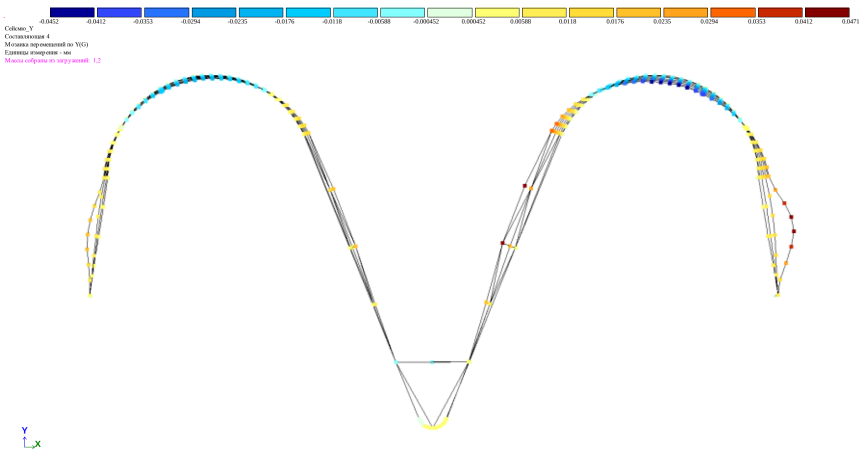
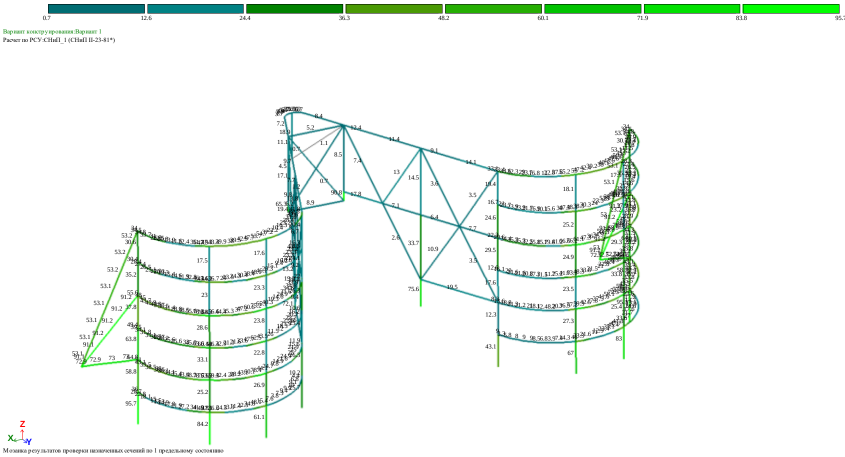


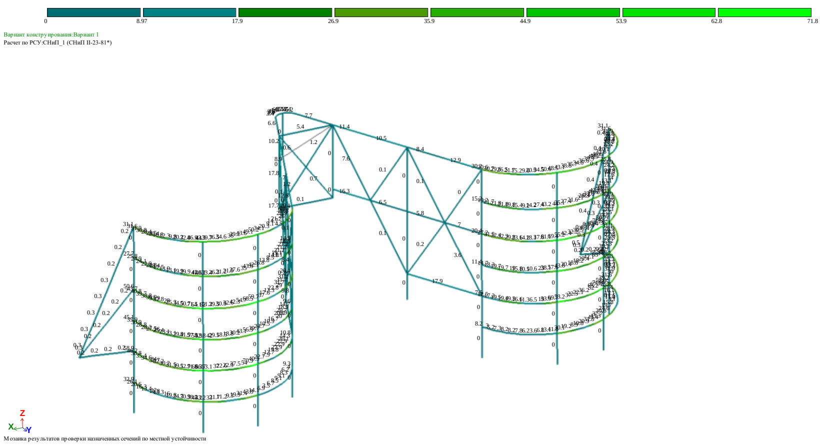
Fig. 4.10. Move in the direction of the Y axis

➢ Calculation results



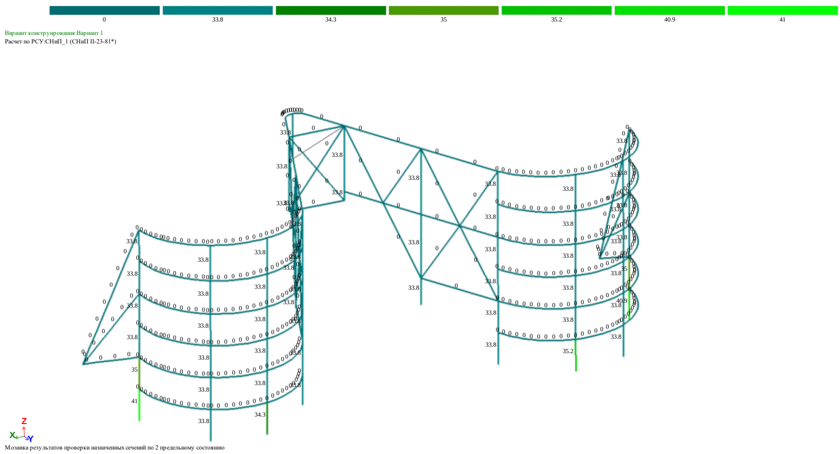
The maximum utilization rate is 95.7%

Fig. 4.11. Inspection of metal sections with I marginal condition



The maximum utilization rate is 71.8%

Fig. 4.12. Checking metal sections for local stability



The maximum utilization rate is 41.0%

Fig. 4.13. Inspection of metal sections with II marginal condition

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 Figs. 4.14 - 4.17.

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 4.1 photo.

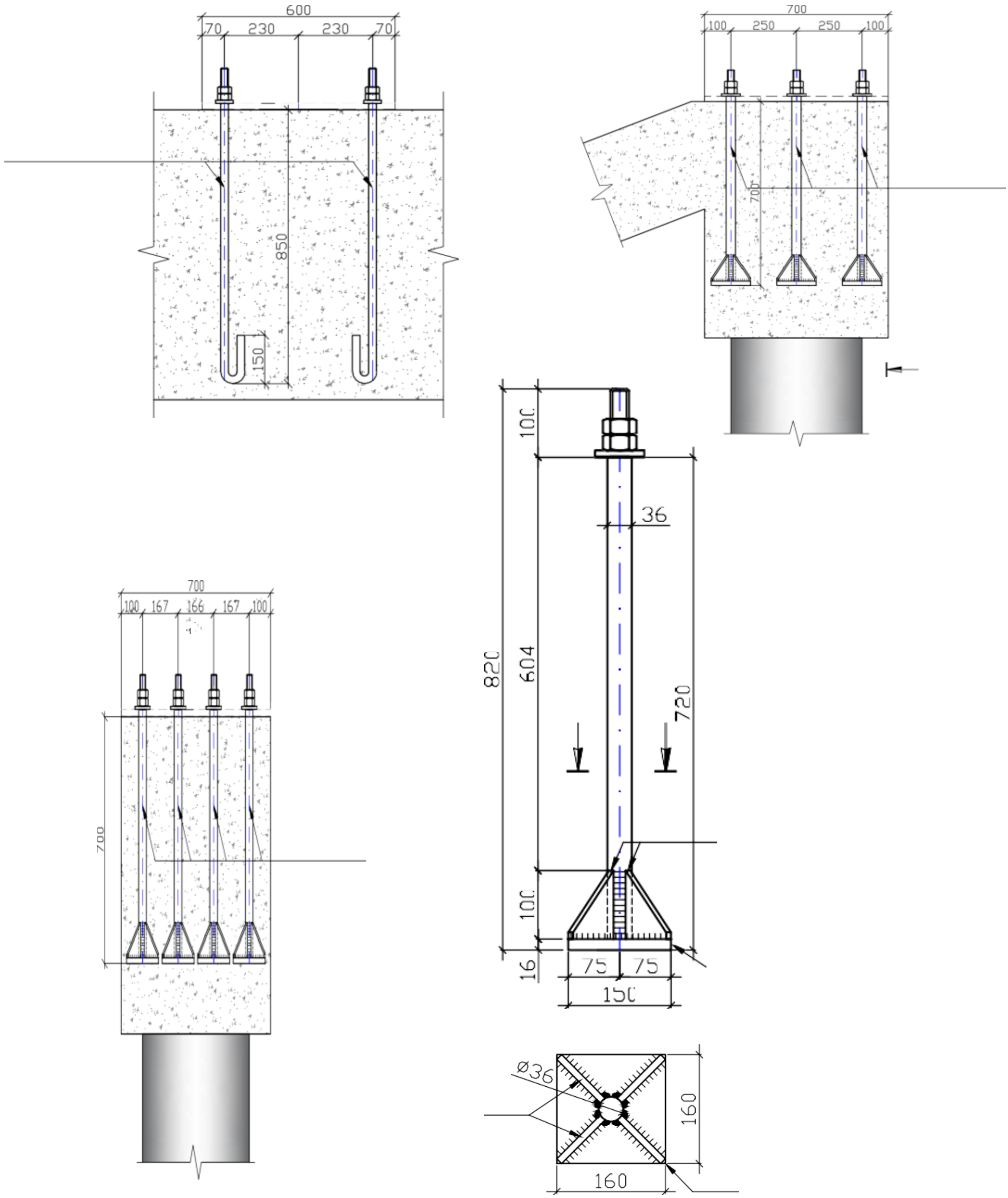


Fig. 4.14. Innovative construction of snow avalanche
Foundation cuts

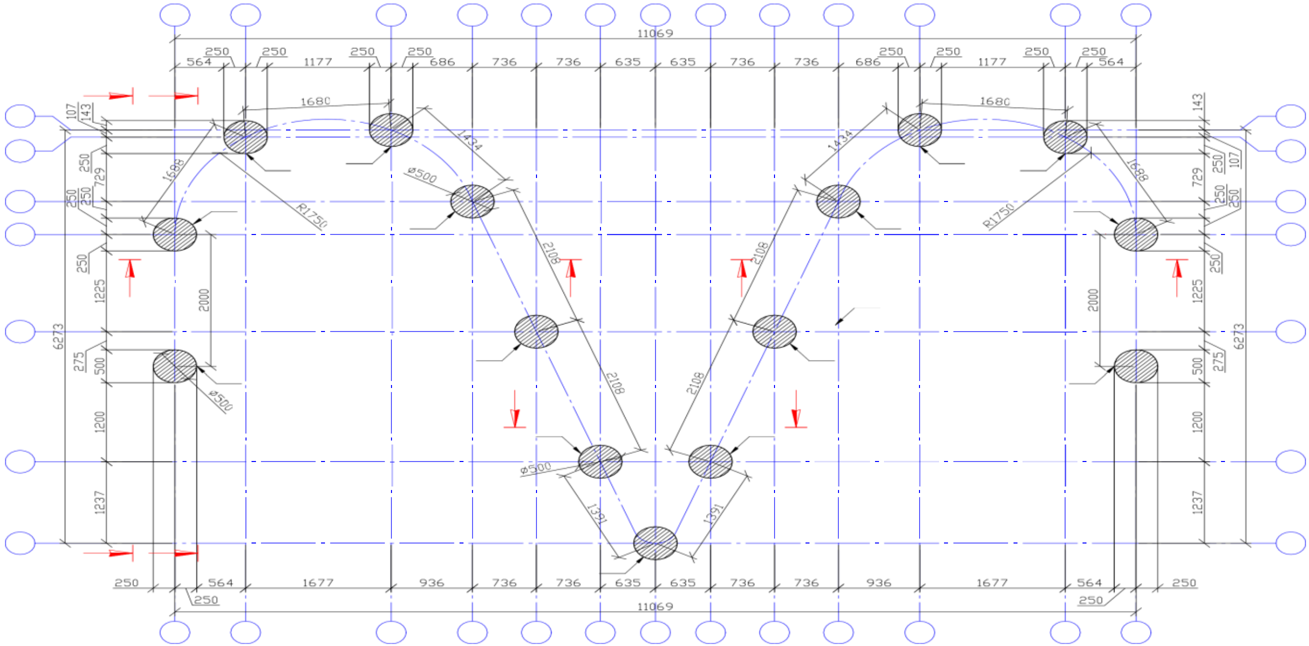


Fig. 4.15. Layout diagram of khiminjes

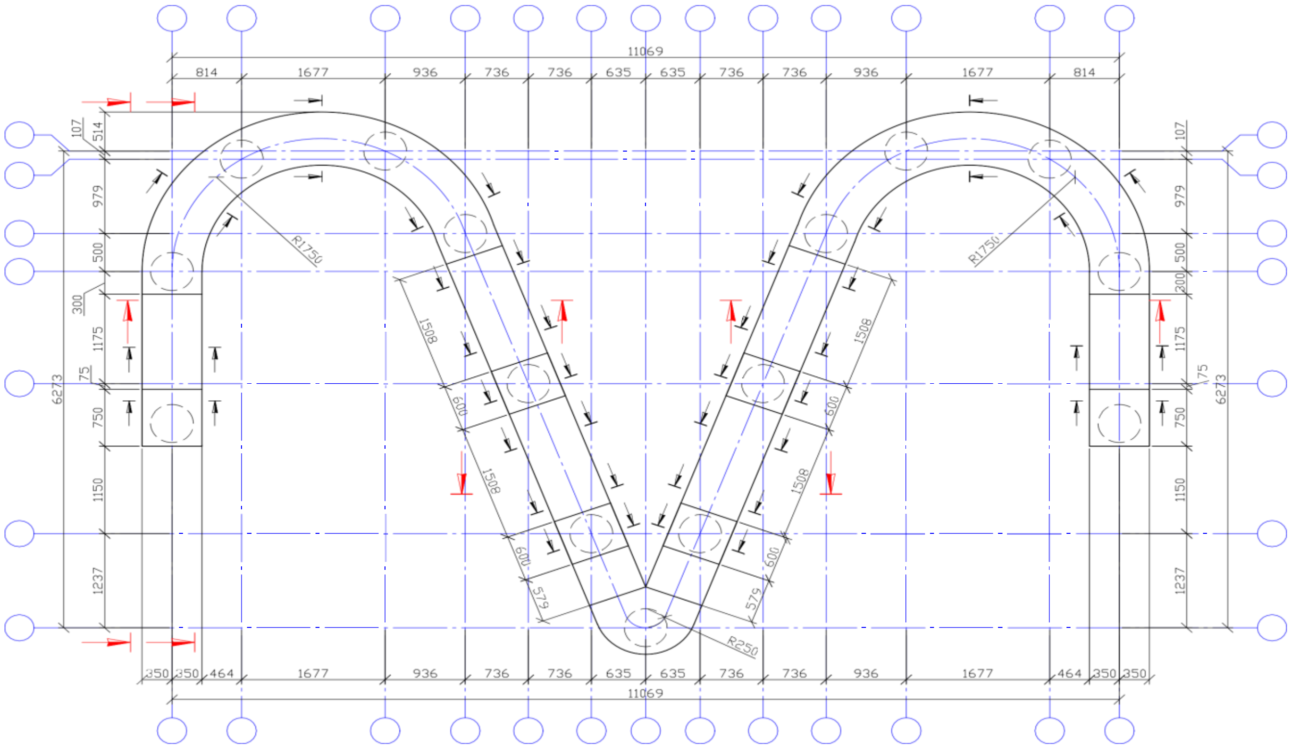


Fig. 4.16. Construction Frostwork plan

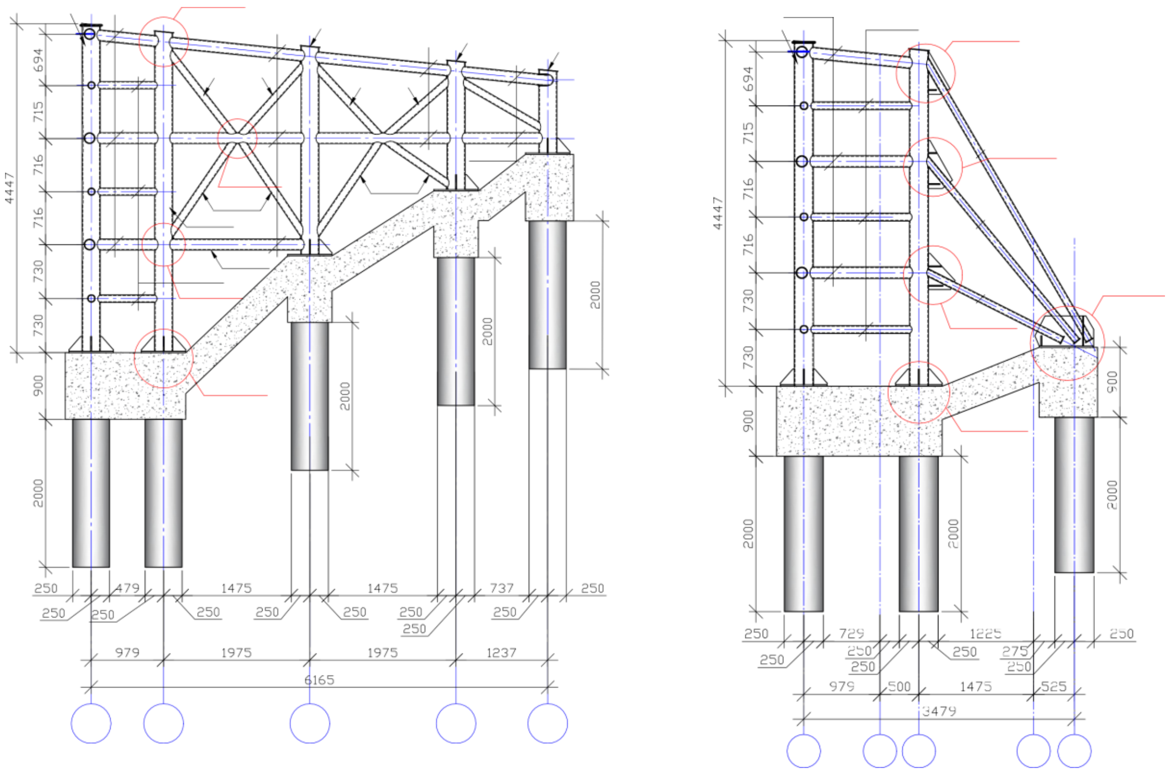


Fig. 4.17. Knots of innovative avalanche construction

Photo. 4.1. An Overview of Innovative Snow Avalanche Construction
Georgian Military Road in Kobi-Gudauri alpine zone (2238 m above sea level)

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Innovative anti-snow avalanche structure

(Structure design methodology, construction norms and rules)

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