Working Out of Recommendations on Protection of the System of Artificial Snow Formation on the Slopes Elbrus Mount from Snow Avalanching

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Abstract. The Elbrus region is the most popular recreational complex of Kabardino-Balkar Republic and of the North Caucasus in general. In perspective in the Elbrus region it is supposed to create 32 aerial ropeways with total spread of 54 km and productivity of 67 thousand people per hour, and 62 ski slopes with total spread of 108 km and square of 506 hectares. It is supposed to realize complex exploration of north-eastern slope of Elbrus – Dzhili-Su region (mountain-recreational and therapeutic complex “Dzhili-Su”). A wide variety of orographic, geological, climatic and physical geographic conditions of the mountainous part of Kabardino-Balkaria predetermine an active development of natural disasters on its recreational territories. The regions of location of existing and newly-created different routes and mountain-recreational complexes on the slopes of Elbrus due to their specific geographical position and natural conditions, are under the influence of dangerous glacial processes, in particular, snow avalanching. The area of the object projection “Reconstruction of artificial snow formation system, Elbrus mount” is also avalanche-risk one.

1. Introduction
The danger of avalanche activity is, first of all, connected with relief of system of artificial snow formation adjoining to the location area. Processes of dynamic snow instability on the slopes with exposition angle of more than 15°, reveal in the form of snow avalanches, rock-falls, which are of great danger for recreants and economic objects.

2. The main aim of the research
The aim is investigation of avalanche processes on the part of the territory of the southern slope of Elbrus mount and working out recommendations on protection of the object “Systems of artificial snow formation, Elbrus mount” from avalanche attacks.

The following tasks: collection, analysis and summary of materials of hydro-meteorological information and map coverage of the territory; reconnoitering exploration of the area of construction; analysis of avalanche processes on the territory of object reconstruction and adjoining area; evaluation of parameters of snow avalanches potentially influencing on the object under projection; paper method with determination of predicted hydrological and meteorological characteristics; working out of recommendations on protection of the object “Systems of artificial snow formation, Elbrus mount” from avalanche attacks, are being solved.
3. Climatic characteristics of location territory of the object “Reconstruction of artificial snow formation system, Elbrus mount”

To determine climatic characteristics of location of the object and adjoining territory, observations on the meteorological station “Cheget” (absolute height is 3040m), observations on the meteorological station “Pic Terskol” (3150m), manuals on the climate of the USSR, Meteorological monthly were used as the main source of information.

The region is characterized as the area with extreme continental climate and vertical zoning. Thermal condition of the territory of investigation is closer to thermal conditions on the meteorological stations “Pic Terskol” and “Cheget”. It should be noted that the station “Pic Terskol” is located at 3150 m above the sea level and refers to south-eastern part of the territory of investigation. Its data may be used to determine thermal conditions of the territory of investigation. The data from the meteorological station “Terskol” give more complete characteristics of adjoining (southern) territory of investigation. Proceeding from this approach, average-annual temperature of the territory of investigation is defined as -2.7°С, and of the territory adjoining from the south +2.7°С.

Air humidity of the territory under investigation is characterized by average-monthly rates from 64% till 73%, at average-annual rate of about 70%.

From 1979 till 2014 increase of annual precipitation with 32.5.mm/10 years velocity is observed. The number of days with precipitation of not less than 5 mm and the number of days with precipitation of not less than 20 mm have been reducing approximately for 1 day/year since 2006.

Here the wind is 15 m/sec. The number of days with such winds is increasing with the altitude of locality.

According to the data from the meteorological stations “Cheget” and “Pic Terskol”, the minimum value of average-annual snow depth in Terskol is about 30 sm, and the maximum one – about 50 sm.

4. Natural conditions of location of the object under projection

The territory of the reconstructed system of artificial snow formation is located on the slope of the southern exposition of the highest mountain of the Caucasus – Elbrus (5642m). Absolute surface elevations within the limits of the object under projection change from +2328.0 m to +2332.0 m in the Baltic system of heights. The relief and landscape of the region is completely conditioned by volcanic activity of Elbrus and gouge and accumulative activity of its glaciers in the historical period and nowadays. The area of actual glaciations of Elbrus is 144 km². Underlying surface is composed of young lava of Elbrus of the recent period which consists of andesites and dacite-andesites. Relief in the areas free from glaciers consists of ridge of the recent lava and the cover of morainic, friable-fragmental materials and fluvial glacial sediments. The presence of friable-fragmental sediments is conditioned by enormous gouge and accumulative activity of glaciers of Elbrus and mechanical alteration in the past and present. Characteristics of relief and snow accumulation foster conditions of snow avalanching. Among phenomena there are “dead glaciers” in the area of the second line of the aerial ropeway near the periphery of snout of Maly Azau glacier which are formed as a result of its retreat.

As the area of research is located in nival-glacial belt and on absolute heights of 2300-3100 m, the landscape structure is subjected to altitudinal zoning. In nival glacial zone vegetation is extremely poor, there are only several vegetation areas which are out of the survey limits and locate in trans-glacial territory. From hydrological point of view there is a permanent stream flowing out of Maly Azau glacier, a stream from the glacier-fed waterfall and a number of temporal water flows of spring snow melting.

Conditions of highlands reflect on climate, creating vertical climatic zoning, irregular distribution of precipitation and temperature, heavy atmospheric heating in valleys and the raise of wind and foehn wind. The climate of the region is being formed under the influence of seasonal circulation of air masses, and at the same time the influence of highland relief is great. Mountain ridges detain and deflect air masses. At ascendant movement by upwind slopes the air cools for 0.5°C at every 100 m of ascent.
For the first time the scientists of the basic research laboratory of the Moscow State University under the guidance of G.K. Tushinsky realized evaluation of the relief as a condition of development of natural disasters for a big territory while mapping avalanche-risk regions of the Soviet Union [1].

According to the investigations [2] the visible bottom of Elbrus is composed of liparite lava, tuff lava and tuffs of the upper Pliocene, lying on eroded surface of more ancient materials of volcanic origin. In the bottom the true soil consists of interstratified lava-breccias, little lava flows of dacite and liparite-dacite composition and pyroclastic masses of rough lava breccias stratification. The power of the true soil is 200-250 m. There is a true soil of light-grey and greenish dacite and andesite-dacite lavas higher.

Middle-Pleistocene masses presented by two generations of quaternary lavas are located on the southern and south-western slopes of Elbrus (the investigation area).

Lavas of more ancient generation compose high lava plateau extremely disjoint by river and glacial erosion, which transformed into rocky crests in the territory of Krugozor station. The total power of lavas of this generation which fulfill Azau Dale, is 300-400 m. The relief of the territory of investigation has typical alpine shapes: high jagged edges, great number of peaks, etc. characterized snow cover all year around and avalanching [2].

According to mineralogical spectrographic composition lava masses of the territory of investigation from Krugozor-Mir station till snouts of glaciers of Maly Azau belong to dacites and andesite-dacites. Dacite and liparite-dacite tuff lavas are banded, extremely solid glassy rocks with inclusion of feldspar, biotite and quartz.

Beside volcanogenic masses, glacial accumulations presented by phasic moraines that fix separate glacial recessions, belong to the upper Pleistocene. The given moraines are on the territory of creation of system of snow formation on the floor and sides of Maly Azau Dale [2].

5. Evaluation of avalanche danger on the territory of investigation (existing and potential avalanche centers, their genetic types and regularities, conditions of formation)

Evaluation of avalanche danger is realized on the basis of working out and analysis of: investigation materials and researches of conditions of development of natural disasters of previous years on the investigated and adjoining territory; results of route investigations; decoding space images received in the result of annual shooting in the period of maximum snow melting from 2000 till 2014.

Avalanche regime of the investigated area is poorly studied. Nevertheless, proceeding from physical geographical conditions of the territory above the area of construction of the system of artificial avalanching, development of avalanche processes potentially dangerous for the object, is possible enough.

Information from several publications also testifies this statement. In particular, in the monograph of the academician of the Russian Academy of Sciences M.Ch. Zalikhanov the episode of avalanching on the territory of investigation in February 1960 is described.

As a result of realized investigations we revealed 7 avalanche centers which avalanches present potential threat to the object under projection. Application of the object to the space image shows that avalanches are active on the object on three sites: on the first site - centers 1-3, on the second site – centers 3-5, on the third site – 5-7 centers. Directions of avalanche cover of the object are marked by red line. (Figure 1).
Dynamic characteristics of avalanches (methods and results of elevation)

Avalanche studies as a science about avalanches cannot explain many processes that emerge at avalanche birth and movement. There are no physical models of avalanche process and advancing avalanche that allow describing with more accuracy an avalanche and evaluate its dynamic characteristics. Existing physical models are based on either ideal mathematical or empirical ideas which simplify greatly the real situation.

On this account all evaluations made on the basis of existing physical models of avalanches, allow describing avalanche process with a definite degree of proximity which should be taken into account while using calculated values of characteristics of avalanche processes.

Selection of methods of dynamic parameters of avalanches is determined by perennial practical and theoretical experience of the authors of this research in the area of avalanche study, including the territory under investigation.

Evaluation of quantitative parameters of snow avalanches on 7 avalanche centers on the slope of Elbrus is realized in accordance with the statements of Industrial construction standards 02-73 [4] and general principles presented in the works of V.P. Blagoveshensky (1995) and others, A.V. Runich (1972), S.M. Kozik (1962) and Yu.D. Moscalyev (1977).

For the territory of investigation non-avalanche risk situation is snow accumulation that do not exceed 30 sm. The given extreme snow depth is characteristic for the Elbrus region, if there is no wind redistribution of snow, according to perennial observations of the North-Caucasian Paramilitary Service and High-Mountain Geophysical Institute. Snow accumulations of such depth are not avalanche-risk ones. Possibility of avalanching on the territory of investigation arises at snow depth of more than 50 sm. According to perennial observations the snow depth on this area does not exceed 50 sm. In this basis, we made evaluations of dynamic characteristics for the snow depth under 50 sm.
The results of evaluation of quantitative parameters of avalanches are presented in the Table 1.

Table 1. The results of evaluation of dynamic characteristics of avalanches at snow height $h = 0.5$ m, according to Industrial construction standards 02-73 Directive on calculation of avalanche weight while projecting constructions.

| № avalanche | maximum height of the nucleus, m | area of the zone of origin of avalanches, $S$, km$^2$ | volume $V$, m$^3$ | speed $G$, m/s | avalanche height, $H$, m | impact force, $P_{\text{av}}$, t/m$^2$ | average slope gradient $\phi$ |
|-------------|---------------------------------|---------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| 1           | 3110                            | 0.002                           | 194             | 29              | 2.6             | 1.2             | 603             | 4.3             | 38              | 33              |
| 2           | 3111                            | 0.0007                          | 67              | 70              | 29.8            | 1.2             | 0.9             | 592             | 4.5             | 40              | 34              |
| 3           | 3099                            | 0.001                           | 97              | 100             | 30              | 1.7             | 1               | 551             | 4.6             | 41              | 35              |
| 4           | 3082                            | 0.0004                          | 38              | 40              | 0.7             | 0.8             | 506             | 4.6             | 42              | 36              |
| 5           | 3093                            | 0.001                           | 97              | 100             | 30.4            | 1               | 1.7             | 530             | 4.7             | 42              | 36              |
| 6           | 3050                            | 0.001                           | 97              | 100             | 25              | 1.4             | 0.9             | 506             | 3               | 28              | 29              |
| 7           | 3010                            | 0.004                           | 392             | 407             | 26              | 3.4             | 1.5             | 385             | 3.5             | 31              | 31              |

7. Recommendations on avalanche protection of the territory of location of artificial reservoir

On the territory of location of artificial reservoir there is a risk of avalanching of small volumes. In connection with it we propose complex protection of the artificial reservoir under projection from avalanche attacks, including: a) engineering decisions: creation of avalanche-protection dams on three sites marked on the Figure 1; b) monitoring of meteorological conditions of the territory adjoining to the object (control of dynamics of snow accumulation, temperature and air humidity registration, etc.) and controlled avalanching at increase of snow depth more than 30 sm in the centers 1-7.

Taking into account location of avalanche centers and their accessibility, controlled avalanching may be realized with the help of the anti-avalanche complex “Nuris” (firing range of 1000m).

At the same time it should be mentioned that for monitoring of snow avalanche regime of the given territory it is necessary to form a separate department on the Elbrus ski resort. In the future this department should determine avalanche regime of this territory and work out recommendations on protection of the territories from potential avalanche attacks. One of the potential decisions on provision of avalanche protection of the entire territory is controlled avalanching with the help of various means (light-gas gun, antiaircraft artillery gun, etc.) Nowadays in the Elbrus region according to the existing license, monitoring and active influence is realized by the North-Caucasian Paramilitary Service (360016, 18 Abidov str., Nalchik, Kabardino-Balkar Republic). The works are realized in accordance with regulatory documents [9].

As the given investigations show, the object under projection - an artificial channel - is attacked by avalanches in three sites with the angle of outlet on channel side $21^\circ$, $26^\circ$, $23^\circ$ respectively. At the same time taking into account angles of overflow of potential avalanches on the channel sides the blow forces calculated with the help of the following formula $P_\alpha = P \cdot \cos \alpha$, where $P_\alpha$ – is a blow force of avalanche overflowing on the object angle wise $\alpha$, $P$ – blow force at perpendicular avalanche strike on barrier (Table 1) does not exceed 4.2 t/m$^2$ for dry-snow avalanche and for wet-snow avalanche – 38.1 t/m$^2$ (Table 2).

The height of avalanche frontal part is from 0.6 to 2.8 m according to the realized calculation. Proceeding from the given characteristics of avalanches: blow force, width of avalanche frontal part and avalanche height, creation of avalanche-detaining barriers on three sites to protect from avalanches at snow accumulation of 30 sm, is proposed.
The suggested sizes of avalanche-averting barriers (dams) are the following: the length of avalanche-averting barrier of 20 m for the first and third sites and 22 m for the second site. The height of barriers is about 2 m.

Evaluation of the boundaries of zones attacked by avalanches consists in determining the width of avalanche front and distance of throw. The width of avalanche front is determined by proportions of avalanche catchment (the area of avalanche birth), and transit, and is defined based on the argument [10].

The values of avalanche width on the point of tangency of barriers of the artificial reservoir are revealed by characteristics of the channel presented in the Table 2.

One of the methods of supposed protection of the reservoir under projection from avalanche influence is the use of snow-detaining constructions in the area of avalanche birth.

8. Conclusion

1. Climatic characteristics of the territory of location of the artificial reservoir are: Average-annual temperature of the territory of investigation is defined as -2.7°C, and of the territory adjoining from the south is +2.7°C. Average-annual humidity of the territory of investigation is 66%. Maximum humidity reaches 100%, and minimum one is about 18%. The number of days with relative humidity ≤30% and ≥80% is from 55 to 68. The territory of investigation has about 880.7 mm of precipitation in average for a year. At the same time, about half of it 450.2 – in the cold period (November-March), and another one 430.5 – in warm months – April-October. In the region of the territory of location of the artificial reservoir wind speeds may reach 70 m/s, at average 6-10 m/s. There are about 20 days with such wind speeds. The number of days with maximum speeds does not exceed 10. The number of days with persistent snow cover on the territory of investigation is 131. Minimum value of average-annual snow depth in Terskol is 30 sm, and maximum one – about 50 sm. The number of days per year with thunderstorms is 64, specific lightning striking capacity is 5/km² per year.

2. The relief and structure of landscapes of the region of creation of the system of artificial snowing is completely conditioned by volcanic activity of Elbrus and gouge and accumulative activity of its glaciers in the historical time and in the present.

3. As a result of realized investigations we revealed 7 avalanche centers above the territory of location of the artificial reservoir which avalanches are of potential threat for the object under projection.

Calculation of dynamic characteristics for potentially dangerous avalanches for the object, is realized.

4. We propose the complex protection of the artificial reservoir from potential avalanche influence, including: a) Engineering decisions. Construction of avalanche-protection dam. b) Monitoring of meteorological conditions of the territories adjoining to the object under projection (control of dynamics of snow accumulation, temperature, air humidity registration, etc.). c) Realization of controlled avalanching at snow depth increase of more than 30 sm in the centers 1-7. r) One of the
methods of presupposed protection of the reservoir under projection from avalanche influence is snow-detaining constructions in the area of avalanche birth.

5. The suggested dimensions of an avalanche-averting barriers (dams) are the following: the length of an avalanche-averting barrier of 20 m for the first and third sites, and 22 m for the second site. The barrier height is about 20 m.

9. References

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