Avalanche processes as a limiting factor in the ski environmental management

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Abstract. In accordance with the federal target program for the development of resorts in the North Caucasus, the Government of the Russian Federation announced its intention to build five more modern European-class ski resorts in the region over the next 10 years. Construction of complexes, including in the village of Veduchi (Chechen Republic is planned). In the territory of the “Veduchi” resort such dangerous exogenous processes as avalanches are largely developed. This work is devoted to engineering and hydrometeorological surveys for the object “Skiing infrastructure on the north-oriented slope of the Veduchi ASTRC”, assessment of avalanche danger.

Introduction

Engineering hydrometeorological surveys are carried out with the aim of comprehensive studying the natural conditions of the surrounding territory and the local conditions of the designed object, determining the estimated climatic and hydrological characteristics in the volumes necessary for choosing the construction site and making design decisions. In determining the composition of these types of surveys, it is necessary to consider the regional nature of the hazardous phenomena and processes distribution.

The avalanche hazard assessment is a part of the engineering and hydrometeorological surveys carried out by the authors at the “Ski infrastructure on the north-oriented slope of the Veduchi All-Seasonal Tourist and Recreational Complex (VASTRC)”. The object is located on the left and right slopes of a narrow V-shaped valley Khacharoyakh (near its middle reaches) and, partly, within adjacent watershed areas (slopes of the Daneduk and Khacharoyduk ridges) in the Itum-Kalinsky municipal district of the Chechen Republic in the Russian Federation.

The main tasks were to identify avalanche basin on the territory of the “Ski infrastructure on the north-oriented slope of the Veduchi ASTRC” object design, to build maps of avalanche areas and to calculate the parameters of snow avalanches on the construction sites.

Based on the analysis of reference, archival materials, route studies and meteorological data, the conditions for the formation of snow avalanches, the duration of the avalanche period, the genetic type and volume of snow avalanches in the territory of the designed complex are identified.

The territory of the Chechen Republic belongs to the territories, little studied in the avalanche relation. The analysis of not numerous literary and archival material [1-8], as well as our studies,
showed that the main factors affecting the avalanche formation regime are the mountain relief and the thickness of the snow cover.

Main part
We carried out the field surveys of the territory of the “Veduchi” ASTRC. The length of the route is 9 km. As a result of the field survey and the analysis of space information from the GoogleEarthPro Internet portal (3D) and the topographic plan of the territory, 16 avalanche foci were found on the northern slope of the Daneduk ridge. Avalanches of 14 outbreaks can threaten the projected facilities of the territory of the “Veduchi” ASTRC (Figure 1).

Figure 1. The map of the survey area on the basis of a surface contour map (with projected objects of recreation) with avalanche manifestations

The Daneduk Ridge, located close to the Greater Caucasus Highest Ridge here, has elevations up to 3524.3 m (Kostenkort town). The relative heights reach 2500 m. At the heights above 2500 m above sea level, the relief has a typical Alpine appearance with traces of ancient glaciation. The sharp dismemberment, significant steepness and rockiness of the slopes, the sharpness and jaggedness of the watersheds and peaks are distinguished. The relief below has smoother outlines, but the steepness of the slopes, especially in the lower part, remains high. Here, relatively flat slopes, favorable for the formation of wasps (slope avalanches) alternate as well as denudation craters and erosion incisions, which can serve as foci of channeled (flume) avalanches. The total exposure is the northeast slope.

Avalanche foci (avalanche nucleation zones) are located at an absolute height of 2221 to 2955 m (middle mountains, high mountains), average slopes here vary from 33 ° to 40 °, snow accumulation areas change from 0.0003 km² to 0.52 km², average avalanche basin slopes (zone origin, transit zone, deposition zone) vary from 25° to 36°.

Evaluation of the avalanches’ quantitative parameters
The quantitative parameters of snow avalanches for 14 avalanche basins (avalanches of which may threaten objects under construction) on the north-oriented Daneduk slope were calculated in accordance with the provisions of VSN 02-73 and the design provisions set forth in the works of V.P.
Blagoveshchensky et al. (1995), V.Sh. Comaia et al., (1992). The areas of avalanche foci were determined using the GIS program ArcGIS 10.4.1.

The height of the snow cover
Intensive snowfalls in Chechnya with the duration in the middle mountain belt for 3–4 days, in the high-mountain belt for more than 10 days are the main factors of avalanche formation. Wet avalanches in the mid-mountain regions are possible in March. At this time a significant amount of snow also falls and a peak of avalanche activity occurs. In addition to these two genetic types of avalanches (avalanches of snowfall and avalanches of spring snowmelt), avalanches of recrystallization occur at low winter temperatures and a small thickness of snow cover. This is facilitated by winter continental conditions. Formed dry avalanches of the dense snow plates, under which the unstable layers of the loose deep-frozen rime are loosened. The possibility of avalanche-like situations of such genesis does not exceed 2-3 days in rare winters with little snow, but in the avalanche zones, located above the forest boundary, this factor (snow recrystallization in combination with snowstorm) is predominant. Thus, for mountainous areas of Chechnya, there is a high-altitude zone avalanche formation [3].

The maximum thickness of the snow cover in the studied areas of the mountain slope (in particular, in the places of possible avalanche nucleation), according to [11], should be determined by the long-term observations.

Since the snow-measuring work was not performed directly on the slopes in the area, the thickness of the snow cover of 1% and 2% of the coverage at the nearest meteorological stations Botlikh (983 m) and Sulak, w / g (2927 m) was used to calculate the snow cover thickness. The following equations were obtained:

\[ H_{\text{max}} (1\%) = 0.04475 H + 92.0167 \] (1)

\[ H_{\text{max}} (2\%) = 0.054 H + 42.9 \] (2)

where \( H_{\text{max}} \) is the maximum thickness of the snow cover in (cm), 
\( H \) is the absolute height of the place in (m).

This dependence was used to calculate the thickness of the snow cover at various heights of 1% and 2% of coverage. The calculation results are shown in Table 1.

| № avalanche | maximum height of the nucleation zone, [m] | security, [%] | estimated snow thickness, [m] |
|-------------|------------------------------------------|--------------|-----------------------------|
| 1а          | 2415                                      | 2            | 1.733                       |
| 1b          | 2451                                      | 2            | 1.752                       |
| 1c          | 2483                                      | 2            | 1.770                       |
| 1d          | 2509                                      | 2            | 1.784                       |
| 2а          | 2529                                      | 1            | 2.052                       |
| 2b          | 2476                                      | 2            | 1.766                       |
| 3а          | 2517                                      | 2            | 1.359                       |
| 3b          | 2515                                      | 2            | 1.787                       |
| 4а          | 2508                                      | 2            | 1.783                       |
| 4b          | 2527                                      | 2            | 1.793                       |
| 5а          | 2274                                      | 2            | 1.657                       |
| 5b- profile A | 2234                                   | 2            | 1.635                       |
| 5b- profile B | 2237                                   | 1            | 1.921                       |
| 6а          | 2225                                      | 2            | 1.630                       |
| 6b          | 2265                                      | 2            | 1.223                       |
| 7           | 2352                                      | 2            | 1.270                       |
| 8           | 2955                                      | 2            | 2.025                       |
The results of the possible avalanches quantitative parameters assessing (when interacting with structures), such as volume, speed, height of the front, distance from the zone of origin to the designed object, the impact force of the avalanche are presented in Table 2.

**Table 2.** Results of the avalanches dynamic characteristics calculations when interacting with the structure (at a height of snow of 1% and 2% provision)

| № avalanche | snow thickness [% / m] | maximum height of the nucleation zone, [m] | threat / absolute height of the object, [m] | area of the zone of origin of avalanches, S, [km²] | volume, V, [m³] | speed in point, \( \theta \), [m/s] | avalanche height, H, m | impact force, \( P_{0,5} \), [kN/m²] | \( P_{0,5}=0,05 \) | \( P_{0,5}=0,45 \) | average slope in point, \( \alpha \) | The distance from the zone of origin of the avalanche to the object, [m] |
|-------------|----------------------|---------------------------------|---------------------------------|---------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| 1a          | 2/1.733              | 2415                            | track VP3/2308,5                | 0.0017                          | 1306            | 1445            | 19              | 4               | 2.2             | 1.8             | 16.5            | 34              | 190.3           |
| 1b          | 2/1.752              | 2451                            | track VP3/2313                  | 0.0036                          | 2804            | 3103            | 21.5            | 6               | 2.8             | 2.4             | 21              | 33              | 251.2           |
| 1c          | 2/1.770              | 2483                            | track VP3/2325                  | 0.0016                          | 1267            | 1401            | 23              | 4.9             | 2.2             | 3               | 25              | 34              | 280.1           |
| 1d          | 2/1.784              | 2509                            | track VP3/2312                  | 0.0027                          | 2149            | 2377            | 25.7            | 6.7             | 2.6             | 3.4             | 30.3            | 33              | 359             |
| 1d          | 2/1.784              | 2509                            | track VP3/2331                  | 0.0027                          | 2149            | 2377            | 25              | 6.5             | 2.6             | 3.2             | 28.7            | 36              | 304             |
| 2a          | 1/2.052              | 2529                            | upper cableway station VL-4/324 | 0.0052                          | 4730            | 5201            | 26.8            | 9.4             | 3.3             | 4               | 33              | 35              | 358.4           |
| 2b          | 2/1.766              | 2476                            | road to the track VP1/2321      | 0.0038                          | 2983            | 3300            | 21.2            | 6.5             | 2.8             | 2.6             | 23.3            | 34              | 265             |
| 4a          | 2/1.783              | 2508                            | track VP1/2306                  | 0.0028                          | 2199            | 2433            | 25.6            | 6.8             | 2.6             | 3.3             | 30              | 32              | 381             |
| 4b          | 2/1.793              | 2527                            | track VP1/2142                  | 0.0024                          | 1889            | 2089            | 35.2            | 9.2             | 2.5             | 6.3             | 56.9            | 32              | 738             |
| 5a          | 2/1.657              | 2274                            | track VP1/2178                  | 0.0091                          | 6585            | 7298            | 16.5            | 5.9             | 3.6             | 1.4             | 12.4            | 27              | 214             |
| 5b-profile A| 2/1.635              | 2237                            | training slope / 2117           | 0.0102                          | 7268            | 8057            | 18.3            | 6.9             | 3.7             | 1.7             | 15.4            | 27              | 259             |
| 5b-profile B| 1/1.921              | 2237                            | track VP1/2164                  | 0.0102                          | 8657            | 9497            | 13.4            | 5               | 3.9             | 0.9             | 8.3             | 24              | 178             |
| 6a          | 2/1.630              | 2225                            | track VP2/2175                  | 0.0017                          | 1199            | 1329            | 12.6            | 2.2             | 2.4             | 0.8             | 7.2             | 31              | 99              |
| 6b          | 2/1.223              | 2265                            | track VP2/2207                  | 0.0016                          | 842             | 932             | 13.8            | 2.4             | 1.9             | 0.98            | 8.8             | 33              | 106             |
| 7           | 2/1.270              | 2352                            | track VP3/2237                  | 0.056                          | 26249           | 29141           | 15.5            | 8.2             | 5.5             | 1.22            | 11.01           | 35              | 119             |
| 8           | 2/2.025              | 2955                            | water intake unit ES100/971     | 0.52                            | 164357          | 183391          | 73              | 111             | 9.5             | 27              | 245             | 26              | 4581            |
| 8           | 2/2.025              | 2955                            | water intake unit ES200/1519    | 0.52                            | 164357          | 183391          | 68              | 101.3           | 9.5             | 23.7            | 213.2           | 32              | 2737            |

**Summary**
1. The field survey of the avalanche hazard was performed on the territory of the Veduchi ASTRC.
2. The analysis of the space information and the surface contour map of the territory with the purpose of identifying the avalanche foci.
3. The estimation of quantitative parameters of possible avalanches in the interaction with the designed structures is performed.

As a result of the field survey, as well as the analysis of space information from the GoogleEarthPro Internet portal (3D) and the topographic plan of the territory, 16 avalanche foci were detected on the northern slope of the Daneduk ridge, 14 of which threaten the designed objects.

In accordance with paragraph 1.10 of the BCH 02-73, in order to ensure the operation of the facilities, it is necessary to provide the avalanche service and preventive measures organization to eliminate the avalanche danger. It is proposed to place slope (above the ski slopes and other projected objects) snow-retaining structures.

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