Eur J Forest Eng 2015, 1(2): 61-68

Avalanche Control with Mitigation Measures: A Case study from Karaçam-Trabzon (Turkey)

Gerhard Volk[1], Abdurrahim Aydin[2*], Remzi Eker[2]

[1] Geoexpert Research and Planning GmbH, Brunhildengasse 1, Stiege 1, 2.Stock. A-1150 Wien, Austria

[2] Düzce University, Faculty of Forestry, 81620 Düzce, Turkey

Abstract

Karaçam Village (Trabzon), located in the eastern Black Sea Region of Turkey, suffers from critical problems as a result of snow avalanches. Interviews with local villagers described three important snow avalanche events which occurred in the region. Despite the incidence of dangerous snow avalanches in the Karaçam region, to date, no avalanche defense measures have been planned. In this study, three different snow avalanche scenario simulations (coded as 1, 2 and 3) corresponding to recurrent periods of 30, 100, and 300 years were developed, and Coulomb friction values were designated in order to provide reliable results. For all scenarios, the Coulomb friction values were selected as 0.26 in the release zone, 0.165 in the track and 0.33 in the run-out zone. Scenario 2, a snow avalanche event in the region with the recurrent period of 100 years, was found capable of causing damage to buildings located on the left side of the track as well as on the opposite slope. Hence, taking into account field surveys and observations, feasible counter-measures were planned according to Scenario 2. Construction of structures for supporting the snowpack in the starting zone, reforestation with supporting snow glide tripods, and installation of wind fences were recommended. In total, 508 m of steel snow bridges, 758 m of wooden snow bridges, reforestation with tripod supports over an area of 7 ha, and 1150 m of wind fences were included in the plan.

Keywords: Simulation, Snow avalanche, Supporting structure, Turkey

1. Introduction

Due to the climate and the mountainous topography of Turkey, snow avalanches are significant natural hazards which at times result in catastrophic events responsible for casualties and/or economic losses. In Turkey, on average, 24 people die in snow avalanches every year. Aydin et al. (2014) claims that, according to field visits and interviews with local people, the archival numbers reflect significantly fewer than the real numbers in terms of casualties and avalanche incidences in Turkey. In particular, the eastern part of Anatolia and the eastern Black Sea Region are prone to avalanche events owing to their high mountain ranges. Karaçam Village (Trabzon-Turkey) located in the eastern Black Sea Region, suffers from severe problems due to snow avalanches. Interviews with villagers described three important snow avalanche events that occurred in the region. As the villagers stated, the snow avalanche caused destruction of some buildings in the village. The historical avalanche events in the village are given in Table 1.

An adequate level of avalanche protection is a prerequisite for further development of mountainous regions. Accordingly, for several decades, public administrators in Europe have provided defense structures to safeguard human life and property (Johannesson et al., 2009; IRASMOS, 2008). These measures are classified by IRASMOS (Integral Risk Management of Extremely Rapid Mass Movements) according to their position within the avalanche path, which is divided into three zones: the release (starting) zone, the transition zone (track), and the run-out zone (IRASMOS, 2008). Depending on their position, different types of mitigation measures are applied. Measures to manage snow danger and protect settlements include: i) land use planning, ii) evacuations, iii) supporting structures, iv) deflecting dams, v) catching dams, vi) wedges for the protection of individual buildings, vii) braking mounds, viii) reinforcement of buildings, and ix) measures to reduce snow accumulation in starting zones (Johannesson et al., 2009). Avalanche supporting structures are mostly

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[*] Corresponding author: Tel: +90 3805423217 E-mail: aaydin@duzce.edu.tr

Received 29 September 2015; Accepted 10 December 2015

installed over inaccessible slopes which have different ground characteristics at high altitudes (Margreth, 2007). Hence, simple, inexpensive, robust and well-proven structural methods are compulsory for their successful implementation. In addition, due to the limited financial resources of the public sector, it is important to consider not only the capability of the measure, but also its economic efficiency. For this reason, it is important to evaluate investment in alternatives having the same temporal duration and to find the most economical one (IRASMOS, 2008). Nevertheless, it should be kept in mind that, unlike with structural measures, administrative actions will pale in comparison with the gain of avoiding loss of lives and damage to property. Although dangerous snow avalanches have occurred in Karaçam region, no technical counter-measures have yet been planned. The main aim of designing technical structures in release zones is to mitigate the release of the snow mass so as to minimize the adverse effects of snow avalanches.

In the present study, using ELBA+ software, 2D numerical snow avalanche simulations were made for different scenarios for three release zones in the region. In line with field observations and surveys with the results of the ELBA+ simulations, technical counter-measures have been recommended.

Table 1. Historical snow avalanche events in the region

Date of Event	Time	Casualties	Nu. of damaged buildings	Remarks
~1880s	*	*	*	The oldest event known in the area.
29.12.1986	10:00	None	45	No casualties but demolishing of damaged houses. The extent was very similar to that of the 1880s avalanche.
February 1992	*	None	5	Three of the buildings were located in the left side of the flow direction, and the remaining two were situated on the opposite slope.

Note: Between 1992 and 2009, additional events which had no destructive effect on buildings were also observed in the region.
* No information

2. Materials and Methods

2.1. Study Area

Karaçam Region, Trabzon (Turkey), was selected as the study area (Figure 1). The site of the avalanche is located between N 601629 - 4494092 and E 603172 - 4492451 in UTM European Datum 1950. Karaçam region is generally under the effect of a maritime climate. The altitude of the Seyrantepe neighborhood of the village is between 1220 and 1610 m (a.s.l.) and the general aspect is north-east; thus, dense snowfalls are experienced in the region and different snow conditions are possible depending on the prevailing conditions. Moreover, due to multiple snowfalls during the winter season, a multi-layered snowpack is expected. Wind plays an important role in the formation of different snow depths (between 4 m and 15 m), depending on the natural shape of land surfaces such as gullies, valleys, and depressions. Wind also has an important effect in the formation of powder snow avalanches, which can be more destructive because of the decreasing water content of the snow mass. The avalanche track length was about 2435 m at an altitude varying between 2155 m (upper point of starting zone) and 1060 m (outer boundary of deposition zone). There were three different potential release zones (PRZ) in the study area. The first PRZ (No. 1) created destructive avalanches. The avalanche path was not a complex structure and included a release zone, a track, and a run-out zone which were clearly distinguishable from one other. The other two PRZs (No. 2 and No. 3) were comparatively smaller in area and their starting zones remained below the treeline. A general view of the PRZs is given in Figure 2. Because of its considerable damage potential, only PRZ No. 1 was analyzed in this study.

The slope gradient of release zone No. 1 was between 35° and 45°. The altitude of the release zone was between 1970 m and 2155 m and the width of the release zone and track was between 90 m and 300 m. The longitudinal profile of the avalanche path is shown in Figure 3 and topographical characteristics of the release zones in the region are given in Table 2.

We don’t have any snow measurement at the study site. But at the Uzungöl district (9 km horizontal distance to the study area) snow depth was calculated for 100 year return interval as 174 cm (Kocyigit, 1997). For deciding to the rupture depth in starting zone we adopted approach of Schellander`s (2004) study in Austrian Alps of Tirol.

2.2. Numerical avalanche simulation with ELBA+ Software

Energy Line Based Avalanche (ELBA+) software has been commonly used for hazard mapping, protection works and design purposes (Sauermoser and Illmer, 2002). The software was developed at the University of BodenKultur and is based on the parametric calibration of 147 well-recorded avalanche events throughout Austria (Volk and Kleemayr, 1999). The simulations in this study were based on the Voellmy model in ELBA+ software, which contains two parameters: the Coulomb friction μ and the velocity squared dependent turbulent friction ξ. In addition to these two parameters, release area (m^2), release height (m), snow density in release zone (kg/m^3), entrainment and resistance areas (optional) and Digital Elevation Model (DEM) data are necessary inputs for the simulations (Aydin, 2010). All the spatial and table information of these inputs was prepared by Elba+ Add-ins for ArcMap. After completing the preparation for all data inputs, the simulation process was carried out by the ELBA+ Simulation Module.

In this study, the release zone was digitized based on field observations over the topographical map of the area. The DEM data with 5 m pixel resolution was created using data obtained from topographical field surveys (Figure 4). Three different scenarios (coded as 1, 2 and 3) were developed for the snow avalanche simulation based on recurrent periods of 30, 100, and 300 years. The release heights of the simulations were taken as 110, 160, and 210 cm for the periods of 30, 100, and 300 years, respectively. For all scenarios, the snow density was selected as 300 kg/m^3. Due to the high amount of snowfall in the study area as a result of the maritime climate, the entire extent of the avalanche was accepted as the entrainment range. Entrainment ratios were selected as 15 cm, 25 cm, and 30 cm corresponding to the recurrent periods of 30, 100, and 300 years, respectively. Turbulent friction was calculated as a function of flow height and roughness while the simulation was being run by the software. For all scenarios, the Coulomb friction was selected as 0.26 in the release zone, 0.165 in the track, and 0.33 in the run-out zone.

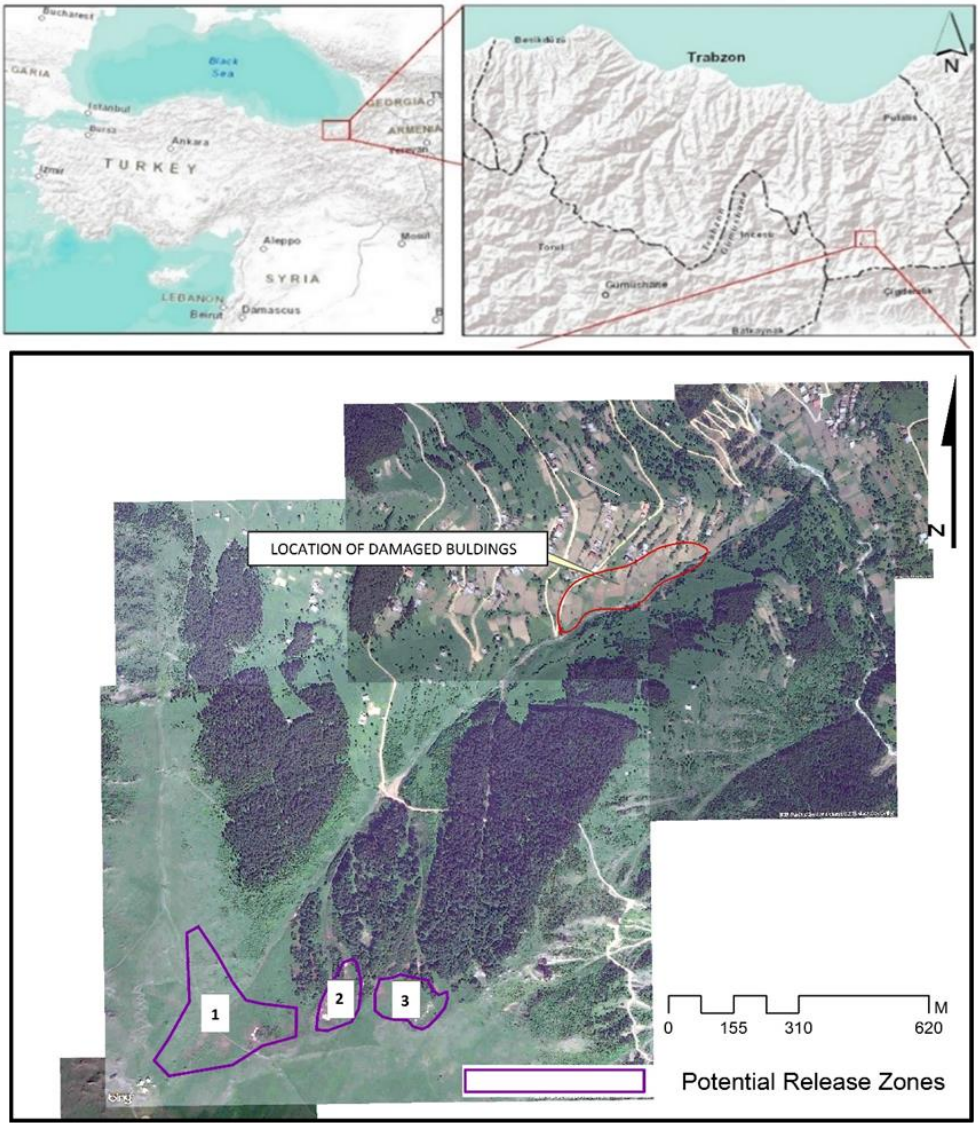

Figure 1. Location map of Karaçam Region

Figure 2. General view of the starting zones

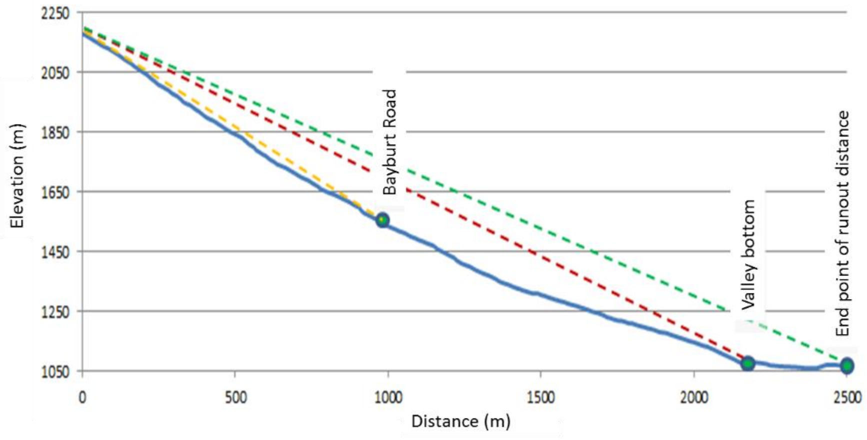

Figure 3. Longitudinal profile of the avalanche path

Table 2. Topographical characteristics of release zones

Release Zones	Min and Max Elevations (m)	Mean Altitude (m)	Average Slope (°)	Max Width (m)	Area (ha)
1	1970-2160	2045	38.0	300	5.53
2	1885-2013	1950	36.3	90	1.19
3	1890-1980	1942	36.1	150	1.59

Figure 4. DEM (5 m pixel resolution) overlapped with aerial photo

3. Results of ELBA+ Simulations

According to simulations in the three different scenarios of 30, 100, and 300 recurrent-years periods, the results provided by the selected Coulomb friction values were reliable. The results of the simulations are summarily shown in Table 3. The results of Scenario 1 with the recurrent period of 30 years showed that the extent of the motion of the avalanche mass was not capable of reaching the area of the buildings affected by the avalanche events in 1986 and 1992. According to this scenario, the avalanche velocity could be a maximum of 40 m/s, with a velocity equal to 23 m/s just a few meters from the location of the buildings. The impact pressure of the avalanche was generally observed to be very high, with values of more than 30 kPa. The flow height, velocity and impact pressure maps of Scenario 1 are shown in Figures 5, 6 and 7, respectively.

The extent of the avalanche in Scenario 2 is the most similar to that of the avalanche event in 1992. In addition, it was observed that the avalanche affected the buildings located over the avalanche path in the same way. The maximum flow height exceeded 30 m and was calculated as 8 m at the location of the buildings. The maximum impact pressure was 30 kPa, while the impact pressure was calculated as 3 kPa at the site of the buildings, thus verifying the reason the 1992 avalanche only damaged the buildings rather than destroying them. The flow height, velocity and impact pressure maps of Scenario 2 are shown in Figures 8, 9 and 10, respectively.

The maximum velocity was 41 m/s in Scenario 3, which was the most extreme situation. At the location of the buildings, the velocity was calculated as 16 m/s. In addition, the maximum impact pressure was calculated as greater than 20 kPa. The flow height, velocity and impact pressure maps of Scenario 3 are shown in Figures 11, 12 and 13, respectively.

Table 3. The results of ELBA+ simulations for 3 different scenarios (adopted after Schellander 2004).

Scenarios	Recurrent Periods (year)	Avalanche Mass Volume (m^3)	Release Heights (m)	Entrainment (m)
1	30	60000	1.10	0.15
2	100	81850	1.60	0.25
3	300	115000	2.10	0.30

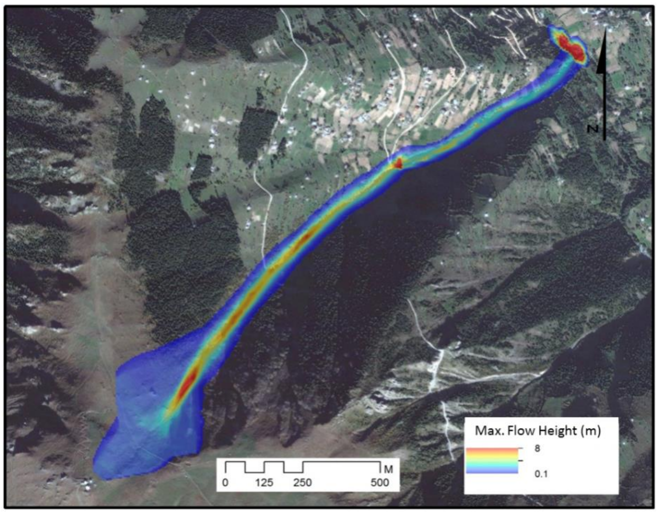

Figure 5. Maximum flow height map in Scenario 1

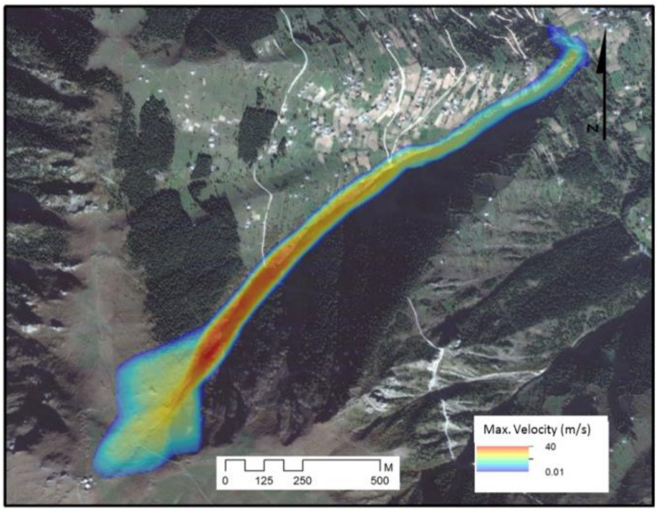

Figure 6. Maximum velocity map in Scenario 1

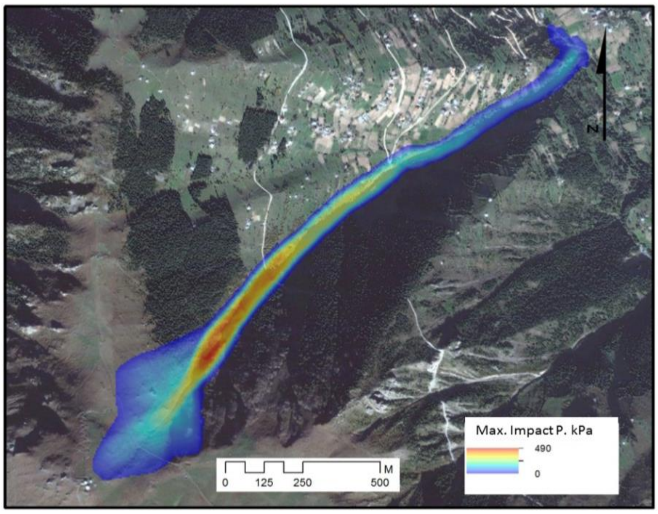

Figure 7. Maximum impact pressure map in Scenario 1

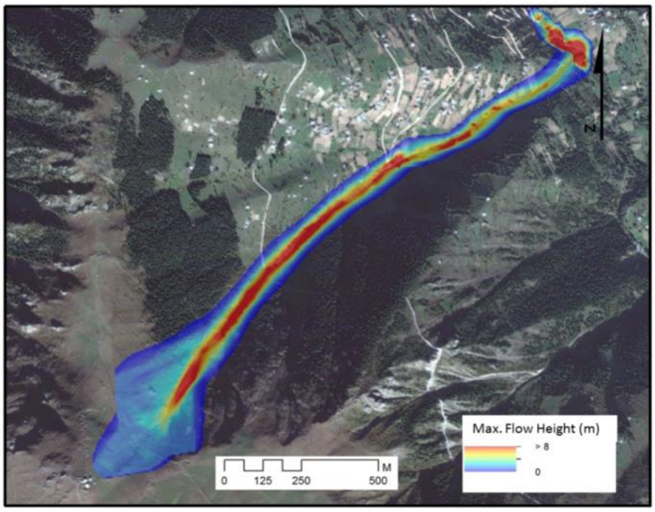

Figure 8. Maximum flow height map in Scenario 2

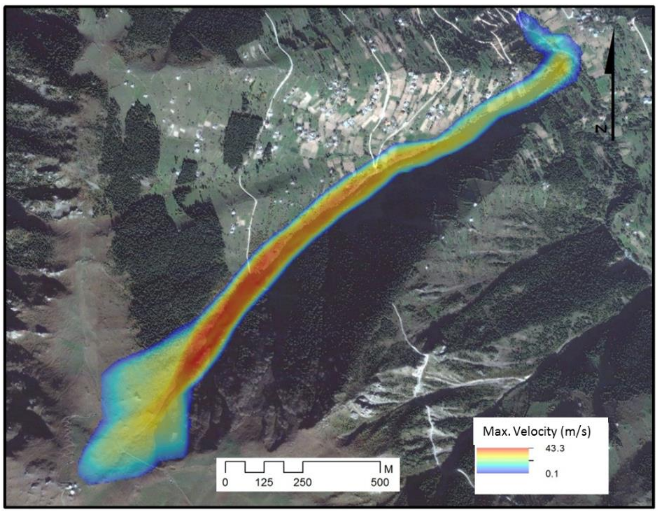

Figure 9. Maximum velocity map in Scenario 2

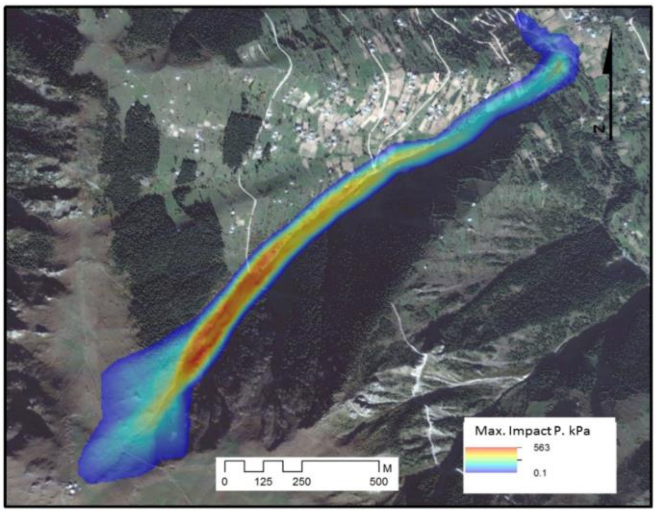

Figure 10. Maximum impact pressure map in Scenario 2

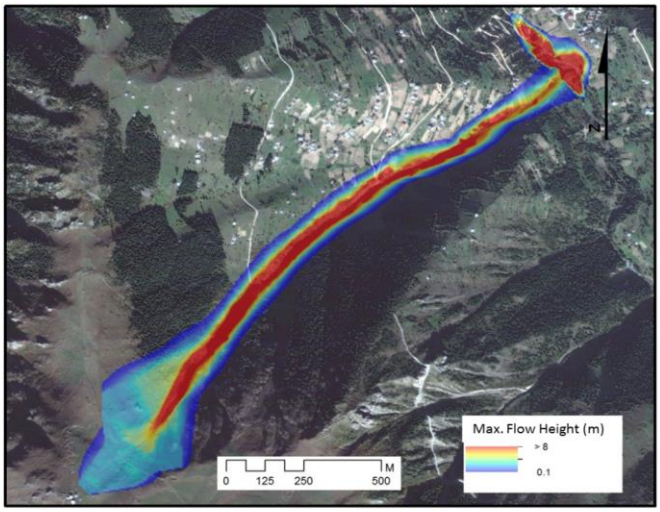

Figure 11. Maximum flow height map in Scenario 3

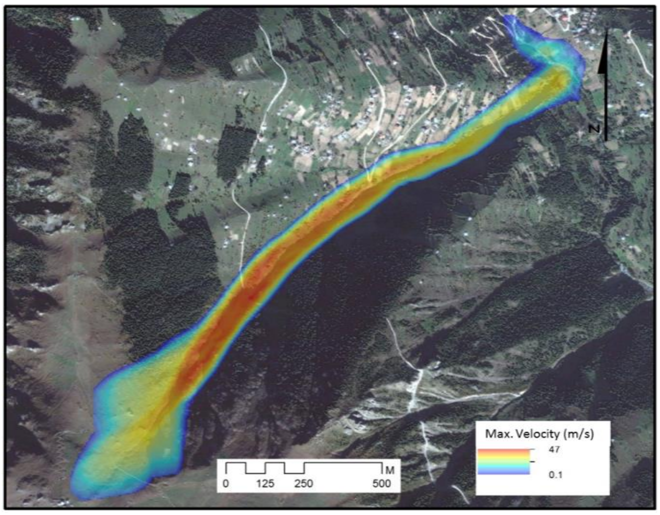

Figure 12. Maximum velocity map in Scenario 3

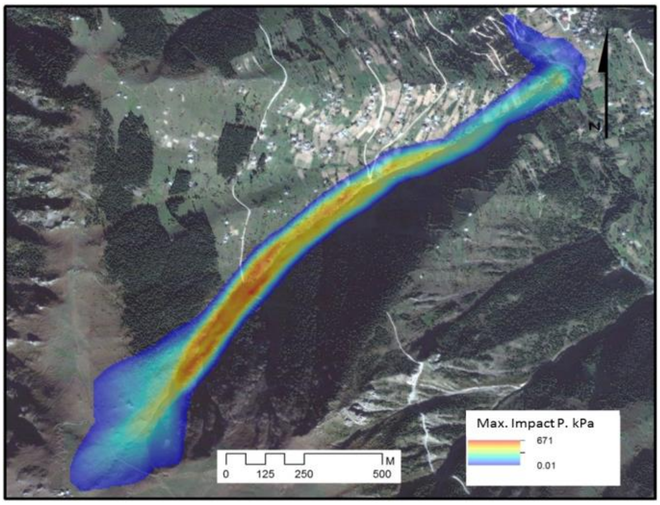

Figure 13. Maximum impact pressure map in Scenario3

4. Recommended Counter-Measures

In the present study, Scenario 1 demonstrated that a snow avalanche event with a recurrent period of 30 years did not have the capability of damaging the buildings in the region. However, as shown in Scenario 2, a snow avalanche event in the region with a recurrent period of 100 years was capable of causing damage to buildings located on the left side of the track as well as on the opposite slope. Hence, taking into account field surveys and observations, feasible counter-measures were suggested based on Scenario 2.

4.1. Snow supporting structures

The construction of permanent supporting structures was recommended to support snow accumulation within the starting zone in the study area. In other words, the snow supporting structures would hold the snow statically in place and preclude the onset of avalanching. One of the most important advantages of supporting structures is their capability of preventing the formation of powder avalanches. In the region, snow depth is observed 260 cm at an altitude of 2300 m by the local people in 2012. According to eyewitness statements, the wind increased the snow depth by up to 4 m in leeward slopes (even higher in gullies). Hence, snow bridges of steel and wood with structure heights of 4.5 m and 3.5 m, respectively, were recommended. Consistent with field surveys, six lines of steel snow bridges with a combined length of 508 m were designed, three lines being continuous and the remaining three discrete. In addition, seven lines of wooden snow bridges with a total combined length of 758 m, four lines being located at the left-hand side of the flow direction and the remaining three at the right-hand side of the flow direction were also designed (Figure 14).The ranges between the lines were determined as 20 m based on the research of Margreth (2007).

In addition to this measure, reforestation supported with snow glide tripods was suggested for an area of 7 ha covering starting zones No. 2 and No. 3. Snow glide tripods constructed from pressure-impregnated wood are the most commonly used snow glide protective measures in the alpine zone. The effective height of a tripod is between 0.8 and 1.5 m (Rudolf-Miklau et al., 2014). The necessary number of tripods per hectare varies depending on the reforestation technique, i.e. there can be 250 tripods per hectare in a group reforestation activity and 400 tripods per hectare in a dense reforestation activity. In this study, it was recommended that 1750 tripods be used with group reforestation (Figure 15).

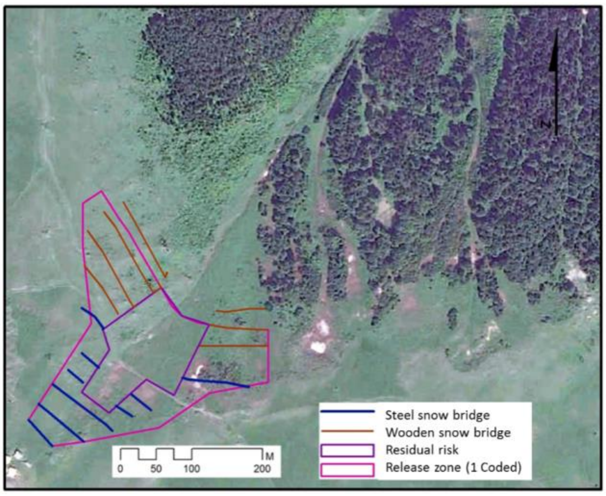

Figure 14. Construction plan of snow bridges in the area

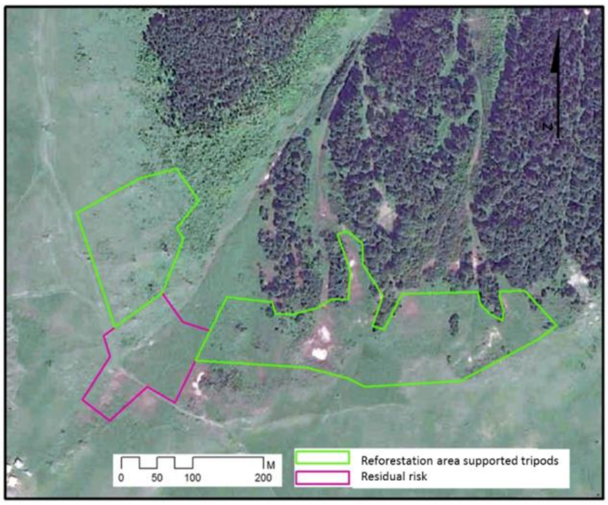

Figure 15. Map of reforestation area with recommended supporting tripods

4.2. Wind fences

Wind fences (snowdrift fences) serve as semi-permeable current obstacles in the wind field and lead to snow deposit by creating turbulence (Rudolf-Miklau et al., 2014). Wind fences must be installed outside of the release zones and their most effective direction is perpendicular to the wind. The height of wind fences in general should be 3-6 m. In the study area, the recommended wind fences have a total combined length of 1150 m, consisting of two lines on the right-hand side of the flow direction of the avalanche and one line on the left-hand side (Figure 16).

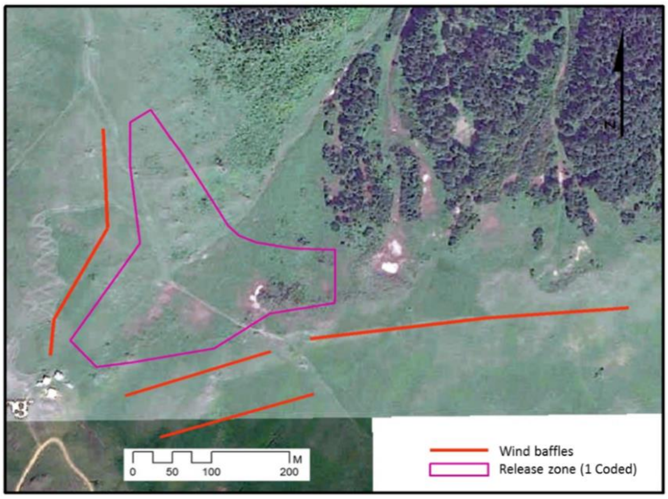

Figure 16. Construction plan of recommended wind fences in the study area

5. Conclusion

The main aim of designing technical structures in release zones is to mitigate the snow mass release so as to minimize the adverse effects of snow avalanches. Although extreme snow avalanches have occurred in the Karaçam region, to date, no technical counter-measures have been planned. In this study, three different snow avalanche simulation scenarios (coded as 1, 2 and 3) were developed based on recurrent periods of 30, 100, and 300 years. According to the simulations, reliable results were provided for all scenarios by the selected Coulomb friction values of 0.26 in the release zone, 0.165 in the track, and 0.33 in the run-out zone. Scenario 2, a snow avalanche event in the region with the recurrent period of 100 years was found to be capable of causing damage to buildings located on the left side of the track as well as on the opposite slope. Hence, taking into account field surveys and observations, feasible counter-measures were planned consistent with Scenario 2. Recommendations included the construction of structures for supporting the snowpack in the starting zone, reforestation with supporting snow glide tripods, and installation of wind fences. In total, 134 steel snow bridges with a combined length of 508 m, 184 wooden snow bridges with a combined length of 758 m, reforestation with tripod supports over an area of 7 ha, and 1150 m of wind fences were included in the plan.

Acknowledgements

This paper was prepared in frame of "Trabzon-Karaçam Avalanche Control Application Project" of General Directorate of Combatting Desertification and Erosion, Ministry of Forestry and Water Affairs.

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