ANALYSIS OF THE WORKING OF DEFORMABLE BARRIERS USED TO MITIGATE THE HAZARD OF AVALANCHES CHANNELLED INTO A TRACK ZONE. TRIALS ON SITE IN WINTER 2013-2014

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ABSTRACT: The project of deformable structures capable of containing a channelled avalanche flow originated from the need to reduce hazard from sites where an avalanche flow coming from a large starting zone interferes, at a specific point, with a roadway or, in general, with a road communication. Under those conditions, risk mitigation provided by management procedures (such as road closing) may involve disruption and economic damage to the community while, in alternative, reducing hazard through structural works, such as works in active detachment zone, may involve high investment costs. The project presented here, even if it is an engineering protection work, does not reflect the traditional rules of structural intervention, but it involves the use of deformable barriers (net barriers installed perpendicularly to the avalanches flow) that intercept the avalanche, retain part of the flow and dissipate its energy both through the deformation of the structure and “the change in the sliding profile” of the flow thanks to the “check dams” function of the filled barrier. Starting from the theoretical outcome of the full-scale experimentation carried out in the avalanche area of “Rio Colombari” San Paolo Cervo, Piemont, Italy, located upstream of Provincial Road No. 513 “Rosazza San Giovanni Oropa”, with the present work we want to practically illustrate the functionality of the tested prototype, the cost-benefit analysis of the project, the effect of hazard reduction and, last but not least, the amount of maintenance required for the functional restoration of the works.

1. INTRODUCTION

This paper presents the research activity and the results of the full scale tests performed to verify the behaviour of passive snow barrier installed along the sliding zone of channelled avalanches. The analysis of the behaviour of the structure, carried out during winter 2013-2014, has allowed us to assess the behaviour of such installations in situations of dynamic impact and of stress due to the over-flow caused by events happened after the filling of the barrier.

After the observation of the avalanches in situ and of their effects on the territory, a back analysis with 2D numerical modeling was carried out, starting from the nivo-meteorological data in the area, to assess the impact of dynamic loads (velocity and pressure of the avalanche flow) and the heights of the avalanche impacting the structure.

The study ends with an assessment of the structural damage and indications of the maintenance works which are necessary to the functional restoration of the barrier.

2. TEST SITE

2.1 - Geographical Location

The area is part of the avalanche starting zone called the Colombari Rio, located in the Southern Pennine Alps, about 26 km from the town of Biella (Piemonte - Italy), NNE direction, in Comune San Paolo Cervo (latitude N 45,648° - longitude E 7,982°- altitude = 1600 m).

Figure 1 – Geographical location of the test site
2.2 - Features of snow-events

The snowfall that affected the area during the winter season 2013-2014 deposited, in 23 significant cyclonic events (ie. event that is associated with a snowfall $H_N \geq 5$ cm), an accumulated snow thickness $H_S \approx 4.80$ m.

The thickness of snow on the ground reached its maximum in the first decade of March 2014 with $H_S \approx 2.50$ m.

2.3 - Avalanche features

The site is known as an avalanche area with a strong activity, in which the annual frequency of avalanches is equal to 1 - 2 events per year.

The starting zone consists of bowl-shaped areas of detachment characterized by medium - high inclinations ($\psi = 35^\circ - 40^\circ$) with classes of ground type 2 and 3 represented by coarse scree ($N_{CH} \approx 1.3$ to 1.8, $N_{FR} \approx 2.6$ or $N_{FR} = 2.6$) and short grass interspersed with low bushes ($N_{CH} \approx 1.8$ to 2.4 or $N_{FR} \approx 2.6$) with sliding zones in couloirs exceeding 750 m.

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2. Snow height from the ground, resulting from the data collected from the ARPA control unit - Bielmonte (UTM 32T E 428083 N 5057024 altitude about 1480 m slm)

3. Glide factor – Suisse standard - UFAM WSL “Defence structures in avalanche starting zones” - Ed. 04-07

Figure 5 – General view of the Colombari Rio avalanche site

The most significant avalanches occurred during the following periods: 24-26/12 and 27/02-01/03 which were characterized by high avalanche activity at all altitudes and exposures.

In particular, for the event on 24-26 December, the avalanche activity was caused by big snowfall in a short period of time (DH3gg ≈ 66 cm and HN ≈ 66 cm) and a high degree of hazard (local danger level 4 – High for 3 consecutive days).

As for the event covering the period 27/02-01/03 the avalanche activity was caused by a big snowfall in a short amount of time (DH3gg ≈ 55 cm e HN ≈ 55 cm) which slipped on a sliding plane containing Sahara sand (degree of local danger level 4 – High for 1 day and level 3 – Considerable for 1 day).

Figure 6 – View of the basin showing the test area

Figure 7 – View of the detaching zone showing the the slab perimeter

Figure 8 – General view of the Rio Colombari basin showing the test area (photo dated 05/03/14)
3. EXPERIMENTATION AND TEST

The tests performed in the 2013-2014 season developed into two distinct steps:

Step A \(\rightarrow\) to assess the behavior, in real scale, of the barrier installed along the sliding zone at an altitude of about 1290 m asl (full scale test);

Step B \(\rightarrow\) to calculate (by back analysis of major avalanches) the dynamic stresses of the impact and the overpressure produced by the avalanche overflowing the barrier.

3.1 - \textit{Step A \(\rightarrow\) Full scale test}

The tests allowed to analyze the behaviour of the barrier subject to the dynamic impact of the avalanche flow according to two types of stress: the first due to the pressure perpendicular to the barrier \((q_d)\) while the second tangential \((q_f)\) and vertical for the over-pressure \((q_u + q_a)\).
3.2 - Step B → Back Analysis

The dynamic analysis of the avalanche events affecting the structure, and in particular the avalanches during the periods 24-26/12 and 27/02-01/03, was carried out by 2D analysis performed by AVAL-1D, a software specifically designed by the Institute WSL-SLF Davos (CH) to study the dynamics of avalanche flows.

Starting from the snow and avalanches characteristics of the site (calibration model), the simulation of the avalanches has allowed us to evaluate the dynamic characteristics of the flow both along the avalanche path (height, velocity and stopping point) and at the barrier (height and velocity).

The following graphs show a summary of the results of the simulation for the two major avalanches that characterized the 2013-2014 winter season.

Figure 12 – View of the test site showing the barrier position (photo dated 06/02/14)

Figure 13 – General view of the avalanche in Rio Colombari (photo dated 05/03/14)

Figure 14 – Height, velocity and pressure of the avalanche flow in the period 24-26/12 at the monitoring point
4. RESULTS

The tests carried out on the structures, the back analysis study and the observations on the behaviour of the barrier after the 2013-2014 winter season have allowed us to evaluate, in relation to the dynamic characteristics of avalanches affecting the site, the pressures which acted on the structure as well as the maintenance and functional restoration to be carried out at the end of the season.

4.1 - Stresses

According to the data obtained from the back analysis, the stresses affecting the barrier for the two most significant avalanche events can be summarized as follows:

**Event dated 24-26/12**

avalanche not overflowing the barrier

| height | h_l = 2.8 m |
| velocity | v_l = 16.0 m/s |

**Event dated 27/02-01/03**

avalanche overflowing the barrier

| height | h_l = 2.5 m |
| velocity | v_d = 15 m/s |
| pressure | q_u = \frac{\rho_f \cdot h_f \cdot v_f^2 \cdot \text{sen} \delta}{l_u} = 14.8 \text{ kN/m}^2 |
| \rho_l = 0.45 \text{ t/m}^3 |
| \delta = 20^\circ |
| l_u = 5.85 \text{ m} |
| pressure | q_a = h_f \cdot \rho_a \cdot g = 12.5 \text{ kN/m}^2 |
| \rho_a = 0.5 \text{ t/m}^3 |
| g = 10 \text{ m/s}^2 |
| pressure | q_{u,r} = \mu \cdot q_u = 4.4 \text{ kN/m}^2 |
| \mu = 0.3 |

4.2 - Maintenance and functional restoration analysis

The dynamic stresses, both direct due to the main flow of the avalanche and indirect due to the “check dams” action, produced permanent plastic deformations in the barrier caused by the deformation of the brake system as well as by the sliding of the interception ring panel on the main ropes.

Figure 15 – Height, velocity and pressure of the avalanche flow in the period 27/02-01/03 at the monitoring point

Figure 16 – View of the barrier after partial melting of the snow (photo dated 05/06/14)

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Figure 17 – View of the barrier after melting of the snow (photo dated 18/06/14)

For the functional restoration of the barrier, maintenance interventions are foreseen aimed at restoring the geometry and the pre-impact energy dissipation capacity of the structure. To sum up, the functional restoration foresees the implementation of the following major maintenance steps:

a) restoration of the dissipation capacity of the barrier through the replacement of the deformed brake systems;

b) restoration of the system geometry through the tensioning of the main upper/lower ropes and the re-positioning of the interception ring panel.

5. CONCLUSION

As a consequence of the tests carried out and the results obtained it can be said that, concerning the structural and functional aspect related both to the dynamic action of the main avalanche flow and to the secondary action of over-flow, the prototype barrier reacted in the proper way and according to the function for which it was conceived and designed.

The retention of the first snow mass allowed to reduce the stopping distance of the avalanche compared to the historically recorded limits, while the "check dams" function, even if tested at a single point, caused a loss of energy in the avalanche over-flow.

Compared to active interventions in the detachment zone, this type of intervention guarantees a minor economic investment but requires, at the end of each winter season, suitable maintenance to restore the pre-impact level of performance.

6. REFERENCES

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