

ACTIVE WORKS IN A STARTING ZONE: MONITORING, MAINTENANCE AND FUNCTIONAL RESTORATION. AN ANALYSIS OF REAL CASES OF INTERVENTION

Raviglione Massimo^{1*}, Flavio Papetti², Barberis Michela³

¹Rock and Snow Engineering, Tollegno – ITALY

²Papetti - Pianificazione, Sviluppo e Difesa del Territorio, Piazza Brembana – ITALY

³MountainS WorkinG sas, Tollegno – ITALY

ABSTRACT: Active works in a starting zone are interventions made with more or less complex engineering structures (usually snow nets, snow bridges, rakes, tripod stands, etc.) designed and built to hold back the snow cover in the releasing area by limiting the gravitational phenomena (snowflow) of the snowpack. Their secondary, but not less important function is to create "breakages" (linear in case of a continuous positioning or punctual in case of an interrupted fragmentary positioning) within the potentially unstable slab so as to reduce the destabilizing forces and, as a consequence, to limit the avalanche trigger. In many cases, not only are the works or the single handiwork exposed to the stresses related to their function of snowpack retention in the starting zone, but they are also subject to "external" stresses (ie. actions due to rockfall, debris flows, landslides, etc.) which are not consistent with the function for which those active works were conceived, designed and installed.

The proposed study, starting from some case studies related to the maintenance interventions on works of active defence carried out by the undersigned, analyzes what has been faced in terms of issues related to "external" stresses not connected with their main function of snowpack retention in the starting zone and shows the maintenance interventions realized for the functional restoration of the structures.

KEYWORDS: active works, maintenance, rockfall, landslides

1. INTRODUCTION

This paper presents the load situations to which active works in the release area are subject during their technical lifetime.

In particular, we have analyzed the "abnormal" load conditions, which are not considered by the standard procedure for active work dimensioning, which mainly concern stresses caused by gravitational phenomena related to snow creep.

This study, which is based on our experience in the planning and supervision of the maintenance and repair of snow barrier structures as well as in the field of consulting to public administrations concerning snow science and prevention of avalanche danger along mountain roads and in populated areas, analyzes the problems detected on structures and outlines the main causes that led to the structure damage.

The study ends with some considerations on monitoring and maintenance procedures these works should be submitted to in order to maintain

the performance standards of the original design unchanged over time.

2. FORCES IN THE DETACHMENT AREA

Active works in the release area are facilities designed and installed in the avalanche detachment area and their main function is to retain the snowpack, counteracting the deformation and the creeping along the direction of maximum slope steepness produced by the shear stresses that characterize the snow creep phenomenon.

The on-site installation involves the construction of continuous lines or, in some cases, interrupted lines of snow barrier structures able both to counteract the snow creep phenomena and to interrupt the slab continuity.

The on-site placement, both in terms of distance between the lines and in terms of coverage of the potential detachment area, must consider in detail the morphology of the slope (in particular: the

slope angle Ψ , the coefficient of friction ϕ snow-ground, the height H_K of the protection works and the glide factor N) as well as the potential issues, not directly linked to the natural accumulation of the snowpack (e.g. snow brought by the wind) which can generate additional stresses on the protection structures. The following paragraphs will illustrate the main stresses to which the works are subject.

2.1 *Snow creep*

The solicitation of gliding in the line of slope generally depends on the slope angle $[\Psi]$, the snowpack density $[\rho]$, the height of the snow cover $[H]$, the exposure and the roughness of the contact plan between the snowpack $[N]$ and the ground.

The Swiss and French directives regulate the input loads to be applied to the calculation of the structures in terms of action related to snow gliding and express this stress through the following relations:

- UFAWWSL SNV - *Defence structures in avalanche starting zones*

$$S'_N = \rho \cdot g \cdot \frac{H^2}{2} \cdot K \cdot N \cdot f_c$$

where:

$S'_N \rightarrow$ component of snow pressure in the line of slope [kN/m]

$\rho \rightarrow$ general average density of snow [t/m³]

$g \rightarrow$ gravitational acceleration [m/s²]

$H \rightarrow$ general snow height [m]

$K \rightarrow$ creep factor [-]

$N \rightarrow$ glide factor [-]

$f_c \rightarrow$ height factor [-]

- AFNOR NF P 95-304 - *Equipements de protection contre les avalanches – Filet paravalanches*

Table 1 summarizes the variation of the load F_n orthogonal to the protection work. The extreme values vary from 9.90 kN/m to 75.2 kN/m as a function of the glide factor N [-] and the height of the snowpack H_n [m].

Tab. 1: total pressure (art. 6.8 della NF P 95-30)

N	2 m	3 m	4 m	5 m
2,0	9,90	22,3	39,6	61,8
2,5	12,0	27,1	48,2	75,2

In both directives, the value of the stress of snow gliding is directly proportional to the snow density, the snow height and the glide factor which represents the capacity of that slope (in terms of roughness and exposure) to offer a suitable "grip" for the anchorage of the snowpack to the ground in order to avoid that creepings should involve the whole height of the snowpack but only the potential gliding planes in the snowpack.

2.2 *Overload from windblown snow*

The action of wind transport from the windward side to the leeward side generally determines the creation of slabs along the leeward side. This phenomenon can create two main problems for active protection works: the first relating to the potential burial of the work and the second concerning the increase of the load on the work. Both issues are mainly related to the increase of the snowpack height and of the portion of wind-transported snow. The increase of the snowpack due to the action of wind transport depends on several factors, but the predominant ones are related to wind speed and the presence of a snowpack with low cohesion. According to the empirical relation proposed by Föhn (1980), the value of wind accumulation is:

$$H_{sd(1gg)} = k \cdot V^3 \text{ for } V \leq 20 \text{ m/s}$$

where:

$H_{sd(1gg)} \rightarrow$ accumulation of snow brought by the wind in 24 hours [m/d]

$k \rightarrow$ empirical coefficient equal to 0,00008 [s³d⁻¹m⁻²]

$V \rightarrow$ daily average values of wind speed [m/s]

In the literature, the extreme values of wind loads for a 24-hour wind action can reach the values shown in Table 2.

Tab. 2: wind loads during 24 hours

$V [m/s]$	$H_s [cm/d]$
5 - 10	5 - 10
10 - 15	10 - 35
15 - 20	35 - 75
20 - 25	75 - 200
> 25	> 200



Fig. 1: example of snow nets partially covered by wind accumulation

2.3 Avalanche between the lines

Special snowmaking conditions linked to high diurnal temperature increases and low nightly refreezing create favorable conditions for the humidification of the snowpack up to the basal layer and an increase in density.

These conditions, which generally occur earlier in the season or in the spring, allow the triggering of creeping phenomena and the formation of ground avalanches of humid and wet snow.



Fig. 2: example of ground avalanche between the lines

Among the lines of the snow nets, it is common to see ground detachments affecting the entire surface portion between two lines.

The stresses on the active work from pseudo-static become dynamic with increasing stress on individual components.

2.4 Rock fall

In many starting zones, rocky outcrops generate phenomena of collapse with rockfall events particularly in periods with higher temperature gradient between day and night.

In such conditions the works in the detachment area, in presence of a modest snowpack or in its absence, are subject to generally punctual dynamic stresses that can cause damage and / or breakage of the components.



Fig. 3: example of the impact of rock blocks on snow nets

2.5 Landslides and debris flow

In starting zones with modest coverage debris (for example land class 4 type smooth scree mixed with earth), localized landslides or small debris flow are frequently seen especially in periods when snowpack is absent.

In areas protected with active works, these phenomena affect the structures with dynamic impacts of earth and rock material which may cause damage and / or breakage of the components.

3. EFFECTS OF STRESSES ON THE WORKS

The stresses described above, in relation to the deformability of the structures, can cause

alterations in the geometry or damage to the snow nets that may compromise their performance or functionality.

The stress due to snow creep generates standard load conditions both in rigid and in flexible snow barriers structures while the stresses caused by both distributed dynamic loads (e.g. landslides and debris flows) and concentrated dynamic loads (e.g. rockfall) can cause greater problems on rigid structures (such as bridges and snow rakes) and semi-rigid structures (for example mono-anchorage snow barriers), whereas the deformability of flexible structures (such as snow nets) allows greater stress distribution.

In the following paragraphs we describe the main problems detected on the foundation structures and the structure connected with the previously discussed "anomalies".

3.1 *Problems at the foundation structures*

The problems at the foundation of active works are mainly caused by asymmetric load (e.g. wind overload) or punctual dynamic stresses (e.g. rockfall) or distributed loads (e.g. small avalanches between the lines, landslides or debris flows). In summary, we distinguish the following cases:

- the uphill anchors of snow nets and mono-anchorage structures are affected by punctual dynamics or shared dynamics.

In such conditions, the little deformable structure transmits almost the totality of traction in the uphill-downhill direction to the anchors that, overloaded beyond the design stress, undergo a non-compatible deformation resulting in its breakage or pulling out;



Fig. 4: example of a complete pulling out of an uphill anchor in a snow net

- the downhill anchors of snow nets are affected by stresses due to asymmetric load or shared dynamic stresses. In such conditions, the little deformable structure transmits almost the totality of traction (caused by the additional pseudo-static load or dynamic action to the anchors) in the downhill-uphill direction to the anchors that, overloaded beyond the design stress, undergo a non-compatible deformation resulting in its breakage or pulling out;



Fig. 5: example of a complete pulling out of a downhill anchor in a snow net

- the foundations of snow net posts, of snow bridges and snow rakes are affected by stresses due to asymmetric load.

In such conditions, the structure transmits almost all the compression to a post in respect to the adjacent one with the consequent impairment of the correct distribution of the loads and the failure or rupture of the foundation.



Fig. 6: example of the failure of the foundation plinth on the support of a snow bridge



Fig. 7: example of downhill rotation and translation of the post foundation of snow nets

Problems at the structure

The issues to the structure of active works are primarily caused by the following conditions: punctual dynamic load conditions (e.g. rockfall) or distributed dynamic load conditions (e.g. small avalanches between the lines, landslides or debris flows).

In summary, we distinguish the following cases:

- the structure of snow nets is affected by punctual dynamics or shared dynamics. In such conditions the structure, and in particular the slightly deformable retaining screen (therefore unable to dissipate the impact energy) undergo a concentrated or distributed overload;



Fig. 8: example of damage in the structure of snow nets

- the structure of snow bridges, mono-anchorage structures and snow rakes are affected by punctual dynamic stresses. In such conditions the structure, and in particular the supporting surface or the crossbeams, generally rigid and non-deformable, undergo a concentrated dynamic load which causes a permanent deformation or rupture.



Fig. 9: example of damages in the crossbeams in the structure of snow bridges.

4. PROCEDURE FOR MAINTENANCE

The maintenance of active works in the release area, regardless of the type of work, involves specific issues connected with constructions sites

and logistics, due to the particular location of the works.

To this purpose, a preliminary monitoring is a fundamental step to assess the time of intervention and to define maintenance and repair activities.

In parallel to maintenance, a number of preliminary activities will have to be considered in order to improve the areas of intervention so as to face potential critical environmental issues (such as rock falls, landslides, etc. ...).

With reference to the *assessment of the physical condition of supporting structures* shown in the Swiss directive, in Table 3 we summarize the degrees of maintenance according to the need for intervention, the time of the problem onset and the consequences which could be triggered for inaction.

Tab. 3: Condition class

<i>Urgency</i>	<i>Loss of security</i>	<i>Onset of the damage</i>	<i>Consequently the damage</i>
<i>Condition class 1 «good»</i>			
none	low	> 5 years	none
<i>Condition class 2 «damage»</i>			
1-3 yers	average	2-5 years	none
<i>Condition class 3 «poor»</i>			
very	danger of collapse	1 year	extreme impairment

As seen in Table 3, when the degree of maintenance increases, so does the urgency for the activation of the maintenance procedure, the loss of safety and the consequence of the damage. At the same time, as the degree increases, the time period for the occurrence of possible damage decreases, as schematically shown in Table 4.

Tab. 4: Possible damages

<i>Condition class</i>	<i>Main types of damage</i>
Condition class 1 «good»	• deformed crossbeams • erosion of foundation block < 10-20 cm • collection of debris on grate thickness < 50 cm • uniform surface corrosion
Condition class 2 «damage»	• slightly deformed supports • displaced cable clips • micropile anchors pushed into the ground • exposed anchors > 20-40 cm (still intact)
Condition class 3 «poor»	• buckled supports • heavily deformed or broken girder • broken or pulled out anchors • buckled micropiles • broken wire ropes

Table 4 shows that as the degree of maintenance increases, damages usually go from little influence on the functionality of the snow barrier structures up to damages that would totally compromise its functionality.

Consequently, the type of intervention to control or restore the functionality of the structures go from a simple inspection of the structure to its complete rebuilding, from grade 1 to grade 3.

Table 5 shows, according to the degree of maintenance, the type of intervention and the time of achievement. As it can be seen, as the degree of maintenance increases, time decreases going from 3-5 years until an intervention to be carried out before the winter.

Tab. 5: Sequence of maintenance

<i>Condition class</i>	<i>Types of interventions</i>
Condition class 1 «good»	inspection and checking after every major event or every 3-5 years
Condition class 2 «damage»	repair wthin 1-3 years
Condition class 3 «poor»	immediate repairs or replacement before the winter

5. CONCLUSIONS

In this paper, we wanted to show the problems to which the snow barrier structures installed in the release area may be subject during their lifetime.

Starting from standard stresses connected with the action of snow creep, we analyzed the "non-standard" stresses related to events not directly linked to the main function of snowpack retention for which the structures were designed.

In reference to the potential damage to which the works are subject and in function of the degree of maintenance, we proposed a sequence of activities necessary to ensure the performance level of the work.

6. CONFLICT OF INTEREST

The authors of this study were not supported financially or materially by any manufacturer.

7. REFERENCES

- AFNOR NF P 95-304 (1992) Equipements de protection contre les avalanches – Filet paravalanches
- Aineva, (2005) Linee guida metodologiche per la perimetrazione delle aree esposte al pericolo valanghe
- Aineva, Neve e Valanghe (04/2004 n. 51) La manutenzione delle opere paravalanghe di difesa attiva
- McClung D., Schaerer P. (2005) The Avalanche Handbook
- Mears A. I. (1992) Snow-Avalanche hazard analysis for land-use planning and engineering
- Raviglione M., Iori M. (2012) ISSW 2012 – Evaluation of dynamic actions on active snow-nets placed in starting zones. Testing in site during winter seasons 2008-2009-2010-2011
- UFAMWSL SNV (2007) Defence structures in avalanche starting zones