# THE "LAVANCHERS" AVALANCHE OF FEBRUARY 23rd 1999, AOSTA VALLEY, ITALY

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ABSTRACT: The purpose of the present contribution is to present and analyse in detail an avalanche event which occurred on February 23rd 1999 in the Western Italian Alps, at Morgex, Aosta Valley. The powder component of a huge mixed–type avalanche released from the Lavanchers basin affected the Dailley hamlet, causing great damage to the buildings and one fatality. The avalanche event is firstly framed within a brief presentation of the snowfall conditions and avalanche activity over the Italian Alps during the critical month, February 1999. Then, its observed characteristics are exposed, in order to address the main unknowns of the problem, such as the evaluation of the release scenario and the interpretation of the type of flow and dynamic behaviour of the avalanche. The destructive effects of the snow flow on the threatened area are also presented and discussed, as well as the subsequent countermeasures undertaken. The analysis of this real world case study gives valuable hints for concluding remarks on key aspects of avalanche risk management, such as prevention and planning of structural defence works.

KEYWORDS: Catastrophic avalanches, Winter 1999, Italian Alps, "Lavanchers" avalanche, protective measures.

## 1. INTRODUCTION

In February 1999 an extraordinary avalanche activity took place in the Alps. A stationary situation with an anticyclone over the Atlantic and a cyclone over north-east Europe characterised the meteorological conditions of this period. Alternately, moist warm air masses from the Atlantic and moist polar air masses advanced with strong north to north-westerly winds towards the Alps. In the space of three weeks record snowfalls were measured along the Alpine mountainous spine, and triggered a series of extreme avalanches from France to Austria. In many cases areas considered safe on the basis of the known historical data and/or of the existing hazard maps where affected, with great economical and human losses.

On February 9th an avalanche released at Montroc, Haute-Savoie, France, resulted in 12 fatalities and 20 chalets damaged, among which 14 with irrecoverable damage (Ancey and others, 2000). In Switzerland, disasters occurred during three subsequent periods in February 1999, with a total of more than one thousand avalanches released from western to eastern Alpine cantons, producing damage to people (17 deaths), settlements, properties, forest, roads and rail infrastructures; the estimated direct and indirect costs were of 450 and 160 million of Swiss francs, respectively (EISLF, 2000). As the concluding act of this dramatic avalanche month, in Austria on February 23rd 38 persons were killed by a single huge avalanche in the Galtür village, Tyrol (WLV, 2000).

In the Italian Alps the avalanche activity was in general much less intensive with respect to the northern side of the Alps and was mostly concentrated between February 21st and 23rd, following two successive periods (6.-10.02.99 and 17.-23.02.99) of frequent, weak snowfalls concentrated over a belt of 10-15 km close to the borders (Figure 1). The main avalanche events of this period were:

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- 21.02: several loose-snow avalanches interrupting mountain roads and damaging forests in Val Zebrù valley and Valfurva valley (Lombardy Region);
- 22.02: loose-snow avalanches on roads in Roja and Melago (Etsch Valley, Alto Adige); interruption of an international road at Livigno (Lombardy Region);
- 23.02: Lavanchers avalanche (Morgex, Aosta Valley), with relevant damage to a village and one fatality.

The detailed analysis of this latter avalanche event is the topic of the present paper.

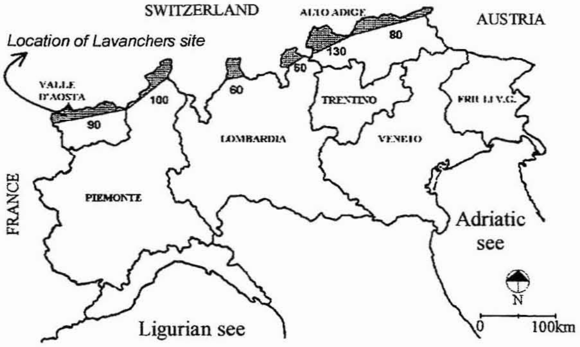


Figure 1: Cumulate snowfalls (in cm) during the week 17.-23.02.99 over the Italian Alpine regions

## 2. LOCATION AND TOPOGRAPHY OF THE AVALANCHE PATH

The Lavanchers avalanche site is located in the Western Italian Alps (Figure 1), about 15 km SE from Mt. Blanc massif and 20 km W from Aosta, on the left orographic side of Dora Baltea river and close to the Morgex village (Figure 2).

It is a big-size S-faced partly-channelled site, with a total vertical drop of about 2000 m, and a track length of about 4.5 km; the average slope of the whole path is about 25°. The upper collecting basin is represented by an ample (about 2.5 km$^2$) and rather homogeneous open bowl, for the most made up with high altitude grasslands, with a wide crest line that extend between the Tête Suche, the Tête Licony and the Tête Drumianaz (Figure 3). The slopes are rather elevated (in the range 30° to 45°), and the basin is ploughed up from torrential-made channels. In the median part the basin forms a deeply incised gully with vertical rocky walls up to 150 meters in the left orographic side and degrading slopes on the right side. At an altitude of about 1100 m a.s.l. the gully opens on an alluvial fan that corresponds to the usual deposition zone of the avalanches, and where the facilities under threat are located (Figure 3).

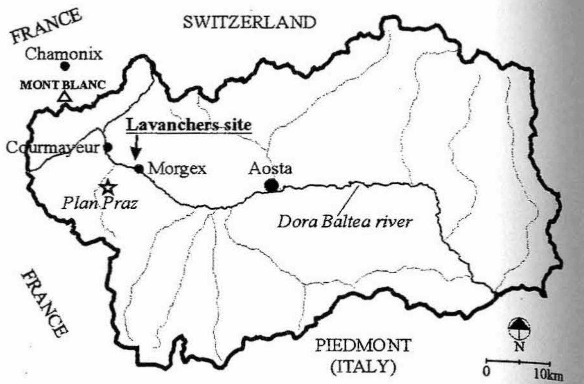


Figure 2: Location of the Lavanchers site within Aosta Valley region; the star indicates the location of the Plan Praz weather automatic station

The potential release zone extends on all the areas forming the upper basin, but more frequently the avalanches release from the central and right sectors, S- and SE-faced respectively. In fact, these sectors are characterised by more suitable inclinations (between 30° and 40°), are located at higher altitudes and represent the zones usually affected by substantial snowdrift accumulations and cornices formation, given that in the winter season the prevailing wind direction is NW.

Figure 3: Aerial view of the Lavanchers site

## 3. DESCRIPTION OF THE AVALANCHE EVENT OF FEBRUARY 23rd 1999

On the early morning (6:30 a.m.) of February 23rd 1999, the avalanche released from the upper basin of the Lavanchers site. The crown line extended for more than 3 km (see Figure 11a), with a thickness ranging from 100 to 170 cm going from SW-faced to SE-faced release slopes; the released snow volume was estimated to be about 500,000 $m^3$. The avalanche developed a mixed type of motion: the dense part spread out on the alluvial fun, as usually does, whereas the powder part, after going out from the channel, deviated from the dense core towards the Dailley hamlet causing one fatality, five injured people and serious damage to the structures and civic infrastructures as well as to the wooded patrimony.

From aerial images taken after the event (Figure 4a) it is possible to distinguish rather clearly a vast area covered from a deposit of compact wet snow (500 m length, 600 m width, a maximum thickness of 8 m and a volume of about 500,000 $m^3$), and a wider area in which the deposit was instead reduced to a thin layer (few centimetres) of dry snow. The avalanche originated from the fracture of wind slabs of compact and dry snow in the higher part of the basin. As soon as the snow mass descending along the slopes reached suitable kinetic energy a relevant part of the moving mass was taken in suspension by the air, forming a big dust cloud; at lower altitudes also the wet snow layers present on the ground (see §5) were carried along.

The complex avalanche dynamic that took place was influenced by two main factors: the convergence in the narrow channel of snow masses simultaneously released from adjacent basins; the presence of two abrupt deviations of the principal gully (at the altitudes 1600 and 1400 m a.s.l. respectively), which forced the snow masses, in particular the powder component, to deviate from the main stream along unusual directions.

The dust cloud arrived in the runout zone with different directional components (Figure 4a). A principal component following the development of the avalanche track and of the dense core motion, which caused relevant damage to the vegetation up to the opposite mountain slope (the "fan" disposition of the uprooted plants in this area is a clear evidence of the impact of this part of the powder component, Figure 4b). At the same time the deflection against the walls of the channel, originated by the abrupt changes of direction of the gully, caused another part of the powder component to deviate from the main avalanche stream and to attach Dailley; to this component the majority of devastation has to be attributed (Figures 4c and 4d). During the impact of the avalanche against the rocky walls of the gully, the upper part of the dust cloud was able to pass over the edge of the channel, accelerating in the direction of the Lavanchers hamlet along the left orographic side of the main channel; this component was responsible for the demolition of a reforestation of about 1600 pines and larch trees planted in the 1948 after a fire (Figure 4e).

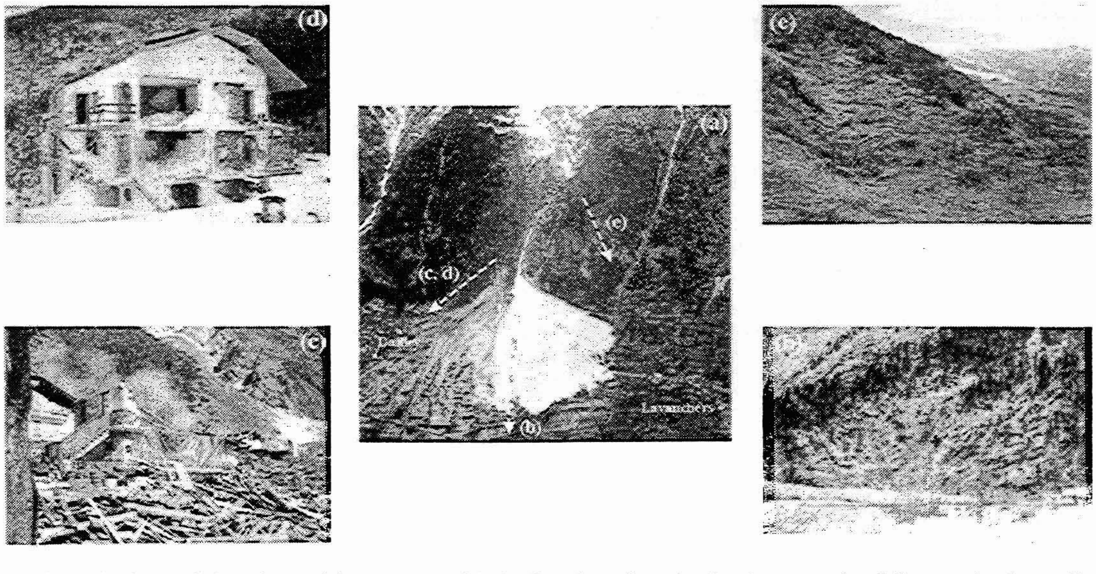


Figure 4: Aerial view of the deposition zone with indication (by dashed arrows) of the main flow directions taken by the powder cloud (a), and of the related damages (b, c, d, e)

In total, the damage to the vegetation amounted to 6570 uprooted plants on a total surface of about 40 hectares. Dendrometric analysis over the vegetation struck by the powder component has allowed to found broken trees up to 100 years old.

With respect to the main structural damage, mostly concentrated over the area of Dailley, the following may be mentioned: collapse of the roof and demolition of masonry in the house where the victim lived (Figure 4c); staving in of side walls (only the reinforced concrete structures withstood), break up of fixtures and handrails, break up with lifting of a stratum of the roof and turnover of its leaning stratum in a residential house located in the SE part of Dailley (Figure 4d), fortunately without any occupants at the moment of the event. Furthermore, damage to fixtures, masonry and roofs for many other buildings less directly exposed to the flow, mainly provoked by flying objects picked up and transported by the air-snow powder cloud.

To these damage should be added the potential damage on the National road Morgex-Pré San Didier, on the State road n. 26 and on the Aosta-Pré San Didier railway, all fortuitously lacking in traffic at the moment of the avalanche event (early morning), as well as on the highway under construction. All these infrastructures were affected by the powder component with an energy high enough to destroy mature plants located in their proximity as well as several hundred meters of guard-rail.

Investigations on the intensity of the forces necessary to produce the structural damage observed in Dailley, led to estimate in this area a lower pressure threshold in a range 0.3 to 0.7 $t/m^2$. A lower pressure threshold in a range 0.07 to 0.23 $t/m^2$ was instead found in the area beyond the Dora Baltea river, by analysing the damage provoked there to the vegetation.

## 4. AVALANCHE HYSTORY

The Lavanchers avalanche is well known and documented (Figure 5), being one of the more relevant of Aosta Valley in terms of dimension, frequency and also for the fact that the debris frequently reaches the valley bottom in proximity of inhabited areas and of an important Alpine corridor (see Figures 3 and 5).

Several significant events have occurred in the past: 1805, the powder component of an avalanche destroyed a dwelling in Dailley, and a whole family was killed by the rubble (this testimony was taken from old church archives, but in the opinion of local inhabitants the avalanche came from another close path); 1911, large avalanche whose powder component dragged a wagon on which a family was travelling up to the underlying Dora river; 1955, different mixed avalanches, with damages to some hectares of vineyard; 1961, the National road was obstructed for 100 meters of length and about 10 meters of height by the avalanche debris, 50 secular walnut-trees were felled and the telephone lines damaged; 1978, avalanche with 20 meters of accumulation on the State road n. 26; 1984, release of a slab of about 800 meters of width, with damages to vineyard and to mature woodland in proximity of the houses of Dailley caused by the dust cloud; 1993, big mixed-type avalanche (Figure 6) with relevant damages by the powder component (destroyed vineyards, uprooted trees up to 150-200 m beyond the railway, broken windows in Dailley and deposit of a thin layer of snow up to the opposite mountain slope). Besides these, many other smaller avalanche events with less relevant damages have occurred on this site.

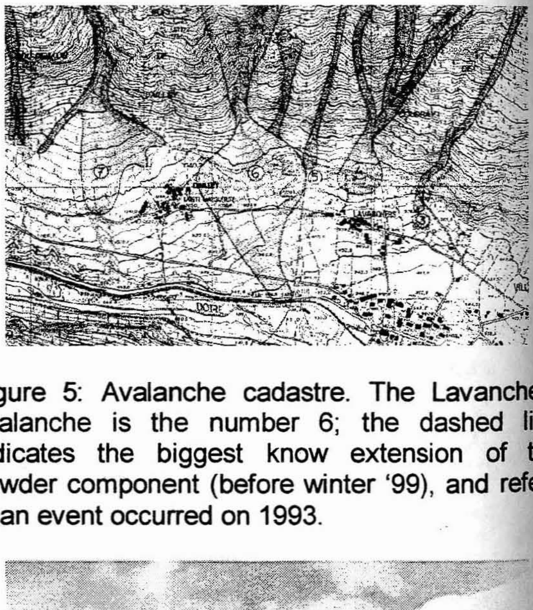


Figure 5: Avalanche cadastre. The Lavanchers avalanche is the number 6; the dashed line indicates the biggest know extension of the powder component (before winter '99), and refers to an event occurred on 1993.

Figure 6: Avalanche of February 26th1993

The high frequency of this avalanche combined with the old origin of the Dailley village (founded in the first decades of the XVII century) allowed the local inhabitants to have a good knowledge of the avalanche. This is confirmed by its mapped limits on the avalanche cadastre and by the ordinary safety measures taken any winter season by the local authorities (winter closure of the Communal road connecting Dailley to Lavanchers and, under dangerous condition, temporary closure of the National road). In actual fact, in terms of area affected the 1999 event was quite similar to the 1993 avalanche concerning the powder component, and indeed not extraordinary with respect to the runout distance of the dense part. However, the serious damage produced by the powder component of the 1999 event had never happened in the past. In this respect, by historic data and dendrometric analysis the return period of such an event has been estimated to be at least 100 years.

## 5. METEOROLOGIC CONDITION PRIOR TO THE AVALANCHE RELEASE

Due to the lack of local gauges on the Lavanchers basin, the analysis of the weather conditions prior to the avalanche release has been based on the data from the automatic station of Plan Praz (Figure 2), situated in the Commune of La Thuile at 2000 m a.s.l. and working since the winter of 1993. The data from this station may be considered sufficiently representative of the area under analysis, particularly with respect to wind direction measurements.

The weather conditions in the days immediately preceding the event are synthesised in the Figures 7, 8a-b and 9.

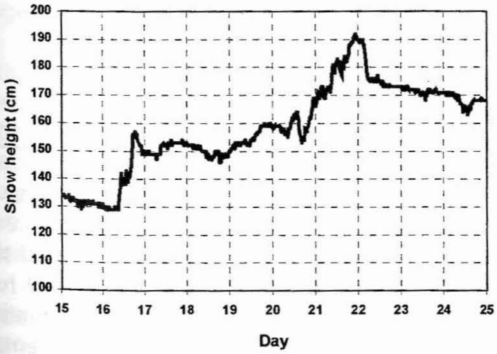
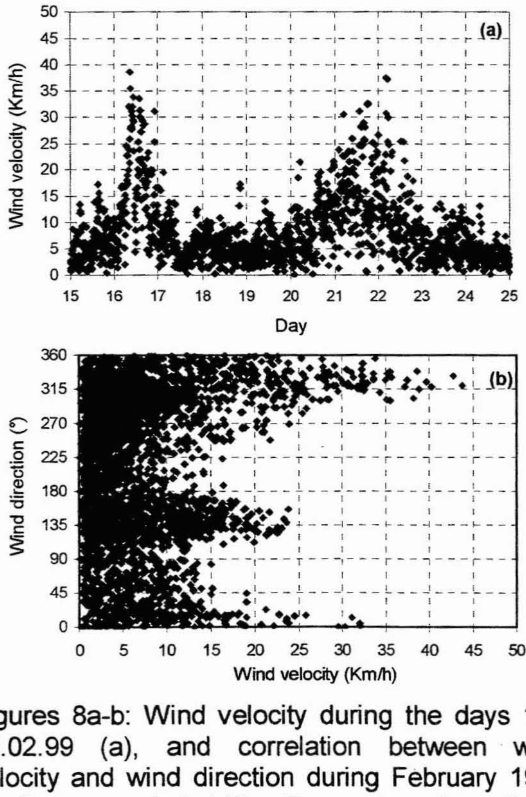


Figure 7: Snow cover depth during the days 15.-25.02.99. Data recorded at Plan Praz automatic station.

On the 17.02.99 a weak snowfall of about 30 cm occurs, with cold temperatures and winds from NW with speed up to 35 km/h, therefore strong enough to allow snowdrift and snow accumulations on SE-faced slope, such as those characteristic of the release zones of the Levanchers site. In the following days the temperatures rises up to 0° (at 2000 m a.s.l.), and remains on these values until the 21st, when a further snowfall of about 30-40 cm occurs (rain below 1700-1800 m a.s.l.). Starting from the 21st the temperature abruptly decreases by at least 10 degrees while the speed of the wind, always blowing mainly from NW, increases progressively (up to peak values of about 35-40 Km/h at 5:00 o'clock of February 23rd, just one hour before the avalanche release), favouring additional snowdrift accumulations on lee slopes.

The fracture initiation seems to have reasonably occurred in the SE-faced slopes, probably induced by snowdrift overloads, or else due to the fall of big cornices. The abrupt changes in the air temperature could have influenced the snow cover instability too. On the basis of snow pits made in the release zone after the events the slab bed was individuated in a basal weak layer formed at the beginning of the winter. However, causes and mechanism of release are still matter of debate, also considered that in many close avalanche paths with similar exposure and snow cover conditions the avalanches did not release.



Figures 8a-b: Wind velocity during the days 15.-25.02.99 (a), and correlation between wind velocity and wind direction during February 1999 (b). Data recorded at Plan Praz automatic station.

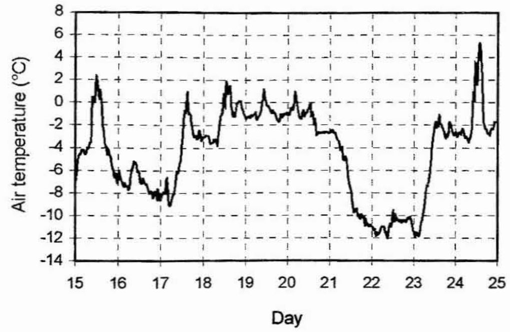


Figure 9: Air temperature during the days 15.-25.02.99. Data recorded at Plan Praz automatic station.

## 6. AVALANCHE DYNAMICS

The VARA numerical model developed in recent years at the University of Pavia for the simulation of flowing avalanches (Natale and others, 1994; Barbolini, 1999) has been applied to back calculate the dynamics of the dense core of the 1999 event. The fitting with observed data (runout distance, deposition pattern) was quite good, and front velocity up to 50 m/s were found to be reached by the flowing snow mass in the steeper parts of the track (Figure 10).

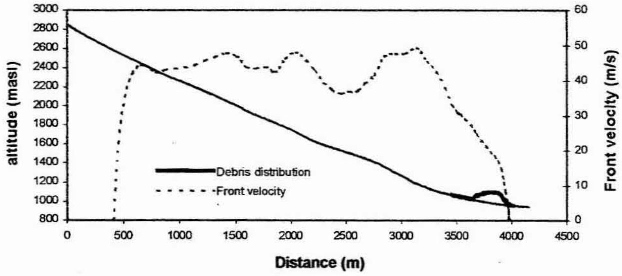


Figure 10: Final debris distribution and front velocity along the path profile obtained by back calculating the 1999 event with the one-dimensional VARA model (deposition depth scale 20:1 with respect to the altitude scale).

This is clearly a preliminary step of the research; in fact, more comprehensive models able to simulate both the motion of the dense part and the possible formation and subsequent dynamics of a powder component are required in cases such as the one under analysis. These kinds of models are currently at the early stage of development in many research institute (Harbitz, 1998), but theoretical and experimental work still remains to be done before they could become reliable enough for practical applications.

## 7. PROTECTIVE MEASURES

### 7.1 *Strategy of intervention*

A correct approach to risk mitigation primarily requires an evaluation of the objectives to be protected, of their characteristics of vulnerability and of their social relevance. A schematic manner of doing that may be to list in a table the involved structures, and evaluate the interference that these have with the avalanche motion, by a value that depends on the degree of exposure they have to the powder and flowing component, respectively. Then, once a "value" is assigned to the involved structures, a priority index may be obtained for the structures to protect. Obviously this procedure is very simplified and purely indicative but may support a rational analysis of the problem. The results for the case of the Lavanchers avalanche, presented in Table 1, indicate as primary objectives to be protected the Dailley hamlet and the communication routes located at the valley bottom. The degrees of exposure presented in Table 1 for the different facilities under threat are based on the hazard map of the area, which was produced immediately after the 1999 events according to mapping criteria (similar to the Swiss one) stated in a recent Regional Law of Aosta Valley regulating land use in avalanche prone areas (Pasqualotto, 1999).

| Structures under threat | Exposure | | | Value | Priority index |
|---|---|---|---|---|---|
| | Powder | Dense | Total | | |
| Dailley hamlet | 4 | 0 | 4 | 8 | 32 |
| Lavancher hamlet | 1 | 1 | 2 | 8 | 16 |
| Morgex village | 1 | 0 | 1 | 8 | 8 |
| Rural roads between Lavanchers and Dailley | 4 | 4 | 8 | 1 | 8 |
| Power and telephone lines | 4 | 4 | 8 | 1 | 8 |
| National road (Morgex-Pre San Didier) | 4 | 4 | 8 | 3 | 24 |
| Communal road connecting Lavanchers and Dailley | 4 | 4 | 8 | 2 | 16 |
| State road n. 26 | 3 | 3 | 6 | 4 | 24 |
| Railway | 3 | 3 | 6 | 4 | 24 |
| Highway | 1 | 0 | 1 | 4 | 4 |
| Rural roads beyond the Dora Baltea river | 3 | 0 | 3 | 1 | 3 |
| Sport Area | 2 | 0 | 2 | 3 | 6 |

Table 1: Evaluation of priority indexes for the different facilities to protect

Different hypothesis of intervention have been considered: tunnels, earth dams, variations of the road's location, active works and systems of artificial release. Once their efficiency has been evaluated in relation of the infrastructures to protect, and of the relative priority index, the realisation of active works in the release zone (snow nets combined to snow fences, see Figure 11b) has emerged as optimal solution.

Furthermore, in order to manage the risk until the defence works have been completed, a local commission for danger evaluation and a specific evacuation plan for the inhabited area potentially affected by the avalanche have been operative since the winter 1999-2000.

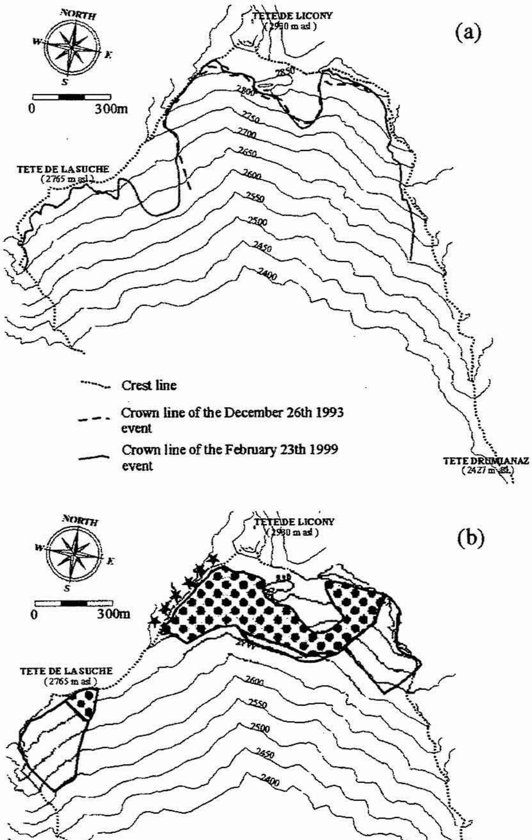
Artificial release by GAZEX system, even though advantageous from the economical point of view, was not considered suitable, due to high residual risks associated with its use in the case in consideration. Conversely, the realisation of tunnels would reduce the risk almost to zero for the communication routes, but this solution would not serve for the protection of the inhabited areas; for these latter it could be thought to a joined protection by means of earth dam, but in this way the problem of the powder component is not solved at all. In this sense, the indication of the community to the politics of the willingness of reconstruct and save the inhabited area of Dailley has certainly "conditioned" the type of necessary intervention.

### 7.2 Optimisation of the intervention

Not being justifiable from the operational, environmental and above all economical point of view to protect the whole release basin by active works, the planned intervention has the objective of contain the phenomenon (say the release volumes), avoiding the formation of relevant powder component and allowing limits of acceptable residual risk for the inhabited areas and infrastructures of the valley bottom. With this respect, in order to properly "centre" the intervention a detailed analysis of the release basin has been crucial, with the aim of singling out the areas with higher propensity to the release of dangerous avalanches.

By means of photo-restitution techniques a numerical cartography of detail (1:2000) of the upper basin has been produced. The 3D terrain model has been then oriented in such a way as to be able to superimpose it on photographic images, where it was possible to recognise the crown lines of past avalanche releases. In this way it has been possible to accurately reproduce and compare on the topographic map the crown lines of avalanches of big dimensions for which ample photographic documentation was available (in particular the 1993 and 1999 events, see Figure 11a). Thus, it has been possible to rather objectively single out the optimal areas for locate the defence structures (indicated as "priority" in Figure 11b), reducing the risk of wrong evaluations leading to interventions, with a waste of economic resources, in zones characterised from natural propensity to snow cover stability or typically originating events of modest dimensions. With this respect, a contingent intervention of "completion" has already been planned (Figure 11b), and will be realised only if the initial one does not prove to be sufficient on the basis of a careful monitoring of the release areas. It is important to remark that the choice of the areas to be secured by snow nets showed in Figure 11b respond also to the need of interrupting the potential front of release - knowing that its extension in the event of the '99 was longer than 3 Km – by operating a physical separation between the adjacent release basins and preventing their simultaneous triggering.

The estimated costs to complete the first part of works (8200 linear meters of snow nets and 40 "cross"-type snow fences) are of about 6,200 kEuros.



Figures 11a-b: Comparison of the crown lines of the 1993 and 1999 event (a), and location of the planned defence active works (b).

## 8. CONCLUDING REMARKS

The analysis of the Lavanchers avalanche events rather clearly shows that in order to prevent the question of defence from natural hazard becoming simply a matter of debate after disasters have occurred, there is a need to move from a "protection" approach to one of "prevention". Protection is in fact based on known hazard, and therefore usually focused on quite repetitive events. However, the safety of communities is primarily threatened by rare and very rare events, and with this respect prevention measures are usually quite insufficient, as in the case under analysis. The general avalanche danger situation during the critical period was quite well forecasted by the local avalanche office (European Scale-based avalanche danger level variable in Aosta Valley between 3 and 4 in February 1999). "Ordinary" security measures were adopted in time through road closure before the avalanche release. In syntheses, there was a good knowledge of the Lavanchers avalanche, safety measures well calibrated on the many known events but a substantial lack of prevention measures accounting also for a possible "extreme" event. In this respect it should be also considered that in many cases similar events could produce greater damage now than in the past, due to the increase of urbanisation in mountainous areas and the associate increase in the density of assets. In this sense, it is interesting to observe that the worst damaged buildings of Dailley were all relatively recently built constructions, whereas the oldest part of the village suffered only minor damage. A correct and feasible way to reduce potential damage in avalanche prone areas seems therefore to necessarily require appropriate land-use planning measures based on hazard zoning, namely on the identification of hazardous areas and application of restrictions to construction. Because avalanche zoning may reduce the risk simply by reducing exposure (and/or vulnerability) it represent the safest and cost-effective risk mitigation strategy. For instance, for the case under analysis, victims, injuries and structural damage could have been avoided, or at least reduced, with a more suitable location and/or a more appropriate method of construction of the houses.

The analysis of this case study also highlight some important open problems that still need to be addressed. In fact, reliable and reasonably accurate hazard mapping requires substantial improvements in avalanche dynamic modelling, as already mentioned in §6. Besides, another aspect that seems to be important to further investigate and to account when evaluating the impact pressure of the powder component against structures, is the possibility of local pressures peaks given by objects moving inside the dust cloud. Compact clump of snow, piece of trees, stones and chunk of wall or roof could be in fact carried away and accelerated by the powder cloud to fairly high speed that, combined with their high density, could create formidable projectiles able to greatly damage structures as well as to represent a serious danger for the life of people outsides the houses or inside to moving vehicles.

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