SLAB AVALANCHES AND " NEW " SNOW

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ABSTRACT : A three-year study based on observations carried out both on the field and inside the laboratory has enabled us to describe accurately 22 slab avalanches triggered by passing skiers or pedestrians, within a limited area. Simultaneously, some systematic measurements have also permitted to describe the real evolution of snow conditions upon a slope much exposed to avalanches, and the weather conditions as well.

A relational database has been developed and used to secure and operate various images and alphanumeric data as well.

Thanks to that new tool, the study of slabs themselves on the one hand and of the weak layers on the other, has shown that quite varied situations are likely to produce slab avalanches (whether from the point of view of grain types or from physical properties of the snow itself). Nonetheless, some major elements have emerged : they concern the important amount of fresh snow along slabs (up to 70 % of precipitation particles and partly decomposed precipitation particles), the peculiar capacity of layer of depth hoar crystals to release both thick slabs and slabs of various texture, and the capacity of fresh snow to build up weak layers.

That set of observations has led us to consider that, on the field, much significant information is derived from an investigation both into the " age " of the last snow-fall (or snow-drift), and also into ascertaining its precise location. This will probably reach priority in a precise analysis of the snow-pack, in order to establish a diagnostic of its stability.

KEYWORDS : avalanche forecasting ; snow cover stability ; snow stratigraphy

0. INTRODUCTION

Far from being related to simple rules of space and time repartition, avalanches are still likely to surprise us. During a three-year study, whose aim was to improve the knowledge about slab avalanches, we tried to find out indications allowing the improvement of stability forecasting, based on the snowpack observation. A large amount of time was used for field observations ; what was left of the activity being divided between snow analysis in a cold room and data process.

After having presented the study conditions and the data process tools devised to exploit observations, we'll propose some of the ascertainment elements about the constitution of the snow slabs and « weak layers ». The crystals and grains shape is to be considered in priority.

Although the avalanche population taken into account was quite reduced (22 events), the elements obtained already lead us to reconsider the parameters hierarchy to be taken into account for stability diagnostic statement. The large diversity of the snowpack which could cause slab avalanches have a tendency to restrict stratigraphic analysis meaning. On the other hand, the period between a perturbed meteorological event and a possible avalanche release, seems to be preponderant.

1. METHODOLOGIE

1.1. On the field

The protocol objective was to describe as precisely as possible the avalanche activity and the nivo-meteorological conditions linked with it in a mountain area [Duclos, 1995]. The main experiment took place in Valfréjus ski resort (Savoy, France).

- The nivo-meteorological conditions were picked up by using the protocol measurement for NX-LOG and for Météo-France network for one part, and on the setting of investigations of a test-slope for the other part. The latter observations, carried out once or several times a day,

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included measurement of snow depth, snowdrift, and also nivological measurements (temperature, density, shear and ram resistance) and the picking up of snow samples.

- The avalanches were recorded on the setting of NX-LOG protocol and Météo-France network. In addition, all avalanches were cartographied, and the snowpack of the starting zone of avalanches triggered by skiers or by pedestrians have being observed precisely (nivological measurements and picking up of snow samples), in one or several points(Figure 2). In every cases, we tried to describe as well as possible the layers involved in the motion (the slab itself), the layers where the shear rupture occurred (under the slab, often called « weak layer »), and some layers which stayed still (Figure 1).

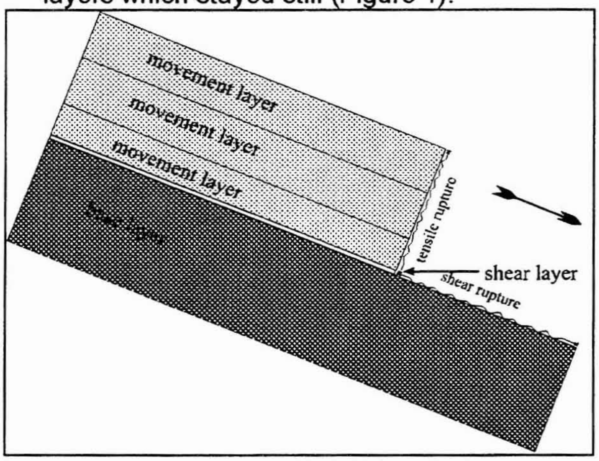

Figure 1. Three different layer types are taken into account on the crown.

Figure 2. The snow layers are observed on the crown location : temperature, density, shear and ram resistance, and picking up of snow samples are performed.

1.2. In the laboratory

Most of the time, when nivological measurements were performed, a sample of the observed snow was picked up. Each sample was then preserved and analyzed according to techniques developed by CEN[1] (Figure 3)[Brun, 1991].

As a result of the analysis of the 133 samples from the first field observations campaign (1994-1995), an expert analysis of the grains pictures was being preferred to the automatic analysis [Duclos, 1997]. The following process was being established :

- Each snow sample is represented by a set of about 40 pictures recorded on an optic disk. 35 of them were magnified 12.5 times and can be exploited later on through an automatic picture analysis [Lesaffre, 1998] ; 5 of them show some details or grains sets with different magnifying powers (the grains size can be estimated directly thanks to the net lines on the picture).
- The expert analysis of the image set of a sample can lead to an information under 6 headings : the first three ones are about the basic shapes of the grains [2] classified in a decreasing frequency order (Fa1 to Fa3), the fourth one is about precipitation particles shape (Fa4), the fifth one is about the riming rate of grains (Fa5), and the sixth allows us to enter a complementary information about the presence of clustered or « old » grains (Fa6). For example, 2 snow samples can be described as it is shown on Table 1. In the first case (*x*), we find that precipitation particles form the greatest part of the sample, and some partly decomposed precipitation particles among which rounded particles are a minority ; precipitation particles include stellar dendrites[3] and, at least, some grains are rimed. In the second case (*y*) we probably don't observe a majority of rounded grains and faceted crystals, but

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[1] CEN : Centre d'Etude de la Neige. Mété-France.

[2] The assumed classification lies on international classification [Colbeck, 1991] and on the one proposed by the CEN which can be found on the stratigraphic profile forms. We added 2 peculiar basic shapes : the rounded particles (partly decomposed particles clearly affected by low temperature gradient metamorphism), and the faceted grains (clearly affected by a large or medium temperature gradient metamorphism).

[3] Most of the time, every precipitation particles shapes observed in a sample cannot be recorded under this heading. The given shape doesn't prevent other shapes from being present.

more likely a set of rounded grains including a few faceted parts, and/or faceted crystals ; those happen to be clustered.

436 samples stem from either the test-slope or an avalanche starting zone have been analyzed this way ; 17 813 snow grain pictures have been realized.

n° of sample / grain shape	Fa1 basic shape the most frequent	Fa2 other basic shape	Fa3 other basic shape	Fa4 precipitation particles shape	Fa5 importance of riming	Fa6 complementary information
x	precipitation particles	partly decomposed particles	rounded particles	stellar dendrites	moderate riming	/
y	rounded grains	faceted crystals	/	/	/	clustered grains

Table 1. Characterization example of 2 snow samples by grains shapes.

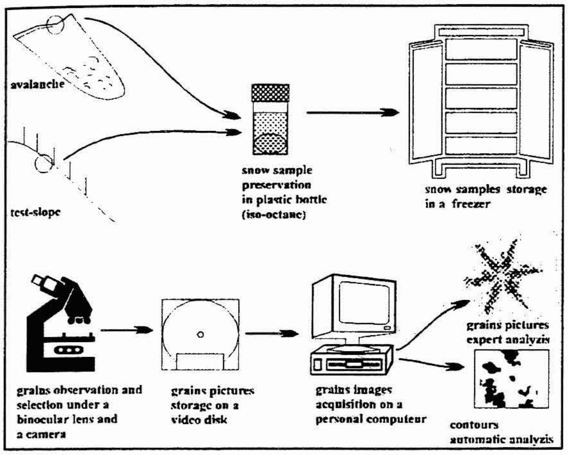

Figure 3. Snow grains from the field to the image analysis.

1.3. At the office

In order to use as well as possible the collected information, we conceived and realized a relational data base according to the MERISE method. This method was choused because it allows to built a data model independent from the needs. The data base can be gradually enlarged, and some new applications can be imagined without having to restructure the initial model (Figure 4).

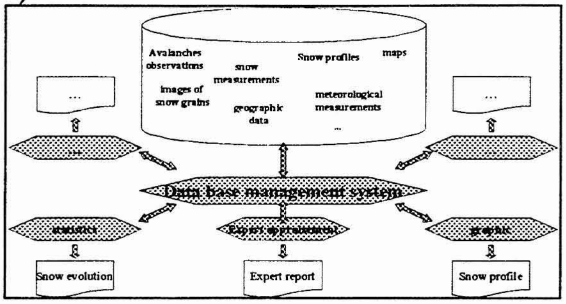

Figure 4. Multi application example allowed by the « data base » approach.

All the data collected in the setting of the study were recorded in the same base, and they were exploited as soon as needs appeared. For example, a form was imagined to illustrate the observed events (Figure 5), and an other one was imagined to represent snow samples (Figure 6). Those data, in relation with others, can be represented under a state form, for example to show the characteristics of snow layers involved in slab constitution (layer movement)(Figure 7).

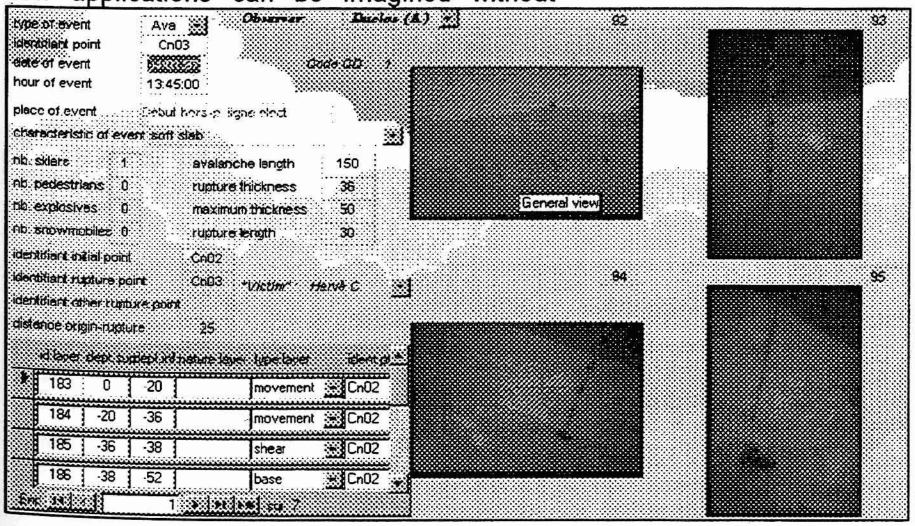

Figure 5. Form illustrating observed events

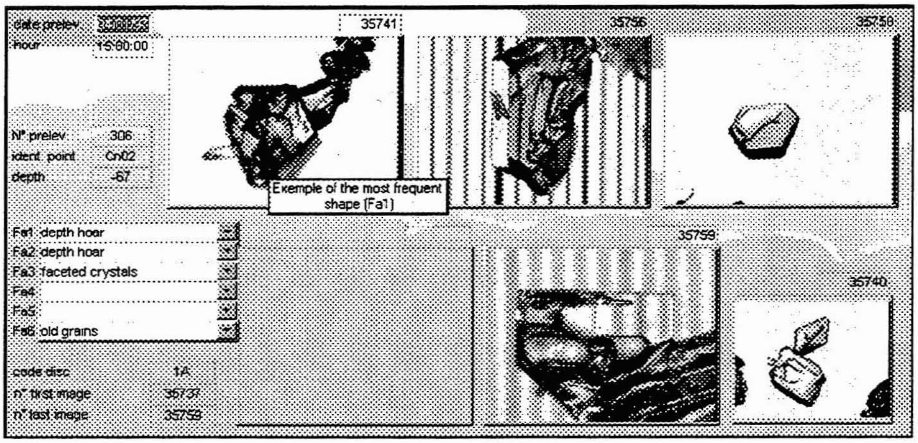

Figure 6. Form illustrating picked up and analyzed snow samples.

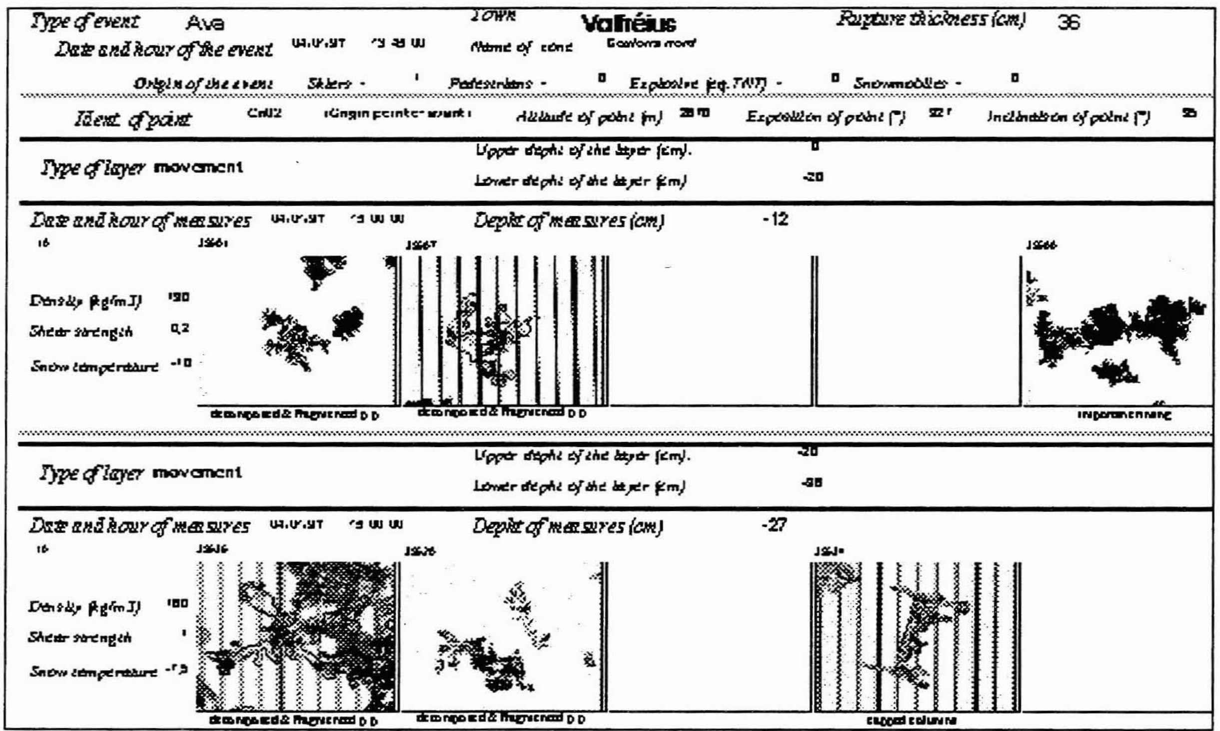

Figure 7. State form created in order to visualize the characteristics of the snow involved in the slabs constitution.

2. RÉSULTS

Out of the 295 avalanches recorded, only 22 of them were selected for this part of the study ; they all satisfy to the following criterions set, and all the avalanches satisfying those criterions were selected :

- Typological criterion : slab avalanches triggered by skiers or pedestrians, except those triggered after a remarkable and durable melting period (several consecutive weeks of positive diurnal temperature).
- Observation quality : avalanches on which measurements and samples pickings were performed exactly on the crown location
- Geographic criterion : avalanches triggered on the Valfréjus skiing area regularly frequented by professionals (ski patrols or ski teachers) or by the ski resort customers (skiers or surfers). Two additional avalanches were taken into account because they were precisely studied after a ponderous accident ; they occurred in two villages near Valfréjus (less than 15 km away) : Aussois and Termignon.

- Observation period : from December 15th to April 15th of the 1994-1995, 1995-1996 and 1996-1997 winter period. An additional avalanche was taken into account because the protocol and observation tools were then ready : the one of April 10th of 1994.

2.1. The snow composing the slabs

Snow layers composing the slabs being of several thickness, this later parameter has to be taken into account in order to estimate the relative part of each layer in the total snow volume. We then assumed a calculated coefficient to each layer according to the following methodology :

The total amount of the 42 layers being equal to 8.36 m, a 0.01 m thick layer, for example, is being affect of a 0.12 % coefficient (= 1/836), and a 0.43 m thick layer is affect of a 5.14 % coefficient (= 43/836).

From the grain shape point of view, the first statement concerns the large diversity of the snow involved in the motion during slab avalanches. Partly decomposed particles are remarkable because they are in majority in half of the volume involved (49 %). The precipitation particles, partly decomposed particles, and rounded particles set, that can be called « fresh snow » is in majority in 67 % of the involved snow layers volume. Snow which evolved into rounded grains or faceted crystals is then only in majority in one third of this volume(Figure 8). Exceptionally, wet grains were also observed (0.1 % of the volume).

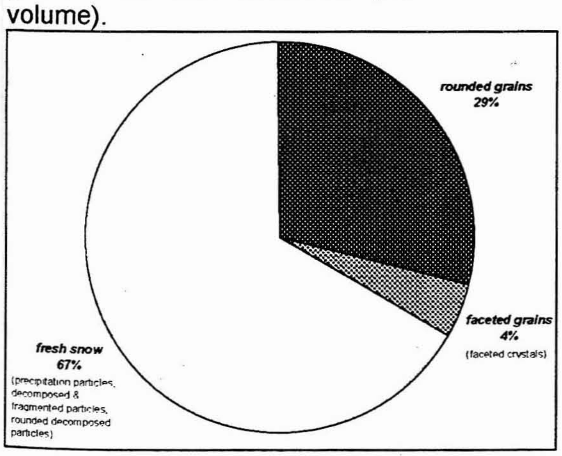

Figure 8. Frequency of the basic grains shapes (Fa1) observed in the snow layers constituting the slabs, related to their evolution state and their metamorphism type.

The lack of depth hoar and faceted particles, as well as the low faceted grains presence (4%), is remarkable.

Still about the grains shapes, some complementary remarks can be done :

- The data test shows that the only **wet grains** layer involved in the slab avalanches selected formed a refreezing crust of 0.01 m thickness.
- Three **faceted crystals** layers were observed. Two of them are thin and mainly constituted of faceted grains (Fa2 = depth hoar or faceted crystals). The third one has a 0.30 m thickness and is constituted of a mixture of faceted crystals and rounded grains (Fa2) ; its density is of 260 kg/m^3 and its shear stress resistance is of 3140 Pa. We then didn't observe in the slabs any faceted grains layers both thick (more than 0.05 m) and showing a low cohesion.
- The eleven **rounded grains** layers are of variable thickness and constitution. Six of them also include fresh snow ; they constitute 42 % of the rounded grains layers volume. The other layers are only constituted of rounded grains (14 % of the volume) or by a mixture of rounded grains and faceted grains (44% of the volume).
- In most of the cases, **fresh snow** is involved : 27 layers out of 42 and 67 % of the volume involved in slabs. Besides, it includes a large diversity of crystals and grains shapes. Namely, precipitation particles shapes are multiples and the riming phenomenon affects the shapes until the partly decomposed particles shape. To estimate a possible relation between those parameters and the aptitude for the snow layers to constitute an unstable slab, we compared the observed layers population in the slabs to the ones observed in every layers in the slopes superior or equal to 22° [4] (that we call « global population).

The part played by the **capped columns** was suspected because we observed them in 3 samples out of the 6 ones we picked up in the layers mainly composed of precipitation particles, in the selected slabs. As a matter of fact, this proportion is far less important in the global population (6 out of 40) (Table 2).

[4] The 22° slope corresponds to the minimum slope we observed required for avalanche release.

Besides, the lack of precipitation particles including **stellar dendrites** well formed in observed slabs is remarkable. Then, there is still an incertitude about the precipitation particles shape influence on the slab formation, without being possible to conclude, because of the reduced amount of data.

In the same way, the fact that riming is often observed on fresh snow particles collected in layers which belong to slabs lead us to pay a special attention to this phenomenon (66% of the cases, Table 3). The study of the « moderated riming » or « important riming » phenomenon frequency on the global population shows that it affects 60 % of the fresh snow population. The similitude in range of those two values lead us to believe that the crystals riming is a common phenomenon, which has no repercussion on the stability of the layers formed that way.

Criterion(s)	*layers observed on a slab avalanche crown*	*layers observed on slopes superior or equal to 22°*
Fa1 = precipitation particles	6	40
Fa1 = precipitation particles et Fa4 = capped columns	3	6
proportion of cases for which capped columns have been observed	50%	15%

Table 2. Compared presence of capped columns crystals in precipitation particles .

Critèrion(s)	*layers observed on a slab avalanche crown*	*layers observed on slopes superior or equal to 22°*
Fa1 = fresh snow	27	244
Fa1 = fresh snow et Fa5 = moderate riming	9	70
Fa1 = fresh snow et Fa5 = important riming	9	77
proportion of cases with moderate or iumportant riming	66%	60%

Table 3. Compared observation frequency of the riming phenomenon in the fresh snow samples.

2.2. Layers where shearing occurs

The 22 selected slabs for this part of the study allowed us to observe 25 snow layers in which the shear rupture occurred (it happened that several shear ruptures were being observed at the level of the crown without being possible to know which one provoked the event). The thickness of the layer where the shearing occurs is often critical : we ignore if the total thickness of an homogeneous looking layer has to be taken into account. It's one of the reasons why most of the described layers were being considered like having low thickness.

The examination of the grains shapes which are involved in the layers where the shear rupture occurred clearly shows that the depth hoar are in majority (40 % of the concerned layers), followed by the partly decomposed particles (20 % of the layers concerned) , and by the faceted crystals (20 % of the layers concerned). By bringing up the shapes as a function of there evolution degree and there metamorphism type, we show the importance of the faceted grains for one part (depth hoar and faceted crystals)(60% of the layers concerned), and of the fresh snow on the other part (32% of the layers concerned) (Figure 9).

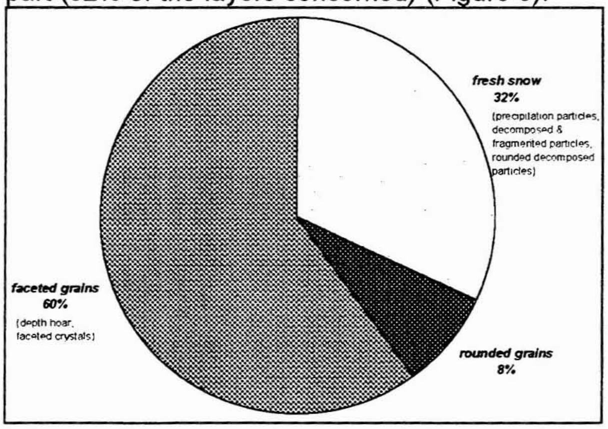

Figure 9. Frequency of the basic grains shapes (Fa1) observed in the snow layers where the shearing occurred, related to their evolution state and their metamorphism type.

A come back to the initial data shows that the two layers described like being mainly composed of rounded grains also include a faceted crystals proportion for one of them, and a mixture of partly decomposed particles for the other. Given the samples picking up method, and the possible fineness of the layers in which the shearing occurs, it's possible that the rounded grains considered as being in majority belonged in fact to the neighbored layers in which the shearing occurred (base layer or movement layer). That is why we wont take those layers into account.

2.3. Slab constituent layers combination

The slab constituent kind of snow diversity lead us to look for a possible organization of this layers, that could be specially unstable. Therefor, we examined the vertical density distribution in the selected slabs. Three different cases were distinguished :

- the ***densities are increasing*** from the slab surface to the base,
- the ***densities are decreasing*** from the slab surface to the base,
- more than two layers are observed and ***the vertical density distribution is inhomogeneous***.

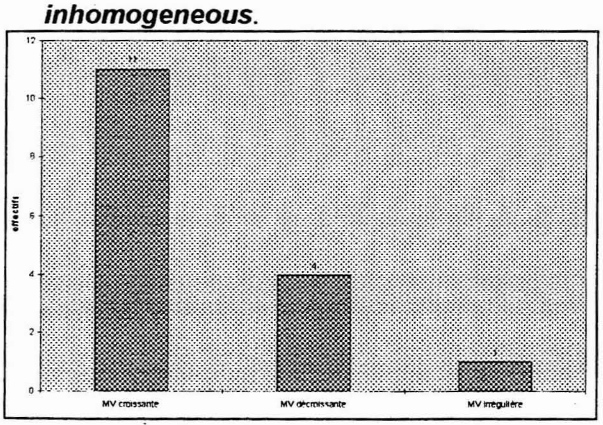

Figure 10. Slab effective in function of the vertical density distribution (from the surface to the base) where several different layers are involved (2 or 3).

Given the Figure 10, it seems that the situations in which the layers have increasing density distribution from the surface to the base are propitious to unstable slabs formation. However, this tendency won't be considered as a rule. As a matter of fact, it's possible that those situations are anyway the most frequents, whatever being the snowpack stability (except in the cases of a medium or a large metamorphism gradient, the deep layers subside). Some slabs were also observed in opposite situation.

2.4. Different kinds of slabs and weak layers

After having established the diversity of the « movement » layers and of the « shearing » layers grains shapes, it clearly appeared that in the movement layers fresh snow was in majority, as well as faceted grains are in majority in the shearing layers.

Let's look now if there are preferential combinations associating shearing layers grains shape and movement layers grains shape. In that purpose, the movement layers are related to the shearing layers which are located to their vertical[5]. To bring the possible tendencies into prominence, we again brought together the set (precipitation particles, partly decomposed particles, and rounded particles) under the name of « fresh snow ».

Two points immediately appears (Figure 11) :

- **When the shear rupture is located in a faceted crystals or fresh snow layer**, the slab above it is mainly constituted by fresh snow and its total thickness can be considered as being a medium one (0.40 m maximum). Two cases aren't in agreement with this statement : it happened once that a rounded grains slab slides on a fresh snow layer (in this case, several shearing ruptures occurred at different depths) ; from an other part, it happened once that a thin wet grains layer was being observed in the fresh snow slab base.
- **When the shear rupture is located in depth hoar layer**, the slab above it is constituted of layers which are often multiples and different natures. The slab thickness can be very large (up to 0.84 m).

[5] In the two cases where several shearing layers were observed, the movement layers are only related to the first shearing layer located on their vertical (toward the base).

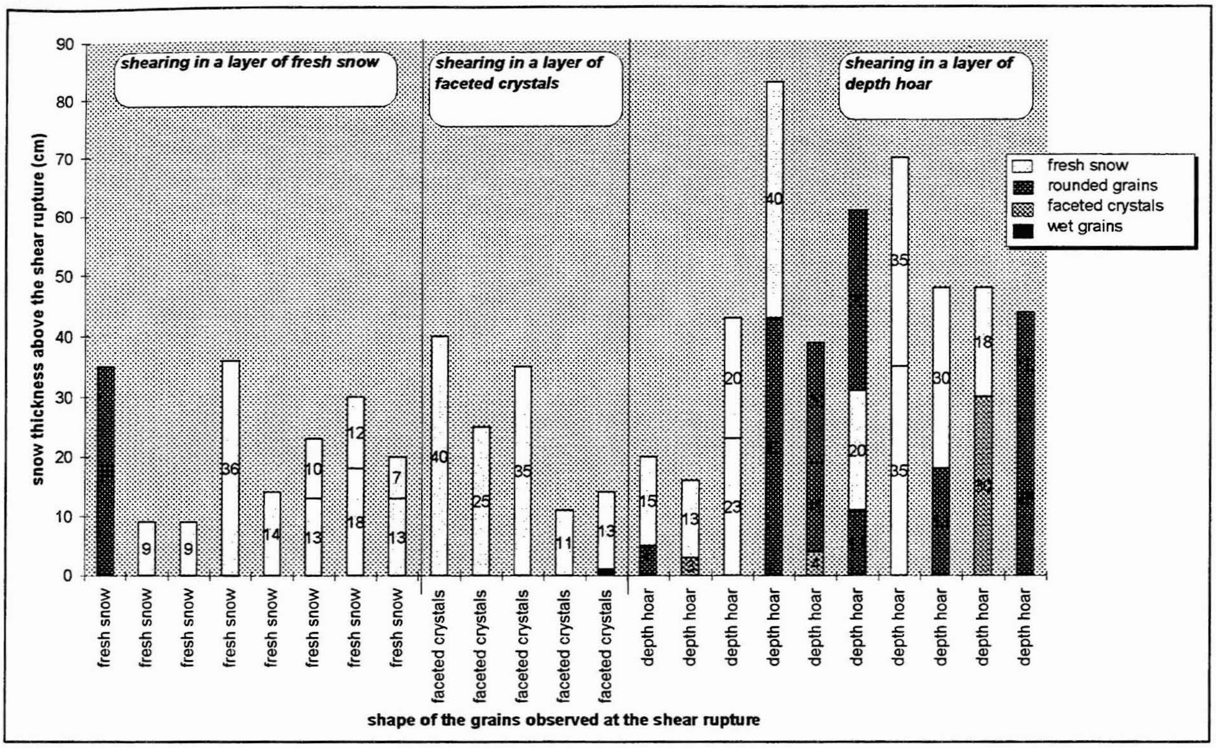

Figure 11. Grains shapes in the slabs versus the grains shapes in the layers where the shear rupture occurred.

2.5. A common factor : « new snow »

The histogram (Figure 11) shows that in 20 cases out of 23, at least one involved layer is mainly constituted by fresh snow. For one of the three left cases, the shearing occurred in fresh snow. This clearly indicate that the events then occurred quite a short time after a snowfall (21 cases out of 23).

Only two avalanches occurred when no layers were described like including a majority of fresh snow (Fa1) :

- The first peculiar avalanche includes a three layers composed slab (0.20 m and 0.15 m of rounded grains, plus 0.04 m of faceted crystals), and a shear located in the depth hoar. A come back to the initial data shows that the observed rounded grains are due to quite a recent snow drift (few days).
- The second peculiar avalanche (triggered on 01/14/97) includes a slab composed of two rounded grains layers (0.18 m and 0.26 m), and a shear rupture located in the depth hoar. This case is very peculiar because only traces of fresh snow were found (Fa3) in the layers constituting the slab. This seems to indicate that the involved snow would date from the last important snow fall followed up with drift that took place between 01/02/97 and 01/03/97, that is to say 11 days before the avalanche. This period between the possible new snow arrival on the slope and the avalanche occurrence is the longest we ever note.

Those observations lead us to consider the « new snow » deposit on a slope like a necessary factor to instability. This « new snow » (recent loading) may include both snow directly coming from precipitation and from snowdrift. It constitutes the only common factor to the all observed slab set.

3. DISCUSSION

Snow layers observation of the snowpack on a vertical axe gives useful information to perform a stability diagnostic. Like other authors (R. Perla, P. Foehn, B. Jamieson, etc.), we verified that faceted grains layers (faceted crystals and depth hoar) are often involved in slab avalanches. We also observed that slab avalanches can occur when no weak layers have clearly been observed (shearing in fresh snow), and that recent loading on a slope seems to be a necessary condition to cold snow slab avalanches release. Besides, we have to admit that the slopes often have a surprising stability when the snowpack seems to be typically unstable (buried weak layers and/or new snow being present)[Duclos, 1997]. At least, it clearly appears that lot of different combinations of snow layers can possibly form unstable slabs.

After this statement, the question of nivological observations utilization for stability diagnostic is to be considered. After having exposed some of the reasons which put in perspective the snowpack observation value, we propose some application extracted from our study results for the use of the ski-mountaineer and of the engineer.

3.1. Limits of a method bed on the snowpack observation

We selected three facts that can explain that the snowpack observation in one point can lead to a false stability diagnostic in an other point, only distant of a few tens of meters from the other one.

3.1.1. Spatial variability of the snow pack in an avalanche starting zone

To specify the differences of snowpack thickness order of magnitude in the same slope, a series of measurements has been performed in April 1995 on the test-slope. We delimited a 50 m side scare, with a quite regular topography (between 30° and 35° degree slope) down stream a wide ridge. The 121 snow depth measurements have been performed every 5 m in two directions (in parallel to the line of greatest slope, and perpendicular to this line)(Figure 12). We noted that the snow depth could vary more than the simple to the double on a 5 m distance (for example from 0.90 m to 1.83 m), and that the snow depth difference could go up to 1.7 m on a 5 m distance (here, between 1.80 m and 3.50 m).

Snow accumulation during one winter on a north-est slope with a west mean direction of the wind. Test-slope.

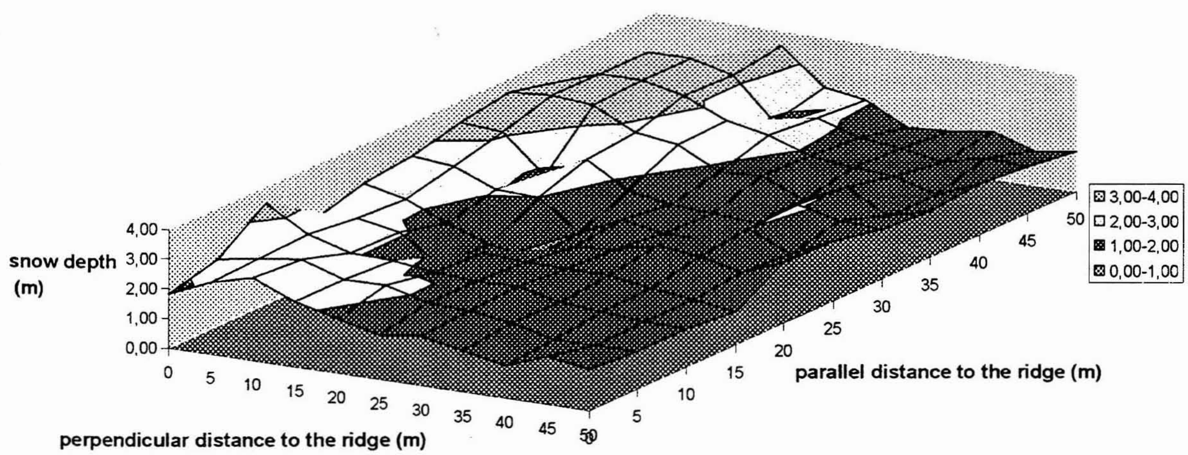

Figure 12. **Snow spatial repartition at the end of winter (April 19th of 1995) on the test slope.**

3.1.2. At a distance triggering

Out of the 82 avalanches triggered by skiers or by pedestrians recorded in the setting of the study, 15 were formally described like having an origin point[6] different from the crown points.

In the observed cases, the nearest crown and origin point were up to 250 m far one from the other, and up to 105 m difference of level. By

[6] The origin point is the location of the snowpack solicitation which led to the triggering.

calculating the difference between the origin point altitude and the crown point altitude, we obtain a value that can be positive or negative depending the relative position of the two points. We therefor note that the at a distance triggering often occurs above the origin point (60 % of the observed cases). They can also occur under this point (27 % of the observed cases (27 % of the observed cases), or at the same level (13% of the observed cases).

3.1.3. Role of the previous avalanches

A slab avalanche occurrence in a starting zone has two consequences :

- the snow quantity involved isn't threatening anymore,
- the weak layer which allowed the triggering probably lost its aptitude to allow a new release.

This underlines that a stability diagnostic can only be performed for an avalanche starting zone if we know the previous avalanches since the beginning of the season. For example, if an important snow accumulation occurred on a slope at the date « d », the stability diagnostic for the date « d+1 » could be the following ones, according to the past avalanches occurrence :

1. the triggering probability is equal to zero if the avalanche occurred at the date « d »,
2. the triggering probability is high if no avalanche occurred at the date « d »,
3. the triggering probability is superior to the last one if no slab avalanche occurred since the beginning of the season, and if a continue buried depth hoar layer has been observed.

3.2. Practical applications

3.2.1. For the ski-mountaineer

Having no precise knowledge about the history of a site (nivo-meteorological and avalanche events), the ski-mountaineers can only give general hypothesis on the snow slope stability. Some simple rules based on meteorological events (mainly precipitation and snowdrift), and on the time that passed since those events took place, allows us to detect the periods during which the avalanches are possible. During a usual winter, those period can involve a large proportion of days number. During those ones, one would either stop himself from frequenting the backcountry (the totally under shelter zones are rare) , either take the necessary precautions, knowing that the risk exists. The only stratigraphic is not enough to help one to take a decision.

3.2.2. For the local avalanche control

For a local forecasting, aimed for example to work protection, it doesn't seem possible to do without nivo-meteorological measurements performed in an area near site studied zone. One also has to perform a « training of the site » phase, in order to know the influence of the measured conditions on the snowpack evolution, and on the avalanche activity in each slope that has been identified as a threatening one. The knowledge of the avalanches which took place since the beginning of the season is necessary. Only if those data are available, a reliable and precise diagnostic seems to be realistic. Having recourse to date processing as an help to decision tools (expert system, statistic system, and data base) now seems essential.

4. CONCLUSION

Being guided by ski-mountaineers' intuitions, three field observation and laboratory campaigns have given some information that could be collected and exploited. If some new concept appears, they encourage us to carry on the method we've used (field observations and relational data base performing), instead of an immediate use of the results.

Even if they aren't based on enough observations to be considered as being definitive, those results can however be reminded.

About the nature of the snow layers involved in the slab avalanches (except melting situations), three important points have to be put forward :

- Fresh snow (precipitation particles and partly decomposed particles) constitute the main part of the slab volume (about 70 %).
- The depth hoar which prevails in 40 % of the layers where the shearing occurred, have a particularity to allow the triggering of thick slabs of varied kinds.

- A fresh snow layer, often impossible to individualize, can shear itself under slabs constituted of fresh snow or rounded grains brought by snow drift.

Two complementary clues emerge :

- No dendritic precipitation particles (capped columns, etc.) seems more favorable to the slab formation than stellar dendrites.
- Snow layers affected by a medium or large temperature gradient metamorphism (from partly decomposed particles to depth hoar) seems to lose their aptitude to form slabs.

Based on those statements, we've proposed the « new snow » concept (snow from precipitation or from snowdrift) as a necessary factor to the triggering of cold snow slabs provoked by pedestrians or skiers.

In addition, having established both the large spatial variability of the snowpack and the possibility to trigger a slab from a distance of hundreds of meters, we shall from now understate the possibility to exploit some local observation on the snowpack in order to perform a stability diagnostic. Moreover, it appears that past avalanche activity highly conditions the present avalanche activity.

That is why we are taking into consideration that ski-mountaineer is seldom able to perform a precise stability diagnostic for a given slope. This kind of diagnostic can probably be performed for starting zones under control, having already been under a training phase, aimed to teach us about each slope reaction to the nivo-meteorological measured events.

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BIBLIOGRAPHIC REFERENCES

Bolognesi, R., 1994 : Local avalanche forecasting in Switzerland : strategy and tools. *Proceedings of the international Snow Science Workshop*, **Snowbird 1994**, 463-472.

Brun, E. and Pahaut, 1991 : An efficient method for a delayed and accurate characterisation of snow grains from natural snowpack. *Journal of glaciologie*, **37**, 420-422.

Duclos, A. and Bolognesi, R. : Méthodologie pour l'étude des plaques de neige à partir de données nouvelles. *Actes du colloque ANENA*, **Chamonix 1995**, 283-289.

Duclos, A., 1997 : Observer la neige pour comprendre les avalanches : difficultés et limites. *Neige et avalanches*, **79**, 2-8.