# MEASUREMENTS OF HUMAN-TRIGGERED AVALANCHES FROM THE SWISS ALPS

Jürg Schweizer* and Martina Lütschg
Swiss Federal Institute for Snow and Avalanche Research, Davos, Switzerland

ABSTRACT: Ten years of avalanche incidents data from the Swiss Alps have been analysed in order to find characteristics of human triggered avalanches. We were particularly interested in avalanche release and snowpack patterns. In the 10 years (1987-88 to 1996-97) the average number of avalanche fatalities in the Swiss Alps was 23 per year. More than 90 % of the victims were caught during recreational activities in the free (not controlled) terrain. Of these, 90 %, were killed by an avalanche that was triggered by themselves or by another member of their group. The recreationist nearly exclusively triggered dry snow slab avalanches. The slab detached of a human triggered slab avalanche is (median values given) 50 m wide, and 80 m long; the overall avalanche length is 150 m. The fracture depth is 45 cm, and the inclination in the starting zone is 38°. The analysis of the 90 profiles available did support most of the mainly unstructured knowledge used in stability evaluation based on snow profiles. The slab failure is only in 38 % at the boundary between storm snow and old snow. The other failures are due to weak layers or interfaces within the old snowpack. A weak layer was found in 42 % of the cases. In all other cases the failure was between to adjacent layers, a so-called interface failure. The median rutschblock score was 3 (weighting). The thin (1 cm) weak layer is usually soft, found between one or two harder layers (above and below) and consists primarily of large crystals (≥ 2 mm) with plane faces: surface hoar, faceted crystals and depth hoar.

KEYWORDS: snow, avalanche, avalanche accidents, avalanche release, snow stability, avalanche forecasting, skier triggering

## 1. INTRODUCTION

In Switzerland, the Swiss Federal Institute for Snow and Avalanche Research (SLF), collects reports on avalanche accidents and involvements since the 1940ties. The reports are compiled and published in the annual report on the snow and avalanche conditions in the Swiss Alps, the so-called "SLF Winterbericht".

In order to better understand the mechanics of human triggered avalanches a 10-year period (1987-88 to 1996-97) of avalanche report data has been entered in a database and analysed. We focused on avalanche release and snow cover characteristics rather than burial and rescue statistics (Tschirky et al., 2000). Field measurements of dry snow slab avalanche features provide important information for safe travel in avalanche terrain, i.e. for avalanche education, and on how slab avalanches fail (McClung and Schaerer, 1993). Assessing the danger of human triggered avalanches is the key factor in modern avalanche forecasting. Stability evaluation and avalanche education is strongly focussed on skier, or more generally, human triggering.

Perla (1977) has given the first comprehensive description of dry-snow slab avalanche characteristics based on field measurements at fracture lines. Ferguson (1984) compared stable and unstable profiles. Föhn (1993) described weak layer properties. Jamieson and Geldsetzer (1996) compiled the Canadian avalanche accidents from 1984 to 1996 and analysed trends and patterns. Some of the key features are also described in McClung and Schaerer (1993). Our study is exclusively focused on human triggered avalanches. The analysis is based on a large number of cases: 636 avalanche records, including 90 cases investigated in detail for which a snow profile is available.

*Corresponding author address:*
Jürg Schweizer, Swiss Federal Institute for Snow and Avalanche Research, Flüelastrasse 11, CH-7260 Davos Dorf, Switzerland
phone: +41 81 417 0164, fax: +41 81 417 0110
e-mail: schweizer@slf.ch

## 2. DATA

The data on human triggered avalanches that can be found in the SLF annual reports on the snow and avalanche conditions of the years 1987-88 to 1996-97 (No. 52-61) are analysed. Naturally released avalanches are not considered. Included were reports from the sections describing the avalanche accidents (called: "accidents") and the snow and avalanche conditions in the region of Davos (called: "Davos"). The source "accidents" contains the reported avalanche incidents (i.e. at least one person has been caught) from the whole area of the Swiss Alps. The second source ("Davos") contains avalanches from the surroundings of Davos reported primarily by the ski patrol of the various ski stations around Davos, by professional guides working in Davos and by SLF members. This data set includes many cases of avalanches with no severe consequences (no fatalities or injuries). Sometimes cases are reported when not even a person was caught, so-called skier controlled avalanches. The data are very basic, but usually complete. The Davos sample was explored for the first time. It should be one of the most complete and homogeneous avalanche data sets at all; it contains 310 cases. Overall the data base contains 636 cases.

The database is structured into the sections: general information (date, location etc.), avalanche (size etc.), release (single skier, group etc.), snow cover, weather, damages and data source. An example of a data record can be found in Schweizer and Lütschg (1999). To enter the data some interpretation was necessary (see below).

The *slope angle* is given for the steepest section of the starting zone. This value has to be representative for a considerable part of the starting zone, in particular in the case that the starting zone is very large. It is still an average steepness. If the slope angle was not measured in the field, if was taken from the map (scale 1:25'000) using a specific ruler and a hand lens. Whenever the location was clearly defined estimated values were checked on the map. This showed that in many cases the estimated value for the slope angle given in the report files underestimated the real terrain steepness. In all these cases the value from the map was used.

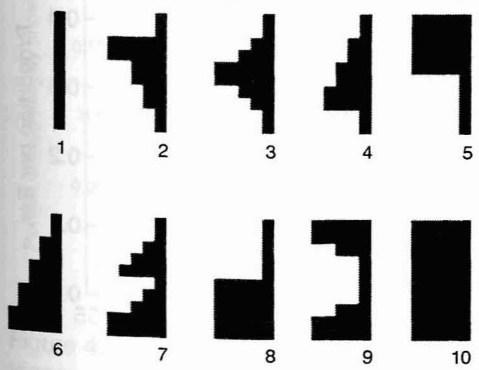


Figure 1: Classification of hardness profiles

*Snow profiles* were available only in about 14% of all cases. In the rare cases were there was more than one profile, the one that was assumed to be the most representative for the trigger point was chosen. The profiles had to be generalised for data entry. The weak layer, and the layers above and below are recorded in detail. If there is no weak layer but the failure occurred at an interface, just the layers above and below are given. The slab and the underlying (remaining) snowpack (called substratum) are each characterised by just one value for type and size of grains, the hardness and liquid water content. In addition the hardness profile was characterised according to the types given in Stoffel et al. (1998), based on the original work by deQuervain and Meister (1987). Two more types (now 5, 10) have been added, so there were 10 types used now (Figure 1). Types 1-5 all have a weak base, whereas type 6-10 are well consolidated at the bottom. Opposed to the two above mentioned previous studies the slab and the underlying snowpack (substratum) were each characterised independently. So to both, the slab and the substratum, one of the 10 hardness profiles was assigned.

## 3. RESULTS

Before the results on human triggered avalanches are shown it is quickly reviewed where and how the fatal accidents happened. Although our database exclusively includes the human triggered avalanches, we will for that purpose shortly consider all fatalities. In the 10-year period considered, the average number of avalanche fatalities was 23. The vast majority of avalanche accidents (93 %) happened in the free terrain i.e. during recreational activities. 90 % of the recreationists in the free terrain were killed by an avalanche that was triggered by themselves or by one of their party members.

### 3.1 Avalanche type and size

The data base nearly exclusively (99%) contains slab avalanches. Only 6 cases are known that are due to a loose snow avalanche. Three of them were wet ones that caused the fall of the involved skiers/climbers leading to 4 fatalities. There is only one case in the database reporting a wet slab avalanche reflecting the fact that wet slabs can hardly be triggered.

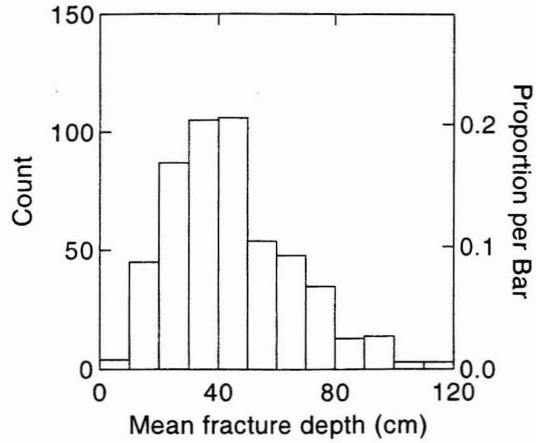


Figure 2: Mean fracture depth of slab. All cases considered (N = 522). Mean: 49 cm, median: 45 cm. 5 cases with depth >120 cm not shown.

The median width of human triggered slab avalanches is 50 m (considering all cases). However, differences exist depending on the selection of the sample from the database. Considering the cases from the Davos region, including many skier triggered avalanches while out of bound skiing reveals a lower value of 40 m. Considering only the avalanches that were triggered during out of bounds skiing the median width is 40 m. Whereas the median width of avalanches triggered during ski touring is larger: 70 m. The larger the width the smaller seems to be the chance of survival since if only accidents are analysed that led to fatalities, the median width is 80 m.

Whereas the width is rather consistently reported, the length is less conclusive. Usually the overall length is given, not the length of the slab detached (from the fracture line to the stauchwall). Considering all cases the median overall length is 150 m, i.e. the typical avalanche is just about three times as long as wide. The median overall length for the fatal avalanches is 310 m. The median length of the starting zone is 80 m considering all cases, and 100 m for the fatal avalanches. The proportion of width to length for the slab released is typically around 1.5.

The fracture depth is probably one of the most interesting parameters in view of the mechanics of avalanche release (Figure 2). The mean fracture depth reported is usually measured at the fracture line (not necessarily being representative for the trigger point). The median of the mean fracture depth is 45 cm. In 98 % of the cases reported the mean fracture depth is ≤100 cm clearly showing that a skier is not a very effective trigger for deep weak layers. In 38 cases (representing only 6 % of all cases) the fracture depth at the estimated trigger point was given. The median fracture depth at the trigger point is 40 cm, the maximum value is 90 cm.

### 3.2 Terrain

The *slope angle* in the starting zone (Figure 3) is known in 97 % of all cases. Considering all cases the median value is 38°, the mean value 38.6°. In 40 % of the cases the slope angle is 40° or more. It has been suggested that out of bounds skiers prefer steeper terrain than backcountry skiers. There is statistically no significant difference in slope angle between avalanches triggered while out of bounds skiing vs. ski touring: median value 39°, mean 38.7° (out of bounds skiing) vs. 38°, 38.7° respectively, for avalanches triggered during ski touring.

The *aspect* is known for nearly all cases (99.7 %). Considering all cases the most frequent aspect was found to be north-east (26 %). However, as opposed to most other parameters the aspect seems to be biased by the large number of cases from the Davos region where most valleys run typically north-west to south-east so that the typical shady slope is north-east. Accordingly, omitting the cases of the Davos region decreases the dominance of the north-easterly direction. But still, north east is the most frequent direction (23 %), followed by north (19 %) and north-west (17 %). About 60 % of the avalanches are triggered in the shady slopes. For most of the Swiss Alps, on the north-easterly

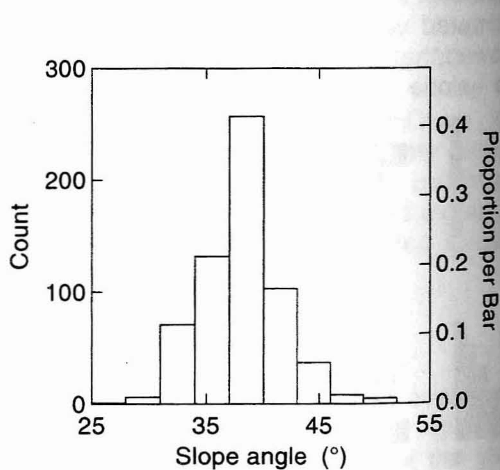


Figure 3: Slope angle. All cases considered (N = 617). Mean: 38.7°, median: 38°.

slopes the unfavourable factors shady slope and lee slope cumulate. The southern aspects (SE, S and SW) contribute 18 %. The rest is triggered in the eastern (15 %) and western (8 %) aspect.

The median altitude of the starting zone is about 2410 m a.s.l.

For 470 out of 636 cases some terrain features are given. Most avalanches are triggered on spots close to the ridge top (52 %), and/or in bowls, gullies and on open slopes.

### 3.3 Triggering

The vast majority of avalanches was triggered by skiers (80 %), 11.5 % by snowboarders and 6.8 % by climbers. The rest is mixed or other type of human triggering. The portion of triggering by snowboarders is clearly increasing (Figure 4). It increased from about 5 % on the average for the first 5 years to 15 % on the average for the second 5 year period. In the last two years (1995-96, 1996-97) the portion increased to about 20 %. This trend did continue in the years 1997-87 and 1998-99.

The majority of human triggered avalanches are triggered while out of bounds skiing (58 %). The rest was primarily triggered while ski touring (41 %) and less than 1 % was triggered within controlled ski areas.

Sixty per cent of the human triggered avalanches are triggered by a single person who is either a party member or travelling individually. During out of bounds skiing single triggering is even more common (73 %) and obviously nearly exclusively occurs during the descent (99 %). During ski touring triggering by a whole group is more frequent (54 %), thereby occurring evenly distributed between ascent and descent. These patterns suggest that the risk involved in out of bounds skiing is clearly smaller than during ski touring, but the amount of dangerous terrain covered by out of bounds skiers is likely larger. Whereas the vast majority of avalanches was triggered by the first person entering the slope or by several persons (group triggering), in a few cases (less than about 10 %) an avalanche was triggered on a very recently skied slope. The avalanche was triggered by e.g. the second or third skier entering the slope, when skiing one by one.

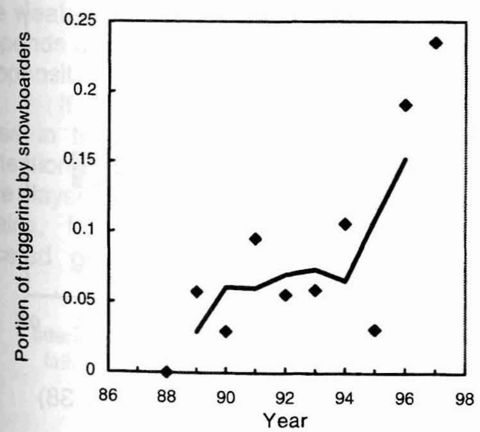


Figure 4: Portion of snowboarders that triggered slab avalanches during the 10 year period (87-88 to 96-97). Line gives trend (3 year moving average).

### 3.4 Snow cover characteristics

The slab failure is only in 38 % at the boundary between storm snow and old snow. The other failures are due to weak layers or interfaces within the old snowpack. There is no failure plane reported within the storm snow. The portion of new snow instability is higher during out of bounds skiing (44%), compared to 28% during ski touring. However the difference is not statistically significant. Groups guided by professionals triggered avalanches with failure planes primarily (83 %) in the old snowpack. These findings suggest that avalanche education is rather successful in recognizing the new snow instability but not so much in detecting old snow instabilities such as persistent weak layers.

A weak layer was found in 42 % of the profiles. In all other cases the failure was between two adjacent layers, a so-called interface failure. Interface failures are more frequently (68 %) found in the case of new snow instability. However the difference is not significant .

A rutschblock test was done in 55 out of 90 cases. The median rutschblock score is 3, the average is 3.6. Four cases exist with scores 6 or 7. These high scores can be explained either by a substantial time delay (e.g. one profile/RB test was done 4 days after the release) or by the location (e.g. profile at fracture line, far from trigger point).

*Slab properties*

The typical slab (79 %) consists of either decomposing and fragmented precipitation particles or small rounded grains, or a mixture of the two. Accordingly the grain size is typically 0.5 to 0.75 mm (74 %). The slab is usually rather soft: in 76 % of the cases the hardness is "fist", "fist to four fingers", or "four fingers". The slab temperature is in most cases between -3 and -8 °C (median: -4.5°C) and the density slightly more than

200 kg/m³. The median value of the slab thickness found in the profiles is 52 cm, in accordance with the values given above. The hardness profile of the slab is most frequently characterized as either type 1 (37 %) or type 6 (42 %) (Fig. 1). The above values reflect typical snow cover conditions in general showing that the slab properties alone are not conclusive for profile evaluation. Only in 3 cases (3.4 %) a crust at the top of the slab was found.

*Substratum*

The substratum is the part of the snow cover that remains after slab release. It consists of all layers below the weak layer or below the failure interface. The typical grain type in the substratum are faceted grains and depth hoar (77 %), the median grain size is 2 mm. The hardness varies strongly. There are many soft (hand hardness less than "4 fingers") substrata (31 %), but hard ones (hand hardness "1 finger" or harder) are equally frequent (33 %). The median temperature of the substratum is -2.5 °C and the density is about 300 kg/m³. All types of hardness profiles are present. Most frequently, but still in only 25 % of the cases, the hardness profile of the substratum was characterized as type 1. Types 4, 6 and 8 are quite frequent as well. Together these four types cover 64 % of all cases.

The combination of the hardness profiles of the slab and the substratum shows that in 55 % of the cases the failure was at the transition from hard to soft or vice-versa from soft to hard. The five most frequent combinations, but still covering only 36 % of all 89 cases, are given in Figure 5.

*Weak layer or interface*

In the 90 profiles analysed a weak layer was found in 38 cases (42 %), the rest was characterised as interface failure. The database for the weak layer is accordingly relatively small. More than 90 % of all weak layers found consisted of large crystals with plane faces: surface hoar, faceted grains and depth hoar, i.e. of persistent grain types (Figure 6) (Jamieson, 1995). The grain size is in most cases (58 %) 2 mm or larger (Figure 8). In 66 % of the cases the weak layer thickness is equal or less than 1 cm, median hand hardness index is 1 (F) and median failure temperature is -4 °C.

The layer above the weak layer typically (58 %) consists of fragmented precipitation particles and small rounded grains of 0.5 to 1 mm in size. Therefore the grains in the layer above the weak layer are statistically significantly smaller than in the weak layer. The hardness index of the layer above the weak layer is 2 (4F) to 3 (1F). Accordingly the layer above the weak layer is statistically significantly harder than the weak layer, and additionally also significantly harder than the slab on average.

The layer below the weak layer consists of a variety of grain types, but faceted grains are most frequently found (55 %). Quite common are small rounded grains, depth hoar and crusts (refrozen wet grains)/ice layers. The grain size is typically about 1.5 mm, again statistically significantly smaller than in the weak layer. The hardness is variable, but the layer below is statistically significantly harder than the weak layer.

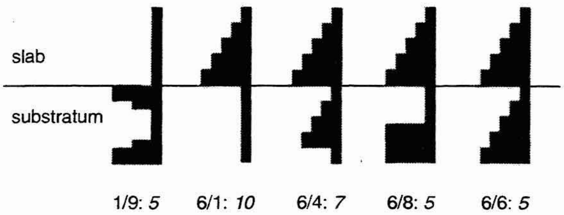


Figure 5: Most frequent combinations of hardness profiles each for slab and substratum. Numbers give type of profile (Fig. 1) and frequency (in italic). Total number of profiles represented: 32 (38 %), total number of profiles analysed: 89.

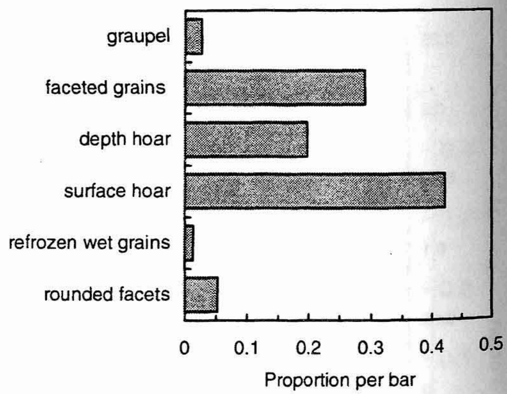


Figure 6: Grain type of weak layer (N = 38)

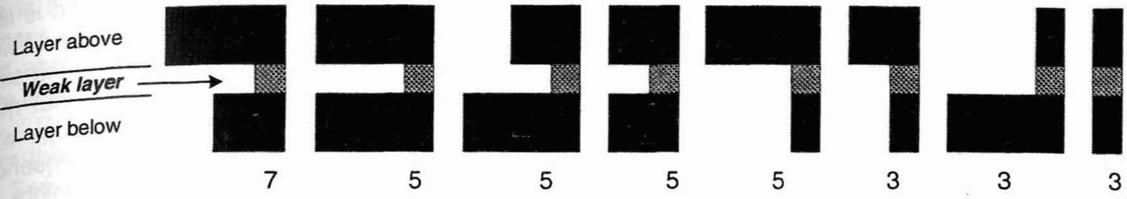


Figure 7: Typical hardness configurations of layer above, weak layer and layer below. 36 of the total 38 cases are shown. The figures indicate the number of counts.

Figure 7 compiles the typical hardness configurations found. In 86 % of the cases the layer above the weak layer is harder than the weak layer suggesting a typical slab structure.

Based on the above analysis a typical weak layer configuration is proposed in Figure 8. The present analysis suggests that it should be not too difficult to detect weak layers, since it seems that based on hardness, grain type and size the weak layer should show up rather clearly. However, the existence is only one thing, and

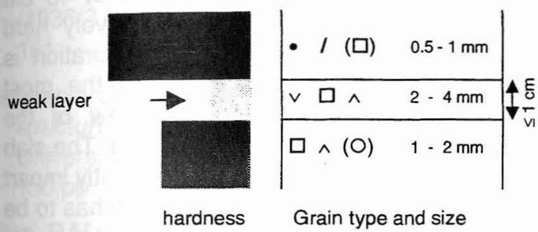


Figure 8: Typical snow cover situation with weak layer.

unfortunately not conclusive. More important are the weak layer strength, the skier stability that also depends on the slab characteristics, and finally the propensity for fracture propagation.

If there is no weak layer which was the case in the majority of the profiles (58 %) the detection of a potential instability is more difficult. The layer above typically consists of rounded grains, fragmented precipitation particles, and faceted grains of about 0.5 to 1 mm in size (median size 0.75 mm). Crusts/ice lenses are quite common as well. The median hardness index is 2 (4F). In the layer below the failure interface faceted grains, depth hoar and crusts/ice layers dominate (88 %). The median grain size is 1.75 mm, statistically significantly larger than in the layer above the failure interface. The hardness is slightly harder than in the layer above the failure interface about 2 (4F) to 1 (1F). There is no statistically significant difference between the hardness of the layers above and below the failure interface. However, there is usually a hardness difference, but sometimes the upper layer is harder than the lower one, and vice versa. Accordingly, as mentioned, on the average, there is therefore no difference in hardness. So analyzing the differences profile by profile shows that the median difference in hardness is 1½ degrees of the hardness index scale, e.g. 1 (F) vs. 2-3 (4F-1F). In 56 % of the cases the hardness difference is 1½ or more degrees of the hardness index scale. The hardness difference is statistically significant. Figure 9 compiles the different hardness configurations found (soft on hard, hard on soft, etc.). In 60 % of the cases the hardness difference is prominent, but in 13 % of the cases the difference is small or even not existent.

Failures on or below crusts are frequently found (48 %) in the case of interface failures. where the failure was below a crust the layer below the crust consisted of faceted grains or depth hoar. On the other hand when the failure was on the crust, in 50 % the crust itself included faceted grains or depth hoar, and in 16 of the 18 cases in the layer above fragmented precipitation

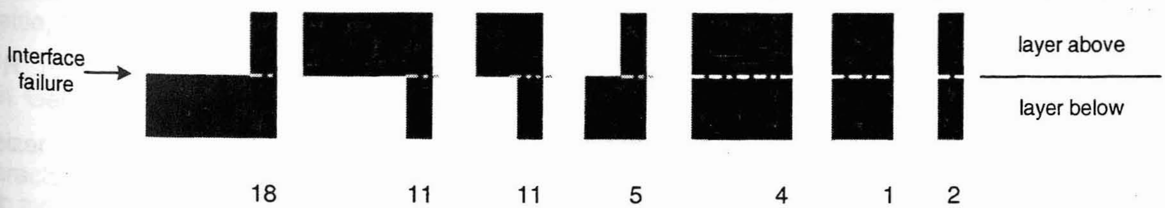


Figure 9: Typical simplified hardness configurations found at interface failures. All 52 cases are shown. The figures indicate the number of counts.

particles and small rounded grains were found. The layers above and below an interface failure are commonly rather thin. Sixty seven per cent of the layers below the interface failure are equal or less than 5 cm thick. The fact that the layer below commonly is a crust is in agreement with this result. The corresponding portion of relatively thin layers (≤ 5 cm) above the failure interface is 27 %.

Considering weak layer and interface failures in 24 % the layer below was a crust. In 50 % of these cases a layer of faceted crystals was found on top of the crust.

## 4. SUMMARY AND CONCLUSIONS

Ten years of human triggered avalanche data that were published in the Winterberichte of the SLF, were completed, entered in a database and analysed, in particular in view of avalanche, triggering and snow cover characteristics. The database consists of 636 cases. A snow profile is available for 90 of the cases.

More than 90 % of the victims were skiers, snowboarders, climbers etc. - people killed during recreational activities in the free (not controlled) terrain. 90 % of these recreationists were killed by an avalanche that was triggered by themselves or by another member of their group.

The recreationists nearly exclusively triggered dry snow slab avalanches. The main parameters are summarized in Table 1.

The vast majority of the avalanches is triggered by skiers, but the portion triggered by snowboarders is rapidly increasing. Triggering occurred primarily during out of bounds skiing (58 %) and ski touring (41 %). Usually the first skier entering the slope releases the slab. Only in a few cases the avalanche was triggered by e.g. the second or third skier entering the slope, when skiing one by one. In other words test skiing was not a reliable stability test. This type of triggering can be considered as rather unusual and is likely due to variation in snow stability (variation of weak layer strength, and variation of load during skiing or between different skiers). The fact that many avalanches are triggered by whole groups while ski touring, usually with serious consequences, suggests that the avalanche risk might be substantially reduced by consequently skiing one by one on critical slopes, by improved route selection and by keeping (probably rather large) distances while climbing up.

The analysis of the 90 profiles available did support most of the mainly unstructured knowledge used in stability evaluation based on snow profiles (Schweizer et al. 1992; Wiesinger and Schweizer, 2000).

Nearly all the slabs found were relatively soft at the surface suggesting good deformation transfer to the weak layer. This finding was expected based on the theoretical and experimental work by Schweizer (1993) and Schweizer et al. (1995). The typical slab is relatively shallow supporting the simple model of skier loading. If the typical slab is about 45 cm thick, rather soft at the top and relatively hard above the weak layer then this configuration is exactly the one that is suggested as the most critical one for skier triggering in view of the present knowledge about skier triggering. The slab must be soft to enable the skier to efficiently impart deformations to the weak layer. The slab has to be relatively shallow, since the skier's impact strongly decreases with increasing depth. A distinct difference in hardness favours stress concentrations at the interface to the weak layer.

Detection of weak layers seems to be feasible based primarily on layer thickness, grain type, grain size and hardness difference. If there is no weak layer which was the case in the majority of the profiles analysed, the detection of the instability seems to be more difficult. However,

Table 1: Characteristics of human triggered avalanches. Between the 1st and 3rd quartiles 50 % of the cases are found. *) The aspect given is the one most frequently found (mode).

| *Avalanche characteristics* | *N* | *Median value* | *1st quartile* | *3rd quartile* | *Mean* | *Standard Error* |
|---|---|---|---|---|---|---|
| Width | 611 | 50 m | 28.8 m | 100 m | 73.7 m | 3.1 m |
| Length of slab | 61 | 80 m | 50 m | 150 m | 109 m | 11 m |
| Aval. length | 619 | 150 m | 80 m | 300 m | 256 m | 11 m |
| Fracture depth | 522 | 45 cm | 30 cm | 60 cm | 49 cm | 1 cm |
| Slope angle | 617 | 38° | 36° | 40° | 38.7° | 0.1° |
| Elevation | 629 | 2410 m | 2190 m | 2610 m | 2421 m | 15 m |
| Aspect* | 634 | NE* | - | - | - | - |

there is in most cases a significant difference in hardness and grain size. Crusts are commonly found above or even more frequently below the failure interface.

Comparing Swiss and Canadian data has shown that the above results are not singular for the Swiss Alps but rather generally valid (Schweizer and Jamieson, 2000).

*Acknowledgements*

This study would not have been possible without the field work of numerous people that gathered the data about avalanche accidents or involvements. E. Beck, Hj. Etter, R. Meister and F. Tschirky compiled the data and made them available for the analysis. Their careful work is greatly appreciated.

## REFERENCES

De Quervain, M. and R. Meister. 1987. 50 years of snow profiles on the Weissfluhjoch and relations to the surrounding avalanche activity (1936/37-1985/86). *IAHS Publ. No.* **162**, 161-181.

Ferguson, S.A. 1984. *The role of snowpack structure in avalanching.* Ph.D. Thesis, University of Washington, Seattle WA, U.S.A., 150 pp.

Föhn, P.M.B. 1993. Characteristics of weak snow layers or interfaces. Proceedings of the International Snow Science Workshop, Breckenridge, Colorado, U.S.A., 4-8 October 1992, 160-170.

Jamieson, J.B. 1995. *Avalanche prediction for persistent snow slabs.* Ph.D. Thesis, Uni-versity of Calgary, Calgary AB, Canada.

Jamieson, J.B. and T. Geldsetzer. 1996. *Avalanche accidents in Canada - Vol. 4: 1984-1996.* Canadian Avalanche Association. Revelstoke BC, Canada.

McClung, D.M. and P. Schaerer. 1993. *The avalanche handbook.* The Mountaineer, Seattle, U.S.A.

Perla, R. 1977. Slab avalanche measurements. Can. Geotech.J., **14**, 206-213.

Schweizer, J. 1993. The influence of the layered character of the snow cover on the triggering of slab avalanches. *Ann. Glaciol.*, **18**, 193-198.

Schweizer, J., P. Föhn und C. Plüss. 1992. COGENSYS™ Judgment Processor (Paradocs) als Hilfsmittel für die Lawinenwarnung. Eidgenössisches Institut für Schnee- und Lawinenforschung, Weissfluhjoch/Davos, Switzerland, Internal report, **675**, 33 pp.

Schweizer, J., C. Camponovo, C. Fierz and P.M.B. Föhn 1995. Skier triggered slab avalanche release - some practical implications. In: Proc. Int. Symp.: *Sciences and mountain - The contribution of scientific research to snow, ice and avalanche safety.* ANENA, Chamonix, 30 May - 3 June 1995. 309-315.

Schweizer, J. and M. Lütschg. 1999. Human triggered avalanches – Characteristics from the Swiss Alps 1987-88 to 1996-97. Eidgenössisches Institut für Schnee- und Lawinenforschung, Davos, Switzerland. Internal Report, **734**, 30 pp.

Schweizer, J. and J.B. Jamieson. 2000. Field observations of skier triggered avalanches. Proceedings International Snow Science Workshop, Big Sky, Montana, U.S.A., 2-6 October 2000, this issue.

Stoffel, A., R. Meister and J. Schweizer. 1998. Spatial characteristics of avalanche activity in an Alpine valley – a GIS approach. *Ann. Glaciol.*, **26**, 329-336.

Tschirky, F., B. Brabec and M. Kern. 2000. Avalanche rescue systems in Switzerland: Experience and limitations. Proceedings International Snow Science Workshop, BigSky, Montana, U.S.A., 2-6 October 2000, this issue.

Wiesinger, T. and J. Schweizer. 2000. Snow profile interpretation. Proceedings International Snow Science Workshop, Big Sky, Montana, U.S.A., 2-6 October 2000, this issue.