Avalanche incidents in Switzerland in relation to the predicted danger degree

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Abstract: All known avalanche incidents from 1987/88 to 1998/99 (12 years) have been analysed with respect to the scale of avalanche danger of the Swiss avalanche bulletin (European danger scale 1-5). The database contains information of 1800 avalanches causing damage to people and property. 45 % of fatal avalanche accidents occurred at danger degree "considerable" (level 3), 30 % happened at "moderate" (level 2). The mean size of the spontaneous avalanches causing an incident increases with the danger degree. For degree "low", "moderate" and "considerable" the fracture depth is 50 to 60 cm, for "high" and "very high" the depth is 150 cm. On the other side for human-triggered avalanche accidents, the avalanche size and fracture depth does not depend on the danger degree level. The inclination of the starting zone of these avalanches is 39° for all danger levels except level "low", where it is 41°. At danger level "considerable" 24 % of all human-triggered avalanches occur under 35° inclination, at "moderate" there are 18 %. Human-triggered avalanche accidents are more or less the same size and occur in similar terrain independent of the avalanche danger degree. Most avalanche accidents on ski tours and most accidents with experienced people occur at level 2 ("moderate"). The largest number of avalanche accidents in out-of-bound terrain (off piste) happens at level 3 ("considerable"). The ratio between the number of injured or killed people to the number of days at which a given danger degree occurred can be used as a risk index". It turns out to increase exponentially with the danger degree.

Keywords: avalanche accident, avalanche incident, avalanche accident statistics, avalanche forecast, avalanche bulletin, avalanche danger degree.

1. Introduction

In the last years an avalanche data base was developed at the Swiss Federal Institute for Snow and Avalanche Research (SFISAR). This unique data base contains all known naturally triggered avalanches causing damage over the last 100 years and all human triggered avalanche incidents in back country terrain of the last 30 years. It contains totally around 11'000 datasets.

The predicted avalanche danger degree of the Swiss avalanche bulletin published by the Swiss avalanche warning service is also stored over 12 years in a data base. This makes all sorts of comparisons possible between avalanche incidents and forecasted danger degree over 12 years (for a description of the danger degrees and products of the Swiss avalanche warning service see Ammann, 1998). The current study includes partly the same data as in Schweizer et al. (2000) and Tschirky et al. (2000). But for the first time a large data set of avalanche incidents in controlled and uncontrolled terrain could be compared with the predicted avalanche danger degree. In this paper detailed investigations of recreational avalanche accidents (back country terrain) for each danger degree are presented (Harvey, 2002).

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2. Overview: Avalanche forecast and incidents

During 12 years (1988-1999), for 45 % of the days danger degree 2 (moderate) was predicted, for 30 % it was 3 (considerable) (Figure 1).

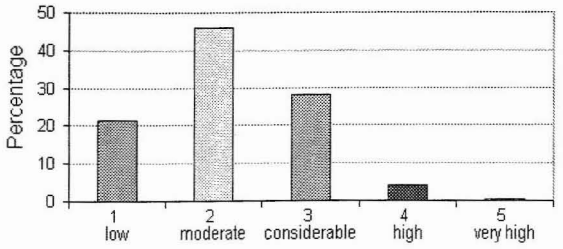


Figure 1: Frequency of the five avalanche danger degrees 1988 to 1999 (12 years).

For statistical evaluation in this study all avalanches causing damage from 1988 to 1999 were analysed by size. Further, a more detailed analysis was made for recreational avalanche accidents. These include all avalanches where people (skiers, snowboarders, mountaineers,...) got caught in back country terrain (tours and off-piste). 95 % were human, 5 % naturally triggered. Typical danger degrees for recreational accidents were level "moderate" and "considerable", where as all avalanches causing damage to property are settled at danger degrees "considerable", "high" and "very high" (Figure 2).

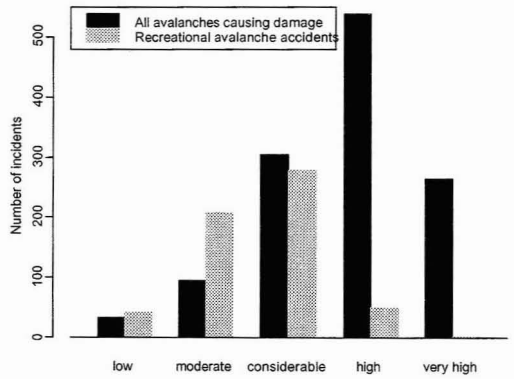


Figure 2: Avalanches causing damage 1988 to 1999 (12 years).

In the period between the winters 1987/88 and 1998/99 23 people were killed yearly by avalanches. In the long-time mean over 63 years the number of fatalities is 25. Since 1987 most fatal avalanche incidents occur at danger degree "considerable" (45 %; Figure 3). 87 % of the people were killed in back country terrain.

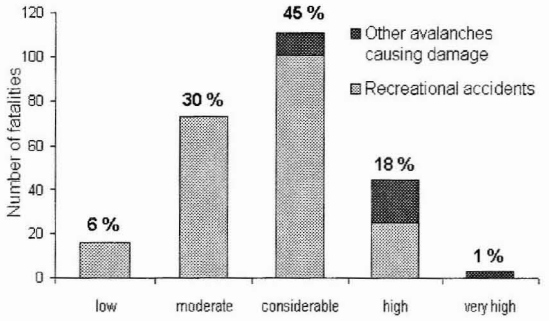


Figure 3: Number of fatalities for each danger degree during the period between the winters 1987/88 and 1998/99. Total number of fatalities during the forecasting periods: 248 (Recreational accidents: 215, others: 33).

About 30 % of all avalanches causing damage to people are fatal. For danger degree "high" and "very high" the percentage is a little higher than for the other danger degrees (Figure 4).

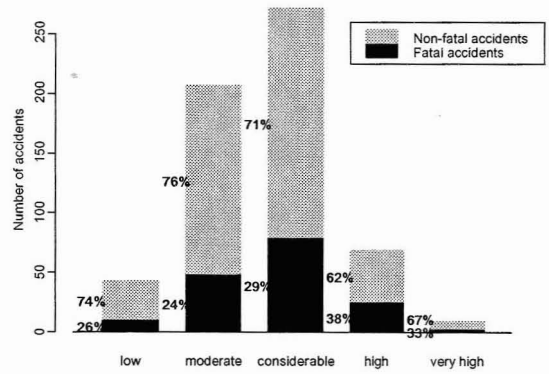


Figure 4: Avalanches causing damage to people 1988 to 1999 (12 years).

3. *Avalanche Size*

3.1 All avalanches causing damage

As shown in Figures 5-7 the avalanche size of all avalanches incidents increases with the avalanche danger degree. Significant differences of the parameters length, width and depth of fracture can be found between danger degree "considerable" and "high". For danger degree "high" and "very high" median length is around 1500 m, width around 200 m and depth of fracture 150 cm.

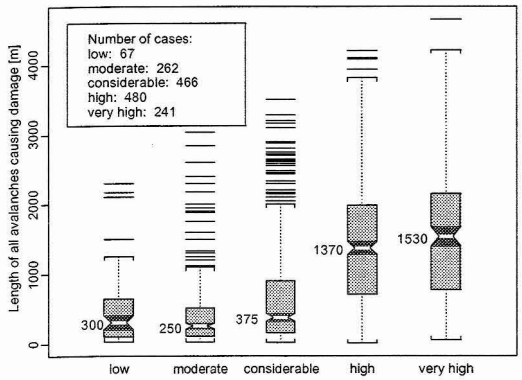


Figure 5: Length of all avalanches causing damage 1988 to 1999 (12 years).

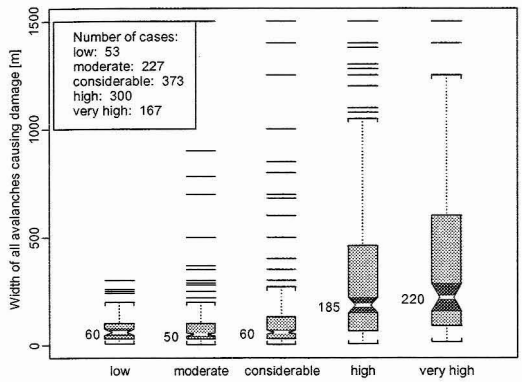


Figure 6: Width of all avalanches causing damage 1988 to 1999 (12 years).

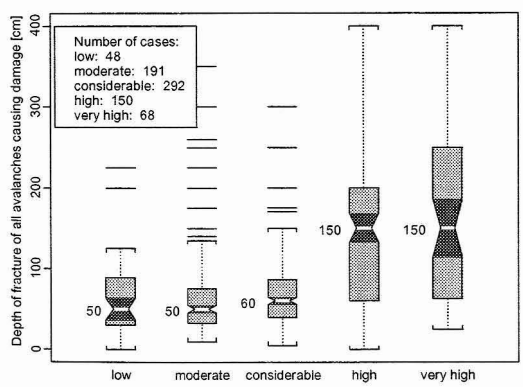


Figure 7: Depth of fracture of all avalanches causing damage 1988 to 1999 (12 years).

At degrees "low" to "considerable" the typical length of avalanche incidents is around 300 m, width around 60 m and fracture depth 50 cm.

3.2 Recreational avalanche accidents

The avalanche size of nearly 500 recreational avalanche accidents is different from the size of all avalanches causing damage. Length, width and depth of fracture are practically the same for all danger degrees ("low" to "high"). Median length is about 200 m, width 60 m and depth of fracture 50 cm (Figure 8-10).

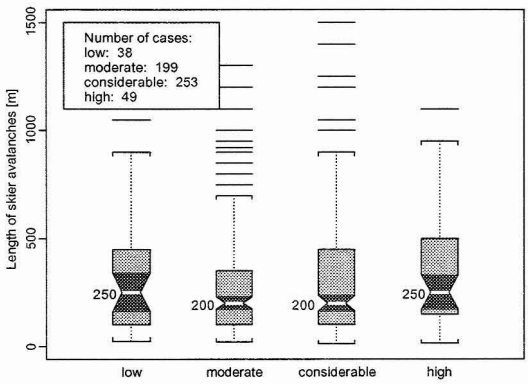


Figure 8: Length of recreational avalanche accidents 1988 to 1999 (12 years).

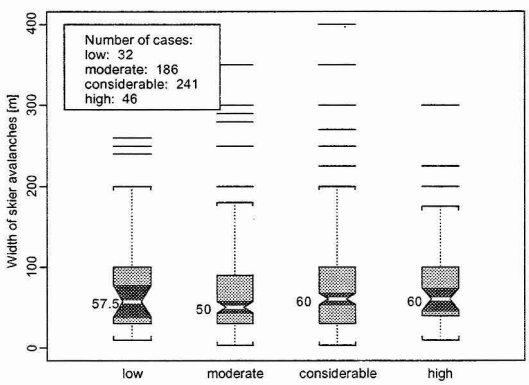


Figure 9: Width of recreational avalanche accidents 1988 to 1999 (12 years).

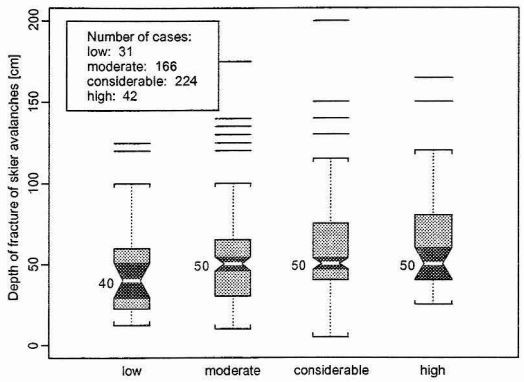


Figure 10: Depth of fracture of recreational avalanche accidents 1988 to 1999 (12 years).

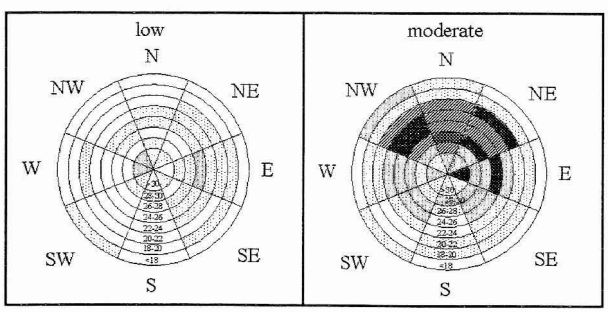
4. Characteristics of recreational avalanche accidents for different danger degrees

The comparison with the predicted avalanche danger degree had to be done without danger level "very high" because of insufficient number of accidents. McClung (2000) analysed fatal accidents of a 10 year database with the five-part-public-danger scale and concluded, that a four-level danger scale is sufficient for back country applications.

582 incidents of recreational avalanche accidents could be analysed with regard to terrain features (aspect, altitude, slope inclination, slope shape).

4.1 Aspect and altitude

At all danger degrees recreational accidents occur mostly in northern aspects. The mean altitude of the fracture line drops the higher the danger level gets. At "considerable" the slice of the aspect circle reaches from West over North to Southeast with a mean altitude of 2440 m above see level (a.s.l.). For "moderate" the aspect slice is tinier (manly Northwest over North to East). The mean altitude a.s.l. is higher and lies at 2560 m (Figure 11).



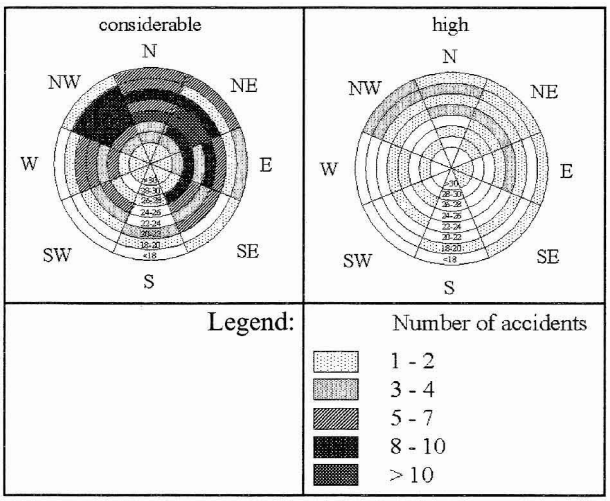


Figure 11: Aspect and altitude for recreational avalanche accident at each danger degree 1988 to 1999 (12 years). (The altitudinal belts are specified in 100 m steps: e.g. 22 correspond to 2200 m a.s.l.). Total number of cases considered: 575

4.2 Slope inclination

Slope inclination is an important key parameter for judgement of avalanche danger. As in the studies of Munter (1997) the slope inclination was measured in the steepest part of the slope out of the Swiss topographical map 1:25'000. For danger degrees "moderate", "considerable" and "high" the median inclination is 39 °, for "low" it is 41 °. At "moderate" danger 18 % of recreational avalanche accidents are less steep than 35 °, at "considerable" its 24 % (Figure 12).

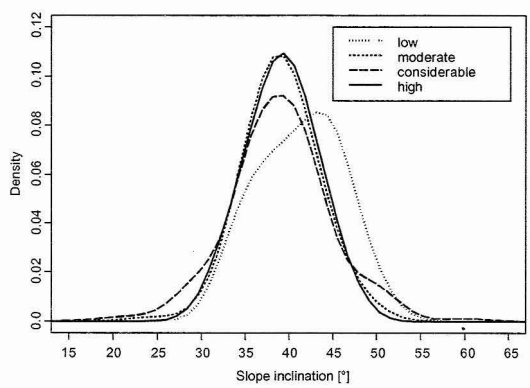


Figure 12: Density of slope inclination of recreational avalanche accident for the avalanche danger degree "low" to "high". The steepest part of the slope of recreational avalanche accidents is for all danger degrees roughly the same. However the trigger probability and the distribution of danger spots are different for each danger degree.

4.3 Slope shape

Recreational avalanche accidents happen in similar slope shapes, independent of the danger degree. About 80 % of the terrains are bowls, gully, rocky terrain (rocks looking out of snow cover) and areas close to ridge top. Only 20 % of the accidents happen in open slope terrain without any special features.

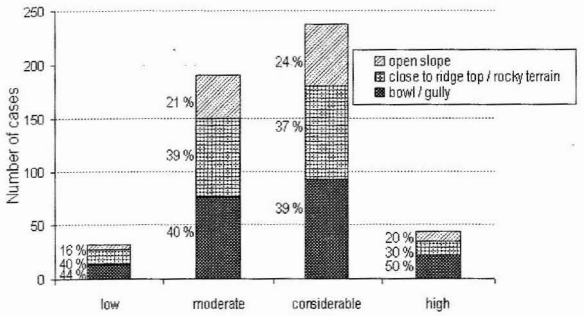


Figure 13: Frequency of slope shapes for each danger degree.

5. Risk Index

With the division of the number of caught people (Figure 14) by the frequency of the avalanche danger degrees over 12 years (Figure 1) a simple risk index (Engler et al., 2001) was calculated for a probable occurrence for damage to people (Figure 15). For all avalanches causing damage to people the ratio turns out to increase exponentially with the danger degree. The individual risk for a single person at each danger level would be very interesting to know, but for this purpose the number of people in potential avalanche areas would be required.

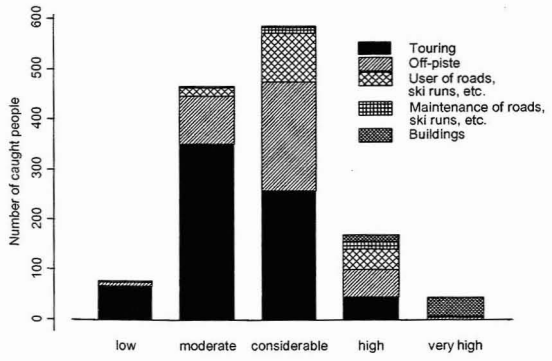


Figure 14: Number of caught people in avalanches at the five avalanche danger degrees over 12 years (dead and surviving people). Total number of people caught: 1341.

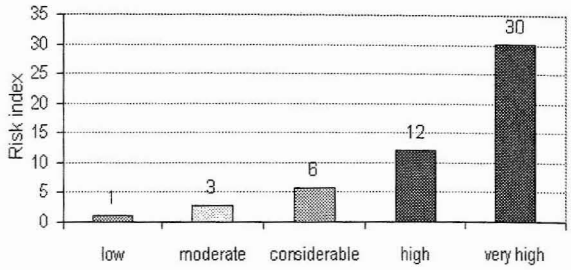


Figure 15: Risk index for the occurrence of damage to people. (Ratio of number of caught people (survived or dead) to frequency of avalanche danger degree).

The risk index was also calculated for people caught in recreational avalanche accidents. The index-calculation was split up in tours and off-piste activities. At "moderate" danger degree most people get caught on ski tours where the majority of off-piste-skiers cause avalanche accidents at level "considerable" (Figure 14). 2/3 of people doing winter sports get caught on ski tours, 1/3 while off-piste-skiing (Signorell, 2001). The risk index for people being caught in back country terrain increases exponentially for activities in off-piste terrain, where as the index for ski touring grows linear (Figure 16). With the actual behaviour of people doing winter sports in back country terrain, off-piste-skiing is saver at level "low" and "moderate" than touring. Unfortunately the number of people doing ski tours and off-piste-skiing at the different danger degrees is not available. Therefore the risk index should be understood as an index and not as an individual risk for a single person.

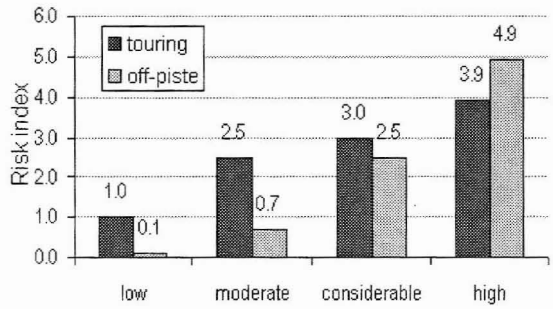


Figure 16: Risk index for damage to people doing winter sport on tours and off-piste. For comparison the touring-risk-index for degree low was set to one and the other indices were adapted accordingly.

6. Conclusions

Recreational avalanche accidents are, at all avalanche danger levels, very similar in size (length, width and depth of fracture) and in characteristics of terrain (slope inclination, aspect and slope shape). Independently of the danger degree the typical avalanche slope is 35 ° to 40 ° steep, northern aspect and bowl-shaped or close to ridge top. Obvious differences between danger degrees occur only in the frequency of accidents and the altitude above see leve. Certainly varieties exist for the trigger probability and the behaviour of people in back country terrain at each danger degree. But in this investigation these parameters were not available. For this reason we can not conclude, that steep slopes are the same risky at all danger levels. The following points must be considered:

a) The steeper a "skiable" slope the higher is the trigger probability for a slab avalanche.

b) At lower danger degrees the trigger probability for slab avalanches decreases and danger spots are less widespread.

Especially for ski touring at danger degree "moderate" many avalanche accidents happen. The risk index for this category is not much different to the one at degree "considerable". One of the reasons can be a much more careful behaviour at "considerable" than at "moderate", where first of all more people are touring in back country terrain and second typical avalanche slopes get touched more often. Furthermore the danger degree "moderate" is very difficult to judge in avalanche terrain and should not be underestimated. Most accidents with experienced people (like mountain guides) happen at this danger level.

7. References

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