

## Snow Avalanches

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### 9.1 Introduction

Snow avalanches represent a threat to societies in many countries of the world. In America, Asia, Australia, and Europe, several mountainous countries are affected by this type of natural hazard. People, housing areas, communication lines, ski areas, animals, and woodland are subjected to the threat of snow avalanches.

On a world basis, snow avalanches do not represent the most serious natural hazard, but in many mountainous areas of the world, snow avalanches are the most frequent and most serious natural hazard.

Every year in Europe, all the Alpine countries including Switzerland, Austria, Italy and France report fatal accidents and major material damage caused by snow avalanches. Other countries like Spain, Russia, Iceland, Sweden and Norway are also affected.

The best known country with snow avalanches is probably Switzerland, not only because of many disasters, but also because of the extensive snow avalanche research that has been performed for more than 60 years. Statistics from Switzerland indicate that about 25 persons per year are killed in snow avalanche accidents, and about twenty living houses are damaged each year on average. Nearly 100 other kinds of buildings are affected each year. In addition, several roads are closed each winter. Apart from the loss of lives, the total material damage in Switzerland added up to SFR 10 million in 1972, or ECU 6 million. The corresponding value for 1998 might be about ECU 40–50 million, which is a considerable amount of money.

Presently, Switzerland uses SFR 26 million (ECU 15 million) per year in research and snow avalanche protection (Föhn 1998, personal communication).

In Austria, snow avalanches are a major natural hazard. Every year, Austrian society spends about 1 200 million Austrian Shillings, (ECU 100 million) on avalanche and torrent control, and 250–300 million Austrian Shillings, (ECU 22–26 million) on snow avalanche control. Like in Switzerland, 20–25 persons are killed by avalanches on a yearly basis. Most of these are ski tourists (Hopf 1998, personal communication).

The most serious avalanche winter in the Alps in this century was in the winter of 1950/51. In Switzerland, 100 persons were killed, and in Austria, 135 lost their lives. Another catastrophic winter occurred in 1954 when 143 persons were killed in Austria, most of them in Vorarlberg.

In Iceland, another heavily affected country, 64 people have been killed in snow avalanches and slush floods since 1974, two persons per year on average. Fifty-two of

these people were killed in buildings, most of them in three major disasters (Johannesson et al. 1996). In one of these accidents, twenty persons were killed in the small town of Flateyri by one single avalanche. The total material loss is estimated to be ECU 50 million since 1974. When the loss of lives is included in the costs, the cost increases to ECU 130 million. The estimated value of one human life is set to ECU 1.25 million. This value is based on figures from different countries in western Europe of what society is willing to spend on life-saving operations.

In Norway, about five persons are killed every year in snow avalanches. In this country, major avalanche winters seem to occur every thirteen years on average. In such major avalanche winters, ten to twenty persons are killed, and material damage is on the order of NOK 100–200 million (ECU 12.5–25 million).

In 1868, 161 persons were killed by avalanches in Norway. In the winter of 1986, 22 persons were killed; sixteen of these were soldiers taking part in a military exercise.

In conclusion, one may summarise the effects and consequences of snow avalanches on society to:

1. Loss of human lives
2. Material damage
3. Forest damage
4. Illness, sickness, and reduced physical health
5. Traumatic effects and reduced psychological health
6. Evacuation costs
7. Rescue and preparedness operations
8. Traffic delay and detours.

Who are affected by avalanche accidents? In brief, the following categories can be included:

- People dwelling in houses
- Persons in huts and other kinds of buildings
- Road and railway users
- Maintenance personnel
- Construction workers
- Military personnel
- Ski tourists
- Climbers
- Hunters
- Snow vehicle drivers
- Domestic and wild animals

In earlier years, most of the avalanche victims were hit in their homes or in other kinds of buildings. In the later decades, an increasing percentage of ski tourists have been killed, and presently the majority of accidents include ski tourists.

## 9.2 Avalanche Formation

In avalanche formation, three factors are important:

- Topography
- Snow pack
- Weather conditions

### 9.2.1 Avalanche Topography

Avalanche topography shows a great diversity in land forms. The vertical height of avalanche slopes ranges from more than 2 000 m down to 10 m. An avalanche may be more than 1 000 m broad and 3 000 m long, and contain more than 1 million m<sup>3</sup> of snow. On the other hand, avalanches released from slopes with vertical drop less than 10 m may be lethal.

An avalanche path is usually divided into three zones (Fig. 9.1):

1. Starting zone
2. Track
3. Runout zone

#### 9.2.1.1 Starting Zone

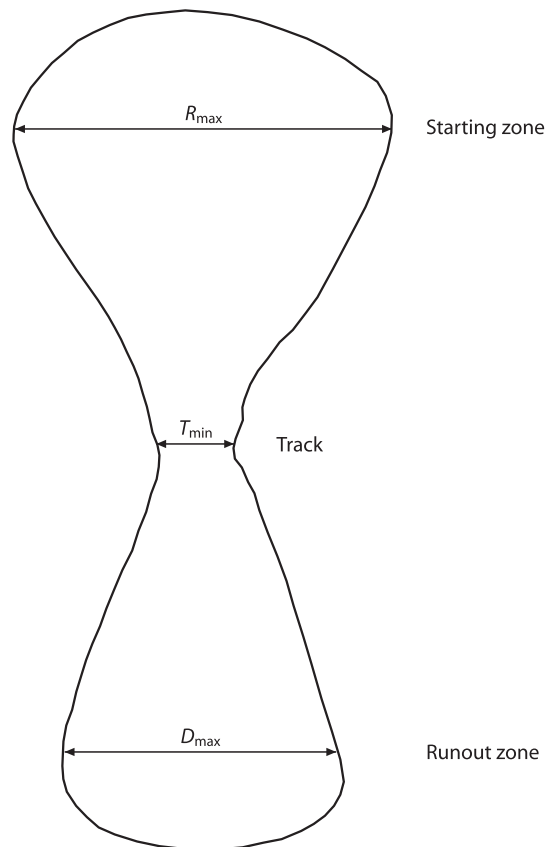
Normally, avalanches that are big enough to create danger and damage are released in slopes with inclinations between 30° and 50° (Fig. 9.2). If the slope is gentler than 30°, the friction forces are big enough to hold the snow cover in place; if it is steeper than 50°, the snow glides off in small portions or sloughs during the accumulation.

For practical purposes, one may say that all slopes and mountain sides within the mentioned limits of inclination are potentially dangerous, if the slope is not covered by dense tree growth or big boulders and other kinds of rough topography that is not covered by snow during the winter.

The starting zone may be more than 1 000 m wide, and down 20–30 m. The starting zones are usually found in terrain formation where abundant snow is collected. This usually includes all kinds of depressions where snow deposition is heavier than elsewhere because of the lee effect. As the wind blows across a mountain slope, snow is eroded away from wind-exposed areas and deposited in areas where the wind velocity is low. The most common types of starting zones are:

- Cirques, formed by earlier glaciation
- Open, shallow depressions
- Deeply incised scars and gullies
- Plane rock faces
- Convex land forms

**Fig. 9.1.** Zones of an avalanche path



### 9.2.1.2

#### **Track**

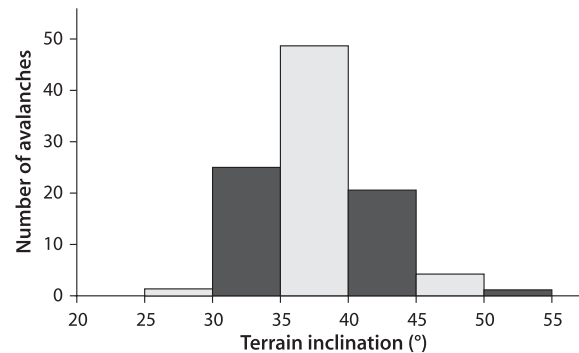
When the terrain inclination is between  $30^\circ$  and  $10\text{--}15^\circ$ , the part of the path is defined as the avalanche track. The track is usually more narrow than the starting zone, as the avalanche normally starts in a relatively wide area and is confined into a narrow track. The track is often a river course, a scar or some kind of depression, but open flat portions of slopes are also seen. Many avalanches are unconfined, as they run in a constant width from start to stop.

### 9.2.1.3

#### **Runout Zone**

In the runout zone, the terrain inclination is less than the friction angle of the snow, and the avalanche is slowed down and gradually comes to rest. Many runout zones are found on river fans, others in flat valley bottoms. The runout lengths of major avalanches are usually several hundred metres, and sometimes big avalanches have

**Fig. 9.2.** Relation between avalanche frequency and terrain inclination



their runout on the opposite mountainside. Major dry avalanches usually obtain the longest runouts on gentle inclined terrain, mostly less than  $10^\circ$ . In wet snow avalanches, the friction resistance is higher, and such avalanches usually come to rest at inclinations between  $10^\circ$  and  $20^\circ$ , depending on the roughness of the terrain and the volume of the avalanche snow.

### 9.2.2 Snow Pack

The typical snow-pack structure related to an avalanche situation is the following:

1. Older snow with high density and strength near the ground.
2. Thin weak-layer with little strength covering the old snow.
3. New snow, moderately wind packed, 0.5–1.5 m thick at the top.

The rupture is commonly thought to occur as a shear failure in the weak layer, followed by a tension failure at the top of the snow slab (Fig. 9.3). Experience has proved that high intensities of snow accumulation in the rupture zone increase the possibility for a failure. Based on a Coulomb-friction criterion for the slab and measured figures for cohesion, it is difficult to obtain a failure for evenly distributed shear stress values. The deformation velocity of the uppermost layer is of vital importance for the stability, as the shear strength will drop to residual values, which are pronounced lower than the peak strength for high deformation rates (Fig. 9.4). In nature, the deformation rates are found to be too low to create a failure without the existence of stress concentrations in the snow cover. Such stress concentrations must be located to superweak spots in the weak layer where the rupture is initiated. The stress concentration increase with the size of the superweak spot or layer, and is inversely proportional to the thickness (Fig. 9.5).

Access to the starting zones with measurements of the weak layers in an avalanche situation is hazardous and for practical purposes not possible. All measurements and evaluations must therefore be performed in areas with different snow and terrain conditions than in the actual rupture area. The evaluation of the snow-pack stability is therefore even today based on subjective methods and practical experience.