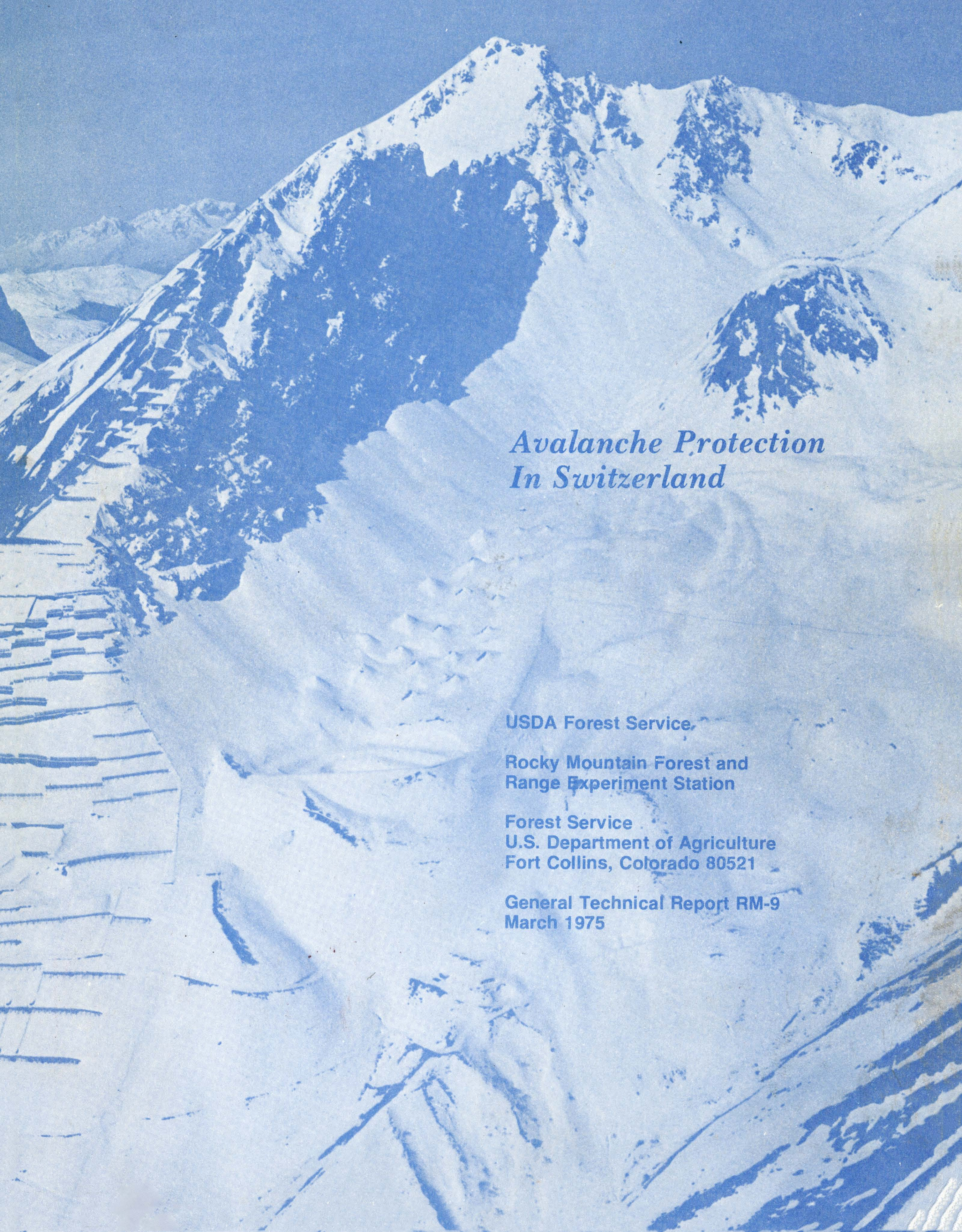

Avalanche Protection In Switzerland

USDA Forest Service

Rocky Mountain Forest and Range Experiment Station

Forest Service
U.S. Department of Agriculture
Fort Collins, Colorado 80521

General Technical Report RM-9
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This translation of a collection of 16 articles by Swiss avalanche experts summarizes the current state-of-the-art of structural control of avalanches in Europe. It includes articles on avalanche formation, damage, and protective measures, and supporting, deflecting, and retarding structures.

Front Cover. Schiahorn/Davos: supporting structures on the left, Dorftaeli retarding and catchment structures in the middle of the picture (photo E. Wengi).

ACKNOWLEDGMENTS

We sincerely thank Mr. G. Bavier, President Administrative Commission and the editors of "Buendnerwald" for permission to translate this series of articles into English. We also want to thank Dr. M. de Quervain, Director Swiss Federal Institute for Snow and Avalanche Research (SLF), for his help contacting the proper organizations and individuals to gain this permission. U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) provided a preliminary English translation which in a few cases was reviewed by the original authors. Mr. Hans Frutiger of the SLF reviewed the English version of his article and provided many helpful suggestions. Dr. Hans Keller, on educational leave in Fort Collins from the Swiss Forest Research Institute, was of great help with many technical terms and in smoothing the English. Mr. E. Wengi of the SLF kindly furnished extra prints of several key photographs including the front cover picture. Any errors or inconsistencies that still exist in spite of the above help remain my responsibility.

M. MARTINELLI, JR.
Project Leader
Alpine Snow and Avalanche Research

AVALANCHE PROTECTION IN SWITZERLAND (LAWINENSCHUTZ IN DER SCHWEIZ)

[Supplement No. 9 to Buendnerwald, journal of the Braubuenden Foresters Association and of SELVA, Association of Graubuenden Wood Producers, German, December 1972]

The administrative commission of the technical journal Buendnerwald takes special pleasure in issuing this supplement "Avalanche Protection in Switzerland." An ad hoc editorial commission, consisting of forestry engineers F. Castelberg, H. R. in der Gand, F. Pfister, and B. Rageth, and the undersigned have striven to present the entire complex area of avalanche protection as comprehensively and clearly as possible. Publication of the supplement would not have been possible without the intensive cooperation of the Federal Institute for Snow and Avalanche Research, Weissfluhjoch-Davos, or without the substantial financial support provided by the Swiss Foundation for the Promotion of Forests and Wood Research in the Canton of Graubuenden.

All those who have cooperated in any way in preparing and publishing this supplement merit our warmest thanks.

Chur, December 1972

Buendnerwald Administrative Commission
The President:
G. Bavier

FOREWORD

The first prerequisite for settlement of a mountainous region is the protection of its communities and transportation facilities against more or less predictable and recurrent catastrophes. As the most important of these preventive and protective measures, avalanche defense continuously acquires increased significance. Both the maintenance of individual mountain communities and the development of entire valleys in the alpine area depend upon it. From the total economic point of view, avalanche construction represents more than merely a local protective device: it is a part of the infrastructure of the mountain region and has become a sort of social security for the mountain population. Does not everyone have a right to minimal protection in his living space? Avalanche defense is a duty of the community.

As a result of the rapid development of travel from abroad and winter sports activities, avalanche control has become even more important. More and more people are entering into regions exposed to avalanche risk or into their vicinity. Fundamentally, it is man himself who increases the risks in his environment and endangers his own safety. Apart from periodic variations, the number of avalanches is not increasing but rather it is the number of risk-exposed people; and at the same time we are becoming more demanding with respect to our personal safety.

Avalanche control is not only the concern of the professional specialist; he himself must work in cooperation with the population and with the authorities. The latter must approve and finance projects. On the other hand these projects are a constituent of local and regional planning. They influence the utilization of ground space. Information, public education, together with mutual understanding and cooperation on the part of all participants are prerequisites of success in any undertaking. Furtherance of such interplay of a broad public is the task and at the same time the reward of this supplement to Buendnerwald, which is not directed just toward the forester and forest owner.

We here extend our thanks to the specialists in avalanche control who try to carry out their often dangerous task on steep slopes, precipices, and overhanging rocks near the upper tree line, unobserved, in a spirit of modesty and self-sacrifice.

Bern, December 1972

M. de Coulon
Chief Federal
Forest Inspector

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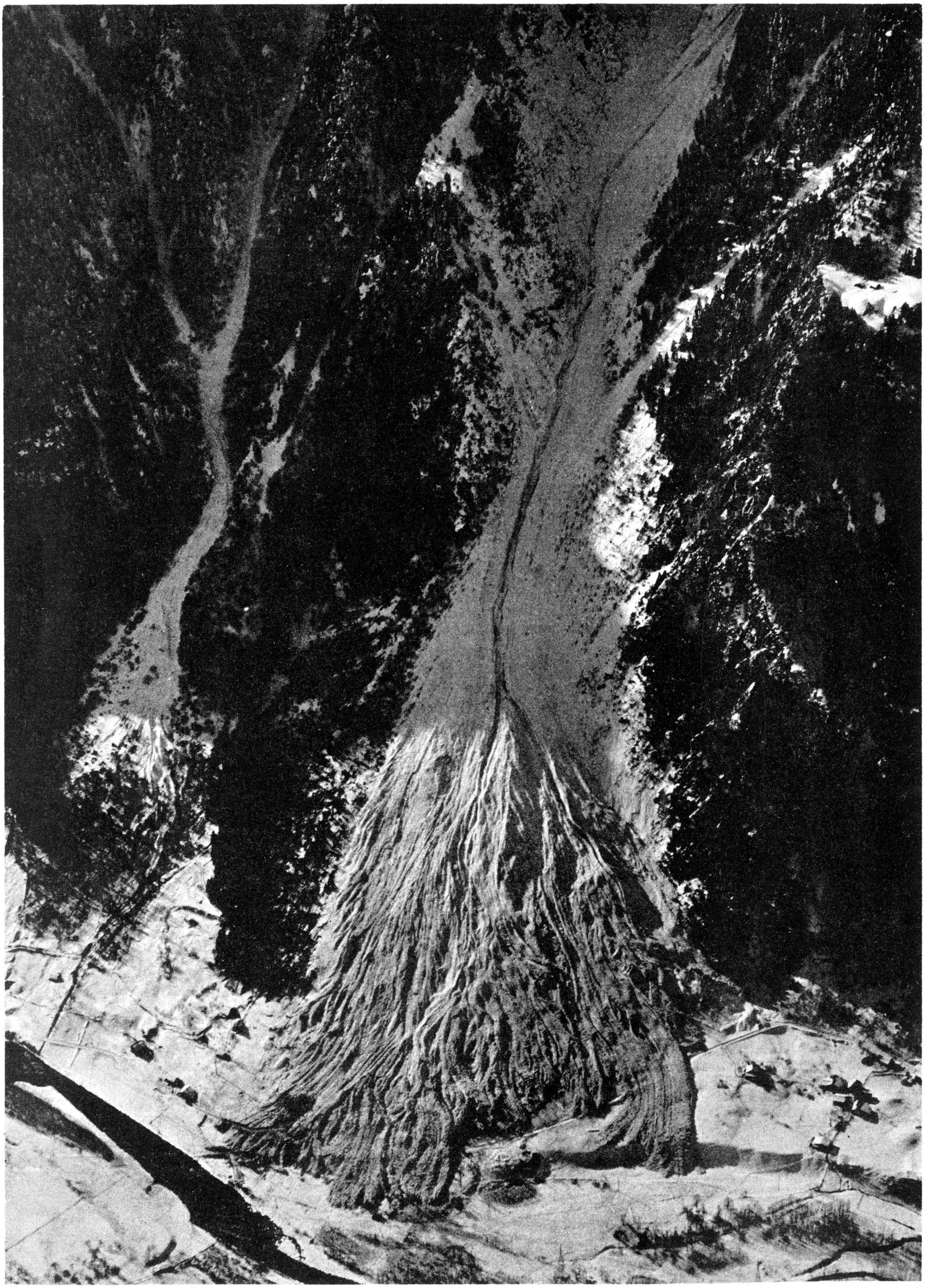

Figure 1.

I. AVALANCHE DAMAGE
(Karl Breu, Switzerland)

1. Introduction

J. Coaz, the Old Master of avalanche control, in his book Avalanches in the Swiss Alps, Bern, 1881, describes avalanche damage as follows: "The damage produced by avalanches consists essentially in tearing up rock and soil, in destruction of grazing lands and forests, of structures, enclosed areas, roads, and finally in the endangerment of men and animals." There is little to add to this enumeration and there would probably be little advantage in classifying here the possible varieties of damage.

Probably of more interest would be:

--the description of episodes of damage,
--the numerical evaluation of damage,
--the investigation of causes,
--conclusions.

2. Examples of Destructive Avalanches

2.1 Wilerlaui Near Silenen in the Cantons of Uri, Unterwalden (Figure 1, photo W. Friedli)

The avalanche came down on 27 January 1968 at about 0610 hours. The avalanche debris cone was 500-600 m wide at the end of the tongue. The snow masses lay in part up to a height of 10 m. The avalanche swept away a dwelling and a stable. A farmer lost his wife and all five children, the neighboring family lost its breadwinner. The picture shows clearly that other buildings of the Weiler Rueti have been severely damaged. The Wilerlaui avalanche comes down several times every winter into the valley without doing any great damage. In 1968 it came down with such force that there was no more room for it in the avalanche track and it pressed up over the edges of the channelized track.

2.2 Motta Avalanche in Partenen, Montafon (Figure 2, photo Illwerk, Vorarlberg)

The avalanche came down on 27 January 1968 at 1058 hours. A fir log (diameter 50 cm) penetrated the house in the second floor along its entire width, penetrated the outer wall (wall thickness 43 cm) into the children's room, broke through the center wall (wall thickness 20 cm), then crossed the adjacent parents' bedroom, broke through the valleyside outer wall (wall thickness 43 cm) and extended 2 m in addition above the outer wall. The outer walls consisted of brickwork. The avalanche destroyed centuries-old alpine huts and forests lying in its path. One house was completely destroyed, five houses severely damaged, and three houses slightly damaged. There were no personal injuries since the inhabitants had been promptly evacuated.

2.3 Dorfbach Avalanche Davos (Figure 3, photo E. Wengi)

The avalanche came down on 26 January 1968 at 2240 hours from the east flank of the Schiahorn. In the late afternoon of the 26th of January the local authorities ordered evacuation of a part of the Egga and Boedenhaeuser. It was thanks to these measures that no more persons were injured. Four persons were killed, nine houses and two garages totally destroyed as well as a bridge of the DPB and a crane and transport car of the Davos-Parsenn railway. Twenty additional houses were damaged. From 1956 on, several dwelling houses had been built in the area on the Egga and in the Boeden. An avalanche of this magnitude was a surprise to everyone. At the steep edges of the Dorfbach Gorge, to a point high up the mountain, old larch trees and firs were dragged along and the iron bridge of the Parsenn railway carried for a distance of nearly 300 m.

2.4 Forest-Destructive Avalanche of Vinadi, Lower Engadin (Figure 4, photo Military Aviation Service)

The avalanche descended in the forenoon of 18 February 1962 from the ESE flanks of Piz Mundin and Piz Alpetta. In three arms it poured into the Inn [River] which lay about 2,000 m further down. The 120- to 130-year-old highland forest suffered total destruction of 90 to 100 hectares. About 20,000 m^3 of timber were knocked down. Additional damage occurred on the Austrian side of the Inn. It apparently involved the worst known instance of forest

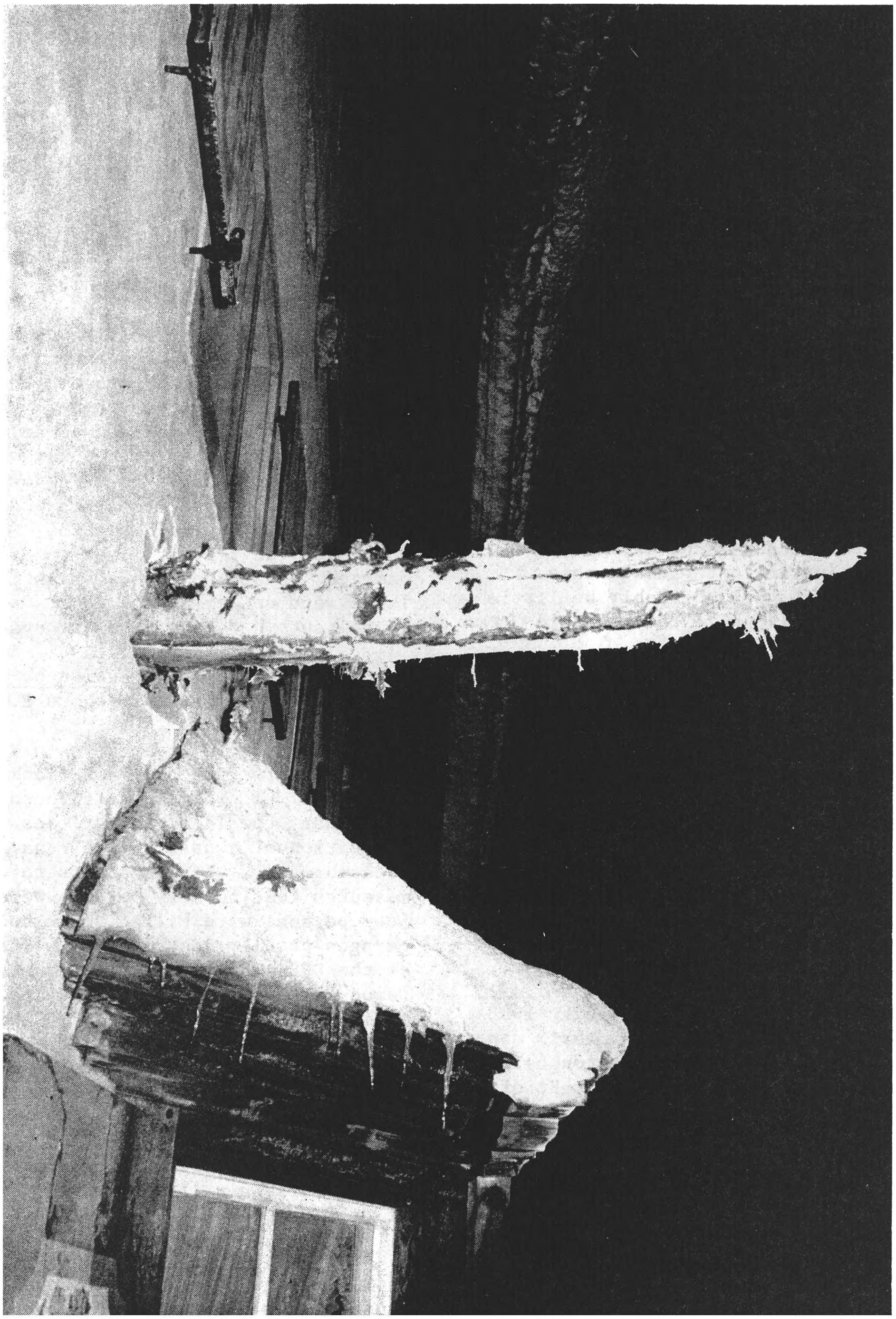

Figure 2.

destruction caused by an avalanche. The national highway was closed for several months.

The length of the avalanche along the slope was about 3.6 km, the mean width 1.5 km. The area was about 5.5 km^2.

2.5 Vallascia Avalanche, Airolo
(Figure 5, photo A. Roch)

The Vallascia avalanche, on the 12th of February 1951, 0045 hours, drove into the hamlet of Airolo with a deep rumbling, cracking,

Figure 3.

and crashing. Eleven houses, 11 stables, and a cabinetmaker's workshop were totally buried and an additional seven houses were partially buried. Of the 15 persons buried, 10 were recovered dead. Previously, the avalanche danger had been thought to be slight because the avalanches descending from the steep slopes of the Corna del Buco and from the Vallascia region seldom reached the hamlet. Only once, in the year 1923, had the Vallascia avalanche produced greater material damage.

3. Avalanche Damage Statistics

3.1 Deaths and Injuries

In the 30 winters from 1940/41 to 1969/70, there were 743 deaths [from this cause] in Switzerland. This is an average of 25 deaths per year. In the same period, 392 persons were injured. That is an average of 13 persons per year.

Figure 4.

In recent years, there has been a clear increase in avalanche accidents affecting skiers. As a result of increased opening up of the Alps and of the lower Alps, ever greater numbers of people are entering the mountains.

3.2 Damage to Buildings

In the 20 winters from 1950/51 to 1969/70, 403 houses were destroyed or damaged and in addition, 1,847 stables, hay-shacks, and alpine buildings.

3.3 Forests and Land Damage

In the 20 winters from 1950/51 to 1969/70 in Switzerland, around 2,550 hectares of forest were destroyed by avalanches. This is on the average of 120 hectares per year. The area of devastated alpine grazing land and meadows was probably about the same size.

3.4 Damage to Transportation Arteries

The damage to transportation arteries has been very great. There is first of all the cost of removing avalanche snow and of somewhat less significance is the damage to the roads and bridges. Even the most important north-south connection, the Gotthard road has not yet been rendered safe from avalanches.

3.5 Material Damage in the Avalanche Disaster in Reckingen

The material damage in the Reckingen avalanche disaster (27 February 1970) is given as 12.8 million francs not including personal damage. If we add to this the costs of necessary building, we get about 20 million francs without including personal damage.

3.6 Secondary Damage Caused by Avalanches

The accumulation of avalanche snow in streams can cause flow obstructions leading to water damage. Such a case occurred in the winter of 1963/64 in Bisisthal SZ, where the Muota washed out a street producing damage of 40,000 francs. The danger is particularly great in the case of streams which carry water only sporadically because of the presence of power plants.

3.7 Summary

For the period 1950/51 to 1969/70, avalanche damage can be estimated in terms of present monetary values, without including personal damage, but at the same time, including the cost of rescues, at an average of about 10 million francs per year. This figure includes damage to avalanche control measures but not the cost of new control measures.

4. The Causes of Avalanche Damage

Primarily, avalanche damage is caused by terrain and climate. Deforestation near the upper tree line, before the forest legislation came into effect, also definitely led to the formation of avalanche paths. In recent times, the dangers resulting from mass tourism (construction of houses in avalanche areas and increasing access to the mountains) must be added to the avalanche danger which was always present in the mountains. One cannot make a blanket condemnation of this development. Instead it must be controlled by means of suitable measures.

Figure 5.

5. Conclusions

The damage resulting from avalanches can be very great. Hence the great significance attached to protective measures. In spite of all efforts, avalanche damage cannot ever be entirely avoided. But, at an increasing cost, it must be reduced as much as possible because it continues to be true that "an ounce of prevention is worth a pound of cure."

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Adresse des Autors: Kreisoberförster K. Breu, Kreisforstamt 2, 6430 Schwyz

English Translation of German Titles

[1] The Avalanches of the Swiss Alps.
[2] Snow and Avalanches in the Swiss Alps.

II. AVALANCHE FORMATION (Marcel de Quervain, Weissfluhjoch/Davos)

1. Introduction

Basically two types of avalanche accidents must be distinguished: a human being, in his domicile or while moving about in settled or opened zones, can be surprised and buried by an avalanche breaking in upon him from high up above or, as a mountain climber, he may enter a dangerous starting zone and himself (generally) trigger the fatal avalanche. One distinguishes these two categories of disastrous avalanches -- or just plain "avalanche," without qualification -- as "catastrophic avalanches" and "touristic avalanches." These designations establish certain focal points; however, they are not always appropriate. Thus, in a period of heavy avalanche catastrophes, there are usually also minor avalanche descents into settled zones, while on the other hand touristic accidents may present catastrophic dimensions. In addition, among the "tourists" who get into avalanche emergencies, there are always the people who are patrolling avalanche-endangered terrain in the course of their professional duties.

Nevertheless, the distinction between these two types of accidents or avalanche situations is logical and useful since these situations generally occur separately with respect to time and place. When the conditions for great valley avalanches begin to ripen, the tourists have usually vanished from the starting zone regions since it is no longer possible to move about. On the other hand, it is precisely when snow is scanty (a time when large avalanches are out of the question) that experience has shown touristic accidents to be numerous.

In the following studies, the emphasis will be placed upon the origin of "catastrophic avalanches" since avalanche control concerns itself predominantly with this category.

2. The Snow Cover and Its Qualitative Development

Although catastrophic avalanche episodes are usually directly connected with heavy snowfalls, the condition of the old snow cover (and thus the entire winter starting with the first snow) plays a role. First we shall glance at the characteristics of new snow. It forms and falls under the most varied weather conditions: at air temperature that ranges (on the ground) from about -30° to $+5^{\circ}$, and at wind velocities from 0 to around 200 km/hr.

Wind turbulence leads to fragmentation of the original new snow crystals consisting of snow stars, platelets, needles, or irregular figures. Hence, the layered new snow can display a highly variable consistency from the outset, ranging from the lightest, fluffy, toothed, wild snow to brittle, fine-grained, stiff snow. Its density varies between 30 and 250 kg/m^3.

A rare type of snow appears on the surface after clear cold nights, namely flat crystals, often in a rosette arrangement. This is surface hoar which accumulates directly on the snow cover and in the course of a few days in shady hollows can develop into layers of several centimeters thickness.

Immediately after it deposits, new snow (especially the fluffy material at temperatures below 0°) undergoes so-called decomposition transformation [equi-temperature metamorphism].[1/] The substance first becomes felty and then round-grained and at the same time progressively increases in density (setting). The process is especially marked at temperatures slightly below the freezing point.

Independent of this and often progressing simultaneously, there is a constructive transformation [temperature-gradient metamorphism]. It is characterized by a general growth of selected snow grains with a change in their shape tending toward edged, planar forms. Reentrant angles and peculiar stepped surfaces appear, occasionally cup-shaped, hollow structures. In its final stage, such

1/ Decomposition transformation and constructive transformation are direct translations. These used to be referred to in English as destructive and constructive metamorphism. Now the processes are called equi-temperature metamorphism [ET metamorphism] and temperature gradient metamorphism [TG metamorphism]. The latter terms will be used in this translation.

snow is called depth hoar or sugar snow. TG metamorphism is a consequence of a temperature drop in the snow and presupposes air permeability. Ice sublimates from warmer snow particles and condenses on neighboring colder particles so that the latter grow at expense of the former.

If snow is warmed by warm air or by radiation to the point of melting and is subsequently cooled again, it is transformed into a round-grained adhesive material (melting transformation [melt-freeze metamorphism], formation of glacial ice). Figure 1 shows the three types of metamorphism.

Normally, the snow surface is colder than deeper snow layers. And after clear nights, it is even substantially colder than the adjacent air -- a fact which is understandable only on the assumption of invisible radiation. In response to the temperature changes, the surface layer is subjected to a marked transformation and in the depth of winter takes on a powdery consistency. After a further snowfall, the old loose surface layer remains in the interior of the snow cover and prevents binding between new and old snow. The separation is particularly clear when snow falls on surface hoar. In great snowfalls, superimposed layers undergo only slight TG metamorphism. They remain fine-grained and under the snow cover burden attain densities of over 500 kg/m^3.

The various types of snow as they are characterized by the nature and degree of their metamorphism have highly variable mechanical properties. Among these is the material strength (shearing, tensile, and compressive strength) which attains maximum values of about 200 kg/dm^2 (tensile strength) in fine-grained layers which have undergone predominantly ET metamorphism. Lowest and barely measurable material strength values are attained in loose layers. Deformability must also be mentioned, which is especially high in "warm" new snow layers. Sharp-grained snow and depth hoar on the other hand display only slight deformability.

The technically correct measurement of snow strength is the business of specialists and even the latter content themselves as a rule with determining a substitute value, ram resistance, which at least gives qualitative information regarding the strength distribution in the interior of the snow cover.

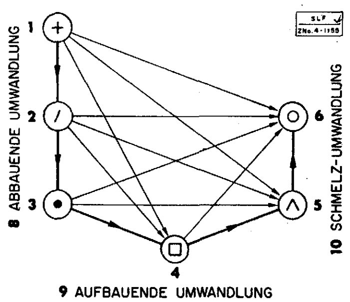
The structure of the snow cover looks quite different from winter to winter and this, as has been shown, also results in a variable long-term basic disposition to avalanche formation.

Figure 2 displays snow profile developments during two winters. That of 1965/66 produced up to the end of January a strong snow cover, while that of 1969/70 on the other hand produced a weak foundation.

3. Avalanche Formation

Strength and deformability of the snow are, next to density or weight per unit volume, the snow properties which are decisive for avalanche formation. In addition, the external friction comes into play after a fracture has taken place. Since each fracture represents the outcome of a contest between stress and strength with strength being the loser, there should first be a discussion of the stress conditions in the snow cover. Actually, they are very complex and scarcely determinable quantitatively. Hence, only a very simplified and basic account can be given.

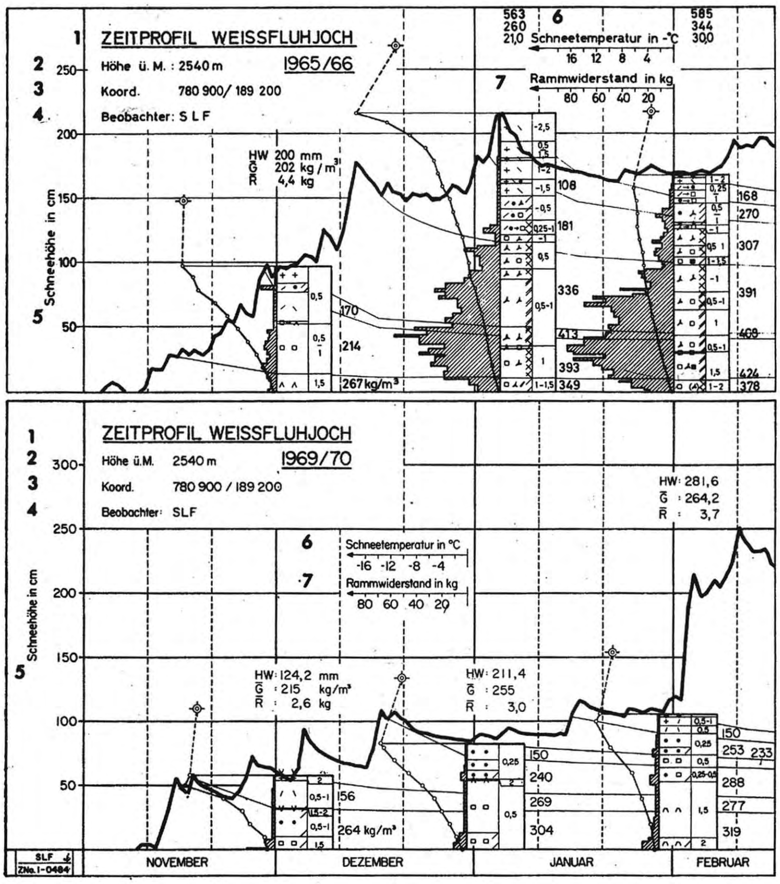
In a horizontal snow cover, there prevails a state of stress which is similar to that in a fluid except for the horizontal lateral pressure. In the case of the fluid, this



Key:

1. New snow (crystals in their original form)
2. Felty snow (crystals partially decomposed)
3. Round-grained snow (without melting)
4. Edged-grained snow (predominantly full forms)
5. Depth hoar (cup or partial forms)
6. Round-grained melting forms (grain growth during freezing)
7. Arrows: possible paths of metamorphism
8. Equi-temperature metamorphism (ET metamorphism)
9. Temperature-gradient metamorphism (TG metamorphism)
10. Melt-freeze metamorphism.

Figure 1. Diagram of snow metamorphism with symbols for the various forms.



Key to Figure 2:

1. Time-profile Weissfluhjoch
2. Elevation above sea level
3. Coordinates
4. Observer
5. Snow depth in cm
6. Snow temperature in ^{o}C
7. Ram resistance in kg

Figure 2. Various types of snow cover development (time-profiles Weissfluhjoch, November to February 1965/66 above and 1969/70 below). Heavy curve: snow depth (daily value). Referred to the profile at month's end: heavy curves: negative snow temperature (abscissa); shaded block curves: ram resistance; block diagrams: layer limits. Grain forms and hardness, grain sizes in mm. Numbers on right: snow densities in kg/m^3. Numbers above monthly profiles: HW -- total water value; $\overline{G}$ -- mean density; $\overline{R}$ -- mean ram resistance. For interpretation see the text.

[pressure] is equal to the hydraulic head [Ueberlagerungsdruck = "pressure of the overburden"]; in snow it is only a fraction of this (about 0.1-0.3). This so-called "nivostatic" pressure is also encountered in an inclined snow cover but changed in magnitude and direction. At the surface it is zero and, in general, increases as one goes downward. If the snow cover is uniformly inclined and everywhere similarly constituted, then all points at the same distance from the surface are in the same state of stress and there exist, apart from the nivostatic pressure, no compressive or tensile stresses parallel to the slope; on the other hand, the snow is subjected to an increasing shear stress as one progresses from the surface to the ground. Thus, the ground everywhere supports the immediately superimposed snow weight in the form of normal pressure and shear stress. Under the prevailing stresses, the snow suffers a continuous deformation which consists of a volume reduction and a shear deformation. The latter is recognizable as a slow creep motion parallel to the slope which ranges from fractions of a mm to several cm per day, depending upon the nature of the snow, slope inclination, and temperature gradient. In pure creep motion, the snow adheres fixedly to the ground, either because it is frozen or prevented by the ground roughness from undergoing a sliding motion. If, on the other hand, the ground is unfrozen and smooth, then there is superimposed upon the creep a gliding motion.

The slope-parallel weight component of the snow cover is then transmitted to the ground as sliding friction.

If now the creep motion and gliding motion are locally modified by differences in the slope inclination, in the snow characteristics or by direct obstructions, there arise marked dislocations of stress. At all retarding and damming obstacles there arise pressure forces which are also effective in the snow as far as the zone of obstruction extends. Conversely, tensile forces form in the snow below anchoring zones and flat regions. Under these conditions, the snow cover is no longer supported at every location by its underlying material. This support continues to exist only in the zones designated "neutral" (Figure 3).

This stress picture which has been sketched here in general terms and the previously described material strength conditions in the snow characterize the formation of <u>slab avalanches</u> (Figure 4). There, where the stress first attains the strength limit, the primary fracture takes place. What actually occurs is a tensile crack perpendicular to the snow cover in the zone of tension or a shear crack parallel to the slope in a weak layer, with a tendency to start in the neutral zone. The lateral shearing crack and compression fracture at the foot of a slope are not likely to be primary fractures. At first glance, the question of the location of the primary fracture appears irrelevant. But when it is a question of avoiding the fracture (touristic) or of hindering it (avalanche control personnel), it is important to know that the origin of an avalanche is just as likely to be in the middle of a slope as in its upper parts.

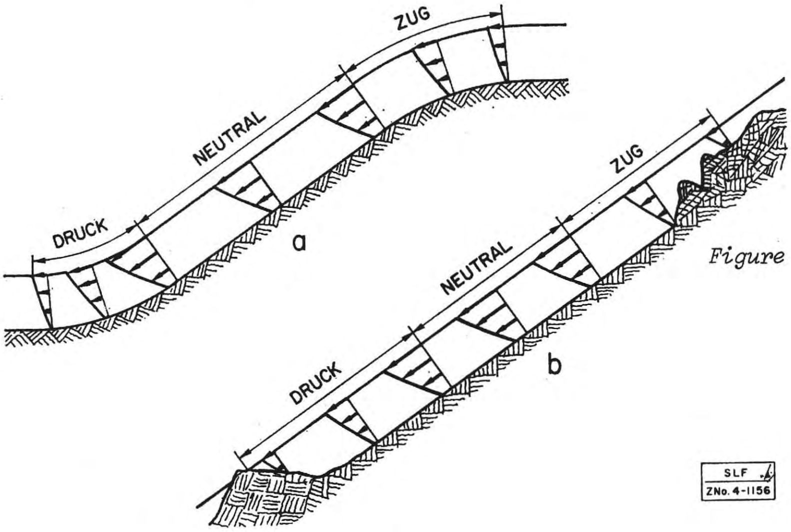


Figure 3. Slope-parallel creep and gliding velocities and stress zones in the snow cover. a) With slope variations; b) With tensile anchoring and compressive support.

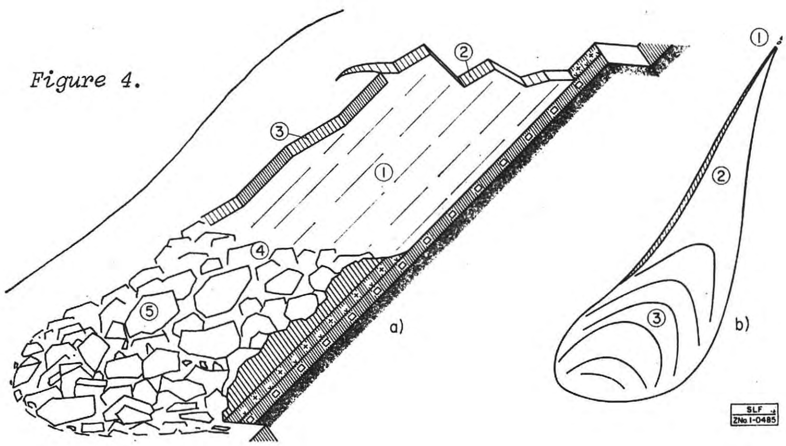


Figure 4.

Types of avalanche fracture.
a) Slab avalanche (upper avalanche) with logitudinal section:
1 -- sliding surface (primary or secondary shear crack); loose layer in the snow cover; 2 -- fracture face [crown face] (primary or secondary tensile crack);
3 -- lateral shear crack (secondary); 4 -- compression fracture (secondary) and stauchwall for sliding snow; 5 -- deposition (possibly continued below);
b) Loose-snow avalanche:
1 -- starting point (starting impulse possibly coming from above);
2 -- sliding surface; 3 -- deposition (possibly continued below).

A primary shear crack which results in an avalanche, propagates surface-wise toward all sides since with resolution of the stress in the fracture surface neighboring regions become all the more heavily loaded. In this way, the fracture also overcomes zones of higher stability. The visible tensile crack occurs in the form of a secondary fracture especially in a location where the shear crack penetrates into a zone of tension. A more precise examination of the shear crack in a markedly metamorphosed loose layer, e.g., in a layer of depth hoar or in a snow-covered surface-hoar layer, shows that such layers are also susceptible to compression which is perpendicular to the slope so that even on horizontal surfaces under additional load (new snow, skiers), structural collapse has been observed which is accompanied by a characteristic "boom" noise and a quick settling. With this collapse there is also a deterioration of shear strength. On the slope, it is usually impossible to decide whether pure shear was at work or whether there was a participating compression collapse. Here, too, a knowledge of the possible compression collapse would be of practical significance. Such a structural collapse can propagate from flat terrain toward a slope and trigger avalanches -- as has been confirmed by reliable observations.

The primary tensile crack is not, as is usually assumed, fully accounted for in this description. It will often be located in hard-pressed, brittle surface layers at the beginning of an avalanche. In this case, too, propagation takes place by stress transfer to neighboring regions with assistance being given -- presumably more than in the case of the primary shear crack -- by the elastic shock arising from the fracture.

The primary fracture does not always result in a sliding of the snow slab, either because the primary crack is halted in snow layers of higher stability or the friction in the fractured shear surface is too high to permit motion. Assuming dry friction, the friction coefficient of snow against snow lies in the range 0.2-0.6 so that slope inclinations of about 12^{o}-30^{o} are needed to produce motion.

In addition to the slab fracture type, another type is observed which cannot be interpreted by means of the above-described mechanism: snow motion develops from a point at the surface and acquires breadth and depth with the snow moving from the outset in the form of individual crystals or clumps. The loose-snow avalanche (Figure 4b) originates, as the name indicates, with snow of slight cohesion. A small impulse suffices to set a clump of snow in motion when it does not start spontaneously. It collides with particles lying further down the slope and these in turn attach themselves to the motion and propagate it. The potential energy released by the sliding serves to loosen further particles and overcome friction; the excess energy goes into energy of motion. Since the lateral propagation of the motion is small, the front becomes ever more violent. On the whole, a loose-snow avalanche develops more slowly than the slab avalanche, and since in its upper course it usually includes only a thin layer, there it is relatively harmless. Also of essential importance is the fact that it arises only on very steep slopes (over about 40^{o}) and only beneath some disturbing agency (e.g., skiers) and hence cannot be triggered from below.

After explaining the fracture mechanism, it is necessary to consider the conditions which make this mechanism possible.

With the loose-snow avalanche there arises the question of the circumstances under which snow becomes labile. In the first hours after deposit, loose new snow possesses a toothed structure which endows it with minimal strength. With the immediate onset of ET metamorphism, the dendritic structure of the crystals is partially lost before a true granular binding can build up. In this state, the snow is ripe for the production of dry loose-snow avalanches. If new snow is exposed to strong solar irradiation or heating, the ET metamorphism can be immediately converted into a superficial wetting and the result is the wet loose-snow avalanche. But coarse-grained old snow is also prone to produce loose-snow avalanches whenever the first thorough wetting in spring decomposes the granular binding before true glacial ice is formed.

Corresponding to the formation mechanism which has been described, the precondition for a slab avalanche lies either in an increase in stress or in a decrease in strength at the decisive locus of minimal stability. But it is possible for both processes to lead simultaneously to fracture. If at first one disregards external disturbances applied to the snow cover either by human or other sudden agencies, snowfall is seen to be the most important source of loading for an already existing snow cover. Since the new snow itself accumulates with relatively slight strength of its own, the stability in the interior of a layer of new snow is often less than in the underlying old snow and during an intense snowfall, under certain circumstances, the strengthening of the new snow can fail to keep pace with the increase in loading. Naturally, a minimal slope inclination and a minimal increase in snow is required to produce fracture. The more heavily it snows, the lower lies this critical slope inclination and the smaller is the critical snow accumulation.

Under otherwise equal conditions, a new snow fracture occurs first in steeper terrain and only later in flatter zones. At the highest snowfall intensities (e.g., snow accumulation of 5-10 cm/hr) the stability on slopes can become critical at an inclination as low as about 25°. Here the nature of the new snow and its temperature play an essential role. Low snowfall temperatures (below about -7°[C]) hinder the development of strength and thus promote the formation of avalanches on steep slopes and in addition extend the risk of avalanches to flatter terrain.

New snow stability is quite decisively affected by wind. Two unfavorable effects should be noted: most important is irregular deposit which in lee zones can produce snow accumulations many times the average. This gives rise to peak loadings which can be further enhanced by irregular creep motions. The second effect of the wind is to make the snow brittle. While this does produce an increase in strength, the stress peaks cannot be equilibrated. This last effect is especially significant for tourists.

How does the stability of the old snow cover behave when loaded with new snow? It is then that the old snow surface is for the first time subject to loading. If, as often happens after cold periods of fair weather, it is subjected to TG metamorphism or even covered with surface hoar, its strength usually becomes less than that of the new snow and the slab avalanche will not be long in coming (primary shear crack). Catastrophic large-scale avalanches are less likely under such conditions since the fractures occur at only moderate accumulation of snow.

In addition to the surface first covered by new snow, there are in the depth of the snow cover, depending upon the previous development of the winter, additional old surfaces of the same type and often in the neighborhood of the ground there is still a weak depth hoar layer from the time when the ground was first snow-covered. These layers do possess a certain set and consolidation, but it can be that one of them, because of the higher loading at deep levels, has the least stability and becomes activated as a fracture surface (old snow fracture). Because of the increased magnitude of the snow mass set in motion, such fractures in old snow have an aggravating effect upon pure new snow fractures in catastrophic situations. Depending upon the course of the winter, more or less strong and dense layers lie between the weak layers and these layers have an avalanche retarding effect if they are not limited to the uppermost snow layers.

Temperature has thus far been mentioned as a factor in avalanche formation only in connecti with new snow. Its effect is concentrated upon the strength development of the snow and is not always easy to survey. On the one hand, of two snow samples having the same structure but different temperature, the colder one has greater strength than the warmer, but on the other hand, the warmer sample can consolidate better as a result of compaction and thus it overtakes the colder sample in strength. Absorption and emission of radiation as well as variations in the air temperature lead to variable temperature drops in the snow and to the metamorphic processes which have been mentioned and which result, according to circumstances, in a retardation or promotion of strengthening.

When snow temperature reaches 0 and melt water is produced, new effects arise. First, the snow becomes sticky or snowbally and hence somewhat stronger. But with more marked wetting a distinct reduction in strength is observable. The first moistening of the layer adjacent to the ground leads to gliding snow motions or to the fracture of wet ground avalanches. Speaking generally, a marked warming results in a critical increase in avalanche activity which diminishes after a while and in particular, after a cooling off.

The underground conditions have a variety of effects upon avalanche formation. Contrary to a widespread conception, ground roughness does not play a decisive role. Once the ground irregularities have been covered and smoothed out by the action of the wind, the formation of upper avalanches (i.e., the slippage of upper layers) is largely independent of the underground. Nevertheless, upper level avalanches are hindered to the extent that roughness elements (blocks of stone, vegetation) project into the snow cover. In early winter, rough terrain can take up much more snow before the descent of avalanches than in midwinter and late winter. In this sense, the absolute snow depth is also a factor in avalanche risk.

4. Snowfall and Snow Distribution

Thus far, avalanche winters have always been closely related to periods of intense snowfall (1945, 1951, 1954, 1968, 1970). Heat waves have probably led to accumulations of serious ground avalanche occurrences, but not to widespread cases of damage. This is a consequence, among others, of the fact that wet snow avalanches generally display smaller extents and are more inclined to stay in familiar paths than are dry surface-type flow avalanches and powder avalanches.

For the practical man, it is important to know where and with what frequency great snowfalls are to be expected with special emphasis being given to daily values of new snow amounting to 50 cm and more. Catastrophic events must be reckoned with whenever the new snow totals over several successive days (sum of the daily values designated by ΣHN) amount to about 120 cm. At low temperatures (under about -8°) the series is not interrupted by a single intermediate day when there is little new snow. On the other hand, snowfall pauses at high temperatures permit the new snow to consolidate and delay or prevent the development of an avalanche. (Naturally it is the temperatures in the region of initial fracture which are decisive.) When strong winds prevail from a steady direction, the catastrophic quantity can be attained at low new snow totals, in which case the danger is concentrated in zones which are in the lee of the wind. Thus, there is a general risk of avalanches with catastrophic tendency for valley situations as soon as a new snow total of about 100 cm is attained within 3 days. The frequency with which this case arises in various regions of Switzerland is shown by the following summary for some stations over a period of 20 years.

Frequency ΣHN ≧ 100 cm in 3 days (1950-1970)

Zuoz (1,730 m)	Once
Barberine (1,820 m)	Four times
Davos-Platz (1,560 m)	Six times
Andermatt (1,440 m)	Seven times
Bedretto (1,400 m)	Fourteen times
Grindelwald-Bort (1,570 m)	Seventeen times

Thus, there exist substantial regional differences, with the alpine border zones being most frequently affected. The extent to which terrain conditions and settlement conditions are involved in catastrophic events is shown by the example of Grindelwald where in the period mentioned, no avalanche catastrophes occurred. (For further references to new snow data, see Th. Zingg in the SLF Winter Report 1961/62, No 26.) A compilation of local snow and weather data from the avalanche periods mentioned at the outset should confirm these generalizing statements.

Weather and Snow Conditions for the Avalanche Catastrophes 1945, 1951, 1954, 1968, 1970

The notation is:

HN	Daily new snow (morning value), cm
$\sum_i$HN	Totaled daily values during i days, cm, up to the time of the avalanche
HS	Total snow depth on the ground, cm
T	Air temperature, °C
W	Wind force (mean value), m/s

Andermatt, Kirchberg Avalanche, 8 March 1945 (afternoon)

Datum	HN	Σ HN 3	Σ HN 5	HS	T	W
5. 3.	30			(170)		
6. 3.	5					NNW 8—11
7. 3.	40				—(7÷10)	(in 2000 m)
8. 3.	55	~115*	~145*	300		
9. 3.	40					

* Includes addition to morning value of 8 March: 15 cm.

St. Antoenien, Meierhof Avalanche, 20 January 1951 (2130 hours)

Datum	HN	Σ HN 3	Σ HN 5	HS	T	W
16. 1.	25			125	—5	
17. 1.	15			124	—7	
18. 1.	12			120	0	SW 4,5
19. 1.	44			158	—5,5	SW 2,5
20. 1.	65	~157*	~197*	200	—1,5	W 4,5
21. 1.	73			240	—0,5	SW 1

* Includes addition to morning value of 20 January: 36 cm. Additional avalanches: at night 18-19 January; 20 January, 0300 hours; 21 January, 2130 hours.

Airolo, Vallascia Avalanche, 12 February 1951 (0045 hours)
(Snow measurement by Bedretto)

Datum	HN	Σ HN 3	Σ HN 5	HS	T	W[4])
4. 2.	12			163	—5	
5. 2.[1])	52			210	—4	
6. 2.	57			253	—2	
7. 2.	25	(134)	(139)	265	—6	
8. 2.	0			250	—5	
9. 2.[2])	1			230	—2	
10. 2.	14			244	—1	
11. 2.[3])	55			285	—1	
12.2.	125	~152*	(~153*)	370	0	
13.2.	46			368	—1	

* Reduced daily value of 12 February: 83 cm.
1 Evacuation of parts of Airolo.
2 Return of the evacuees.
3 Repeated partial evacuation.
4 No reliable wind observation by Bedretto. In the heights generally SE wind 5-10 m/s

St. Antoenien, Aschueel Avalanche, 12 January 1954 (0030 hours)

Datum	HN	Σ HN 3	Σ HN 5	HS	T	W
9. 1.	—			27	—22	
10. 1.	16			42	—13	
11. 1.	50			91	—12	SW 7
12. 1.	85	~129*	(~131*)	171	—12	(Höhe WNW 15) **
13. 1.	4			145	—11	

* Reduced daily value of 12 January: 63 cm.
Additional avalanches on 11 January.
** Data from the Weissfluhjoch. (High level WNW 15)

Davos, Dorftaeli Avalanche, 26 January 1968 (2240 hours)

Datum	HN	Σ HN 3	Σ HN 5	HS	T	W **
23. 1.	—			97	—6	NW 5—8
24. 1.	—			94	—7	NNW 11—23
25. 1.	18			106	—8	NNW 17—20
26. 1.	42	~107*	(~107)*	138	—4	NNW 21—32
27. 1.	79			185	—3	NNW 16—28
28. 1.	15			166	—5	NSW 3—6

* Includes addition to morning value of 26 January: 47 cm.
** Wind values from the Weissfluhjoch (high fracture region).
Additional avalanches: among others, 27 January, 0030, 0400, 0600 hours.

Reckingen, Baechital Avalanche, 24 February 1970 (0550 hours)
(Observations by Muenster)

Datum	HN	Σ HN 3	Σ HN 5	HS	T	W
19. 2.	5*			139	−6	SW 3
20. 2.	11			144	−2	NW 3
21. 2.	22			154	−5	O
22. 2.	48			186	0	O
23. 2.	21			194	+1	SW 16
24. 2.	16	85	118	196	−4	O

* From the 3d to the 18th of February, the new snow total amounted to as much as 126 cm.

Comment: In the Andermatt (1945) avalanche, in view of the low temperature, presumably the new snow total of 5 days was a factor, although the 3-day value almost attained the assumed catastrophic mass. In St. Antoenien (1951), the relatively high temperatures had a somewhat delaying effect and allowed the catastrophic mass to exceed 150 cm in the last 3 days alone. The Airolo (1951) avalanche would have been almost ripe on 7 February. With the 2-day snowfall interruption at a relatively high temperature the situation recovered and an additional equally large load of new snow was required to generate the avalanche.

In St. Antoenien (1954), the effective agent was exclusively the snow accumulation of 3 days, fallen at low temperature and moderate wind.

In the Davos (1968) case, one is struck by the relatively low new snow total (107 cm) at the onset of the extraordinary avalanche activity. Here, for an explanation, one can appeal to the sharply blowing winds coming always from the same direction. The Reckingen (1970) avalanche probably includes all the February snowfalls, which represent an unusual sequence.

5. Avalanche Dynamics

Depending upon the nature of the snow and the terrain conditions, broken masses of snow move in quite varied ways. In the case of slab avalanches, there develops a translatory motion in clods which sooner or later decompose into a lumpy, powdery, or (in the case of wet-snow avalanches) even pasty mass. The sliding motion is triggered by a flow having a velocity which increases from the ground to the surface. The motion soon becomes turbulent, and if the snow is dry and fine-grained or downy, at a velocity of about 10 m/s snow dust begins to separate at the surface. As long as the mass follows the ground substantially, one speaks of a flowing avalanche and after most of the snow component has been carried up turbulently into the air, one speaks of a powder avalanche. Often both forms are represented side by side as a flowing avalanche component and a powder avalanche component.

A jump over a terrain edge can almost cause the flowing component to vanish and result in a practically pure powder avalanche.

The loose-snow avalanche often develops at first a peculiar form of motion in which the displaced front continually presents new snow in front of it. In this case, the position of the front propagates more rapidly than the snow particles themselves. But later the front will shoot away over the resting snow cover and the latter will only then resume involvement in the motion. It is then scarcely possible to distinguish between the slab avalanche and the loose-snow avalanche.

With regard to the size of the velocities attained by smaller and average avalanches, we possess some information from measurements, observations, and photography. Of catastrophic large-scale avalanches, there exist in general no measurements and eyewitness reports are often very divergent. Well known are the observations by M. Oechslin of some avalanches (1938) in UR which in part give almost unimaginably high values (up to over 380 km/hr).

In all observations and measurements, it is frontal velocities which are involved while it must be assumed that in the interior of a mixed flowing and powder avalanche (apart from the cited case of the loose-snow avalanche), there prevails a somewhat higher core velocity. Since the friction forces (turbulent and viscous friction) themselves depend upon the velocity, for a given descending mass a certain mean terminal velocity is attained. This will generally lie substantially below the velocity of the frictionless case over a drop distance h ($v = [2gh]^{1/2}$). Because of their small friction component, powerful powder avalanches can attain high terminal velocities.

Realistic mean velocities of large avalanches may be expected, in a descent path having 38-40° inclination, to lie roughly in the following ranges:

Wet-flowing avalanches	10-30 m/s
Dry-flowing avalanches	20-40 m/s
Powder avalanches	30-70 m/s

The most important phenomenon accompanying moving masses of snow is the pressure on opposing obstructions. It is proportional to the density and to the square of the velocity. With full frontal obstruction at a wall, it amounts to

$$p = \frac{\gamma}{g} v^2 \ (kp/m^2)$$

where γ equals specific weight (kp/m^3)[2/], g equals gravitational acceleration 9.81 m/s^2, v equals velocity (m/s). In the case of flow around obstacles, form factors must be employed. The specific weight of a moving avalanche is not precisely known. Reasonable estimates are:

Wet-flowing avalanches	300-400 kp/m^3
Dry-flowing avalanches	50-300 kp/m^3
Powder avalanches	2- 15 kp/m^3

The intermediate range from 15 to 50 kp/m^3 is encountered in the transition zone of mixed flowing and powder avalanches.

As early as 1936, pressures in heavy flowing avalanches of 50-60 t/m^2 have been measured (Goff and Otten, USSR) and these have subsequently been confirmed several times in Switzerland. Powder avalanches, despite their bad reputation and their high velocity, are less violent. Pressure values above 10 t/m^2 probably occur rarely. Nevertheless, normal buildings and forests cannot possibly withstand such forces, especially as these usually attack several meters (5-20) above ground.

There is often ascribed to powder avalanches an air pressure effect speeding ahead of the actual avalanche front with a force of the greatest destructiveness. Undoubtedly an air cushion arises immediately in front of the visible avalanche front, and the compressed air must escape from there forward and upward at avalanche velocity. But since it is essentially lighter than the dust cloud, the pressure effect of this advance wind will be slighter than that of the snow dust -- which is not to say that it is incapable of destruction.

References to further dynamic phenomena, particularly frictional conditions, flow heights and ranges of action may be found in the paper by B. Salm ("Five Principles of Avalanche Control").

6. Classification of Avalanches

Observations relating to avalanches may be subdivided into observations relating to the external appearance of the avalanches and those which have to do with the conditions of formation. Hence, one distinguishes a classification of appearance forms (morphological classification) and a classification according to the conditions of formation (genetic classification). International efforts are underway to create uniform classification procedures, with the schemes introduced in Switzerland as early as 1955 serving as guides.

A true genetic classification which unambiguously assigns complex conditions of formation to observed or expected avalanches does not yet exist, and will perhaps never be set up in this form. On the other hand, with regard to avalanche formation, it is possible to isolate decisive factors and to present a clear overall picture of their significance. For the present, it must be left to the person making a judgment of a developing avalanche situation or of an avalanche event to apply the correct weights to the interplay of genetic factors. Automated computer procedures are still in their initial stages.

The terrain occupies a special position in classification. It constitutes a precondition which is locally fixed and constant in time and displays both morphological and genetic aspects.

For the features of interest, the observed (or to be expected) characteristics are used alternately in suitable combination. Occasionally, two characteristics enter as components. Example: dry, soft-slab avalanche, starting as upper avalanche with old snow fracture, descending as trough avalanche with predominant powder component.

Complete description of an avalanche requires supplementation by means of measurable (quantitative) quantities such as fracture elevation, breadth, volume, velocity, etc., which require no classification system.

[2/] kp = kilopond force: 9.806 kp = 1 newton. The magnitude of kp measurements is the same as for kilograms.

6.1 Morphological Classification (According to Appearance)

Feature	Characteristics	
Upper fracture boundary	Linear Slab avalanche[3/]	Point Loose-snow avalanche
Position of the sliding surface	Within the snow cover Upper avalanche New snow fracture / Old snow fracture	On the ground Ground avalanche
Fluid water in the avalanching snow	Lacking Dry-snow avalanche	Present Wet-snow avalanche
Form of the path (transverse profile)	Flat Flat [unconfined] avalanche	Trough-shaped Trough [channelized] avalanche
Form of the motion	As dust cloud Powder avalanche	As a flowing mass Flowing avalanche

[3/] May be further divided into soft and hard slab.

6.2 Summary of Genetic Avalanche Factors (Formation Conditions) (Survey)

Condition	Effect Upon Avalanche Formation
Recent weather (3-5 days)	
New snowfall	Progressive increase in avalanche tendency. Most important factor!
Growth and intensity	Mainly upper avalanches (see special table 6.2.1)
Wind	Local slab formation
Velocity, duration, and direction	Amplified on leeward slopes (snow drifts) with and without snowfall. Wind $\gtrsim$ 4 m/s.
Air temperature and radiation balance (Effect through snow temperature)	With increasing snow temperature decreasing strength and increasing deformability. Effect complex. Often temporarily increased avalanche activity (especially with wetting). Low temperature preserves the existing situation. Secondary temperature effect: snow metamorphisis.
Old snow conditions	
Total snow depth	In general a subordinate factor. With increasing snow depth reduced avalanche retarding effect from ground roughness, sometimes increased avalanche volume in the case of an old snow fracture.
Stratification of the old snow cover (Record of the development of the winter)	Strength development of the lower and intermediate layers (TG metamorphism, surface hoar) decisive for old snow fracture (sometimes avalanche risk without new snowfall).
Triggering conditions	
Natural formation	Spontaneous avalanche (without sudden disturbance). Natural trigger (with sudden disturbance).
Trigger by man	Accidental trigger (unintentional). Artificial trigger (intentional).

6.2.1 New Snow Depth and Avalanche Formation

(Guide values, valid for wind up to about 4 m/s, temperature -2^{o} to -10^{o}

New Snow Total in 3 days (cm)	Avalanche Formation
Up to 10	Rare, very local snow movements (mostly loose-snow avalanches).
10 - 30	Occasional local slab formations. Frequent loose-snow avalanches.
30 - 50	Frequent, local slab avalanches, mostly on steeper slopes (>35°).
50 - 80	Widespread slab avalanches also on more gentle slopes (>25-30°). General risk above the tree line. Individual larger avalanches down to the valley floor, mostly in familiar paths.
80 - 120	Frequent, large avalanches down to the valley floor, occasionally also outside familiar paths.
>120	Extraordinary conditions. Rare and hitherto unknown great avalanches possible.

At temperatures below -10°, the summation period should in some cases be extended to 5 or more days. At wind above 4 m/s, the evaluation class for leeward exposures should be raised by one to two levels depending upon velocity and duration.

6.3 Classification of Terrain Conditions

Terrain	Effect Upon Avalanche Formation
Slope	
0° - 11°	Expansion and deposition stretches of dry flowing avalanches.
11° - 20°	Dry, flowing avalanches in motion run through.
20° - 30°	Rare formation of slab avalanches (tendency increasing progressively with slope).
30° - 50°	Normal range for slab avalanches.
40° - 60°	Normal range for loose-snow avalanches.
> 60°	Frequent continuous sliding of loose snow.
Exposure (orientation)	
With regard to the sun	Variable effect of irradiation. Southern exposure: Temporarily increased avalanche formation (in some cases wet-snow avalanches). Increased consolidation. Northern exposure: In general, bad lower layers, depth hoar, surface hoar (see table 6.2, air temperature and radiation balance).
With regard to wind	Displacement of snow from windward slopes to leeward slopes (slopes protected from the wind); see table 6.2, wind.

General shape	
Flat surfaces, gentle changes in slope	Tensile and compressive stress zones, fracture regions.
Corrugations, gullies	Boundary of starting zones, avalanche paths.
Steps, hollows	Jump intervals (powder avalanches!), trap intervals; see table 6.1, morphological classification.
Roughness	
Smooth flat areas, grass	Gliding snow, ground avalanches possible.
Rough gravel	Adherence of the ground layer (depending upon roughness), upper avalanches possible.
Shrub vegetation	Avalanche-retarding, as long as not snow-covered.
Forest	Avalanche-retarding if dense (limited retarding and trapping capacity).

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III. AVALANCHE PROTECTIVE MEASURES (Hans Oppliger, Glarus)

1. Introduction

In his book The Avalanches of the Swiss Alps, Chief Forest Inspector J. Coaz wrote in the year 1881: "In the first decades of our century, the Alps of Switzerland, and in particular the actual high mountains themselves, were seldom visited, very scantily investigated, and hence still rather unknown -- almost a terra incognita rising directly out of the midst of countries which are among the most heavily populated and the most cultivated on earth. Since then, the situation has become quite different, and nowadays every summer there takes place a small migration toward the Swiss Alps and many visitors penetrate into their most remote regions in pursuit of the most varied intentions."

In those days, Coaz was experiencing the beginning of the conquest of our Alps. He could have no idea of the future extent of this development, which today has still not been concluded. Actuality has surpassed even the boldest expectations. From what were formerly small mountain hamlets sandwiched between avalanche trails, there have now arisen sophisticated summer and winter holiday resorts and more and more people live part of the time today in the mountains. The enlargement of the mountain hamlets and the associated expansion of transportation routes in and through the mountains confront the responsible authorities of entire regions with almost insoluble problems. Special difficulties arise during the winter when in many parts of our alpine valleys avalanches descend which often advance down to the floors of the valleys. This can directly endanger settlements, transportation routes, and transportation facilities. The population of our mountain regions knows the risk associated with avalanches; in fact, they must live with avalanches. As a consequence of the marked expansion of travel from abroad, but especially through the popularization of winter sports and of winter tourism, more and more inhabitants of flatland are being confronted with avalanche endangerment, either as temporary guests of winter resorts, as travelers on mountain roads, or as tourists who have left the beaten path of safe transportation routes. An understanding of the danger of avalanches and a knowledge of possible protective measures has become an absolute necessity of life in the mountains. The entire public must concern itself with the resulting technical problems and financial costs; for in many mountain valleys an effective avalanche protection is an essential condition of the continued existence of numerous communities.

All avalanche-protective measures pursue the goal of protecting men and property from damage: men as inhabitants of communities exposed to avalanche risk or of individual farms and as tourists, or as users of public communication routes and transportation facilities (paths, roads, railways, cablecars, ski lifts), in open work places (building sites, forests), or in closed working places (workshops, factories, hotels); the property consisting of buildings, furniture, cattle, transportation facilities, technical facilities, forests, and fields. Basically, a distinction can be made between short-term and long-term protective measures. Both types have their advantages and disadvantages. In the individual case, they must be weighed against one another while taking into account engineering possibilities, the protection task, urgency, the time required, costs, and legal principles. In planning them, it is also necessary to evaluate the ratio between financial cost and the importance of the object to be protected.

2. Short-Term Avalanche Protective Measures

Short-term measures for the prevention of avalanche accidents relate to individual avalanche situations in which the special episodes of danger must be evaluated from case to case. Often it is a matter of personal measures which have been left to the judgment of an individual, such as selection of routes, the decision to dispense with planned undertakings, observance of general and local avalanche warnings or evaluation of local snow, weather, and terrain conditions. As collective protective measures, short-term protective measures also include all precautions taken by avalanche services, ski-slope services, or rescue services. These measures are avalanche warning; closure of endangered routes, transportation services, and regions; evacuation of endangered communities or parts of communities; artificial triggering of avalanches and readiness of rescue services. Short-term protective measures should also be taken to avert an acute avalanche danger in order thereby to bridge the gap produced by the time-consuming planning and design phase of long-term measures.

2.1 Cautionary and Protective Measures in Patrolling Avalanche Endangered Regions

It should be possible to assume that all visitors to and inhabitants of mountain regions will observe the most elementary measures of caution. Unfortunately, it is precisely in the case of ski tourists that the most surprising carelessness with regard to avalanche danger may be seen. Many a major avalanche accident claiming many lives might have been avoided if reasonable safety precautions had been observed.

Probably the most important protective measure is clarification with regard to the urgency of an entrance into avalanche endangered zones. In a doubtful case, one should dispense with carrying out an undertaking which is not absolutely necessary. Before beginning an unavoidable patrol, all risk factors must be thoroughly investigated. Serviceable in this connection are: the general avalanche bulletin, local avalanche warnings, snow reports, and information released by local avalanche or ski-slope services. The greatest care should be accorded the selection of routes, by evaluating topography, snow quantity, type of snow, snow distribution, and weather. In gathering this information, connoisseurs of local conditions should also be consulted. In particular, unconditional heed should be given to the warnings, instructions, and closures issued by the local avalanche services. Before any dangerous undertaking, the responsible leader must be aware that his project will endanger the lives of not only himself and those accompanying him, but also those of any members of the rescue service which may possibly be required.

2.2 Avalanche Service

The avalanche service is organized by the political authorities of a community or of an entire region. Its range of tasks includes, as a rule, keeping watch on all avalanche paths existing within a community which represent a source of danger for a settlement, for individual objects, for transportation facilities, or for tourists. The existence of an avalanche service does not make the personal protective measures of individuals superfluous. The population of endangered regions must take basic cautionary measures in every case and without being specially called upon. This applies especially to the patrolling of zones which manifest certain degrees of risk even when there is only slight general avalanche danger but which are not covered by the avalanche service at all or only in certain cases.

The avalanche service fulfills two main functions. On the one hand, it takes all measures for prevention of avalanche accidents, and on the other hand, it organizes the measures of assistance which are necessary after the occurrence of an avalanche accident. From this double task there arises a division into various services to which specific tasks are assigned. The lookout service begins its activity when there are intense snowfalls. A continuous situation evaluation is carried out with the aid of the weather reports of the Swiss meteorological central institute and its internal announcements together with the avalanche bulletins of the Federal Institute for Snow and Avalanche Research (EISLF) and in cooperation with the snow and avalanche specialists of this institute. The evaluation of observations and announcements of specialists serves as the basis for recommendations to the avalanche commission or to the community council which then, through the warning and alarm service, institutes the alarm measures which it considers necessary. The levels of warning and alarm to be employed must be precisely described and established in an official regulation. The warning and alarm service sees that all levels of avalanche alarm are supplied under all circumstances, and immediately to the persons concerned. After the avalanche danger has passed, this service is also responsible for complete withdrawal of the warning. The institution of certain alarm levels gives rise under certain circumstances to evacuations and closing of roads. The evacuation service is responsible for the execution of evacuation orders. In preparation for the smooth execution of evacuation procedures which are not always simple, actual evacuation plans are set up in which there are established the measures necessary for all levels of alarm. This includes precise lists of all persons to be evacuated and the emergency accommodations assigned to them. The closure and surveillance service provides for maintaining the road and traffic closures which have been decreed, provides for the surveillance of evacuated localities, and in the event of avalanche accidents, provides for closing off and surveillance of accident sites. Under certain conditions, the artificial triggering of avalaches is carried out by the avalanche service. The avalanche shooting service is concerned with these problems (compare section 2.3).

Upon the occurrence of an avalanche accident, the rescue service is concerned with providing the immediate and properly directed employment of the required rescue facilities and crews. The health service keeps the personnel required for assistance in readiness, while the materiel service makes the required rescue equipment available. The materiel service is also responsible for appropriate storage and maintenance of the existing equipment. A special maintenance and provision service organizes housing and provision for evacuees and in the case of avalanche catastrophes for those who have lost their homes. The necessary accommodations are made ready in cooperation with the evacuation service. The correct functioning and the coordination of the various service branches through the leadership of the avalanche service are guaranteed by a special communications and message service. Communication is carried out by radio, telephone, and message-runners. In avalanche catastrophes, the information service of the mass media is also important. Often the radio is the only still functioning communication device in contact with cut-off homes or settlements. The information service is concerned with the orientation of press, radio, and television, and provides for wireless communication with isolated settlements. The provision of thorough and objective information for all interested parties is very important in avalanche accidents. A mood of panic is often generated by sensational news reports, and this panic can sharply interfere with rescue operations in progress.

The construction of a comprehensive avalanche service is urgently necessary for many communities in our alpine valleys. Proper rescue services exist in many cases (SAC-rescue columns, ski-slope services of the sports areas) and usually can be made available on short notice. What is lacking are the comprehensive avalanche services which are primarily concerned with the prevention of avalanche accidents. These services are of the greatest significance for very many mountain communities and tourist regions.

2.3 Artificial Triggering of Avalanches

The artificial triggering of avalanches is a further measure for the prevention of avalanche accidents. It is employed principally to protect tourist regions and transportation routes.

The most direct, cheapest method of artificial avalanche triggering, but not without danger and limited in its effect, is the technique of stepping or jumping on the snow to release avalanches. In an emergency, this method can be practiced in difficult situations by experienced skiers. True preventive avalanche triggering consists of blasting loose or shooting down avalanches by means of hand operated explosives or by means of artillery.

In Switzerland, avalanches were shot down for the first time in the winter of 1934/35 in the Bernese Alps. The division of military engineers at that time carried out experimental firings with the infantry cannon, the 7.5-cm [75-mm] mountain gun, and with the 8.1-cm mine thrower [trench mortar]. Subsequently, the trench mortar also showed itself to be the best firing device for keeping the upper alpine highway open in the winter 1939/40, and in opening up the Klausen Pass in the spring of 1940. Since these first experiments carried out by the army, preventive avalanche triggering has become widespread in the entire alpine region. Today in Switzerland during a normal winter, between 5,000 and 10,000 explosive trials are run for the purpose of triggering avalanches. The most common practice here is the process of hand operated blasting with safety explosives, which is a very good and not very expensive method. Its greatest disadvantage is its small range of only about 30 m.

Today the standard firing device is the 8.1-cm trench mortar. Its relatively great range, up to about 4,000 m horizontally and about 2,200 m vertically (for 500-600-m horizontal distance), guarantees the safety of the operating personnel, and the great explosive force of the shells makes it a reliable weapon in the battle against avalanches. The ammunition fired has instantaneous ignition. When shells having delayed ignition are used, they do not explode until they have penetrated into the snow cover or into the ground. This merely results in a snow crater without any further effect. When trench mortars are fired, because of the possible propagation of the fracture in the snow cover, one must always reckon with the possibility of unintentional large-scale triggerings of avalanches. The trench mortar can also be used from fixed firing positions. By using pretargeted shooting elements, it is possible to shoot without seeing the target. During long-lasting snowfalls which can lead to dangerous avalanche situations, it is thus possible to carry out continuous firing trials.

Recently the rocket tube has also been used as an avalanche weapon. Its great precision gives it very high hit reliability and, because of its low weight, a mobility is attained which makes the rocket tube an interesting and, for certain uses, ideal weapon; this is in spite of its smaller range (up to 1,600 m) in comparison with the trench mortar and despite its substantially higher ammunition costs.

A further possibility for artificially triggering avalanches lies in the use of minefields. In this process, prior to the first snows, explosive charges are placed in the fracture zones of dangerous avalanches in some suitable arrangement so that they can be electrically fired as needed from a safe location. Because of patent laws, this method is very expensive; hence it is little used in practice.

The artificial triggering of avalanches involves extraordinarily great risks. Incorrect handling of the weapons or of the explosives can endanger the operating crew or third parties. The same consequences can also follow from aiming errors in shooting with trench mortars and rocket tubes. Unintentional avalanche descents or large-scale collapse which can lead to extensive damage are not impossible. Hence, the artificial triggering of avalanches is out of the question for inhabited zones and can be employed elsewhere only within the framework of a well organized avalanche service. One must presuppose the existence of the various service branches such as surveillance, closure, evacuation, firing, and rescue service. Only trained personnel should be employed for operating the weapons and army safety specifications also apply to the civilian use of the various weapons.

Members of the firing service must also concern themselves with the tactical aspect of avalanche shooting. Depending upon the conditions prevailing in the particular case, two different procedures must be distinguished. Large-scale avalanches can be prevented by periodic shooting or the protection of a threatened region can be undertaken only after the conclusion of a period of precipitation or storms. Both procedures require precise and careful preparation.

3. Long-Term Avalanche Protection Measures

Long-term protective measures are understood to relate to numerous avalanche situations. In this way, extreme situations can be taken into account and the measures are as a rule carried out or prepared long before emergence of the danger. Such measures are:

a. Recognition and designation of avalanche endangered regions and prevention of the construction of permanent facilities such as highways, railways, high-voltage lines (avalanche cadastral survey);

b. Designation of zones of prohibited construction and limited construction in endangered regions (avalanche zone plan);

c. Resettlement away from endangered zones;

d. Avalanche control by means of operations in the starting zone, track, or runout zone.

3.1 Avalanche Cadastral Survey

All measures for the prevention of avalanche accidents can actually be successful only when the possible avalanche regions are known. The mapping and comprehensive registration of all significant avalanche paths in our Alps is therefore an extraordinarily important basis for the protection of avalanche zones.

The demand for the collection and processing of avalanche statistics or avalanche cadastral surveys is an old one. As early as the year 1872, the forestry inspectorate of the Canton of Graubuenden commissioned its chief foresters, in a circular, to carry out the collection of cantonal avalanche statistics. On 7 January 1878, the federal forest inspectorate invited the cantons of the federal forest district to employ their forest personnel in the collection of data necessary for the construction of avalanche statistics for the entire Swiss Alps. In order that these first Swiss avalanche statistics should attain a certain uniformity, tables were created which permitted the tabulation of a large number of facts for each avalanche. In the avalanche maps published by Coaz, these statistical data have been evaluated. Unfortunately, the collection of Swiss avalanche statistics was not continued and the original collections are also no longer available.

The idea of creating a comprehensive survey of the occurrence of avalanches persisted in our country and was again taken up after the avalanche winter 1950/51. In the "Guidelines of the Federal Department of the Interior With Respect to Afforestation and Control Projects in Avalanche Endangered Regions" dated 17 June 1952, instructions were included calling for the setting up of avalanche cadastral surveys and avalanche zone plans. Then in the year 1955, the EISLF began the collection of data for a new Swiss avalanche survey. By way of example, the Tavetsch, the Loetschen Valley, and the Hasli Valley were worked up in order to get experience in data gathering, methodology, and presentation of the cadastral survey. For personnel reasons, it was not possible for the EISLF to single-handedly take over the data collection for the entire Swiss alpine territory.

In a circular letter dated 1959, the Federal Department of the Interior recommended once again to the forestry offices of the alpine cantons the establishment of avalanche cadastral surveys and of avalanche zone plans based on the surveys. However, in 1962, the conference of cantonal chief foresters maintained the position that the working up of the avalanche cadastral survey was primarily an affair for the federal government. Hence this work would have to be carried out by the EISLF, with the cantonal forest services being obliged to cooperate in the collection of basic data and in the selection of observers. After this new regulation of the cooperation of the EISLF and the cantonal forest services, it has been possible to work up the survey for various regions. Nevertheless, the work has not yet progressed very far, and up until now, it has been possible for the avalanche cadastral survey to cover only about 5 percent of the target area.

The avalanche cadastral survey has three goals:

a. Scientific investigation of the entire avalanche phenomenon,

b. The establishment and followup of comprehensive damage statistics,

c. The determination and mapping of all zones endangered by avalanches.

By means of the scientific evaluation of a very large number of observations for various avalanches of the alpine region, it is possible to determine the relationships between climate, weather, topography, and avalanche formation. For this a uniform cadastral survey must be set up and there must be continuous observation of the mapped avalanche paths. All information is to be reported to the EISLF which, as a collecting and evaluating center, provides for the subsequent scientific processing of the data. Together with the reporting and recording of all cases of damage, the avalanche cadastral survey constitutes a good aid to avalanche research.

Reliable observation, over a fairly long time span, of the avalanche paths listed in the avalanche survey finally permits a comprehensive review of the danger affecting certain zones of our mountain districts. This will have the effect of facilitating the clarification of various questions having to do with access, patrolability, and of structural and tourist zone planning. The avalanche survey thus becomes an important foundation of local and regional planning.

As a rule, the avalanche survey covers an entire region which has been subdivided into various districts (Figure 1). To each district there is assigned an observer who must cooperate right from the start with collection of basic information and later takes over surveillance of the mapped avalanche paths. The cadastral survey consists of three parts:

a. The description of all mapped avalanches with as much data as possible regarding descents and damage,

b. Damage statistics, in which the reports of observers are collected,

c. An avalanche map (scale 1:5,000 to 1:25,000), in which the avalanches are plotted in their greatest known extent.

Uniform forms are available for the description of avalanches and for the various reports.

3.2 Avalanche Zone Plan

Like the avalanche survey, the avalanche zone plan is also a basic part of avalanche protection. It contains all danger zones in the settled and tourist regions of a precinct and should be contained in the precinct construction ordinance as an integral part of it. The endangered regions are drawn in a plan (scale 1:1,000 to 1:10,000) and the safety regulations applying in these regions are described. As a part of the local planning, the zone plan serves the competent authorities in the evaluation of building applications. In endangered regions, it also forms the basis for construction of the alarm organization within the avalanche service.

The designation of avalanche zones can have drastic effects upon the property owner. Hence, in working up the zone plan, all available information must be utilized. The most important documentations are:

a. The avalanche survey,

b. The topographical conditions,

c. Avalanche dynamic calculations (determination of potential avalanches and their forces),

d. The avalanche chronology of the precinct,

e. Avalanche paths in the terrain,

f. Any available danger zone map within the framework of a regional plan,

g. Testimony of competent local authorities.

The avalanche survey provides information regarding all avalanche events which have actually occurred and have been recorded. Descents which occurred very far back are not usually contained in it. It is precisely the great and dangerous avalanches with a very long period of recurrence which are missing in the relatively new avalanche surveys. A thorough evaluation of the topography and of the precipitation conditions is therefore important for only by this means can possible avalanche zones be designated on the basis of avalanche dynamic computations. Also the danger zone map, which is substantially based upon the survey and upon avalanche dynamic computations (taking into account terrain and climatic and meteorological conditions) constitutes a valuable aid in working up zone plans. Today unfortunately, these danger zone maps are still largely lacking.

Basically, in the avalanche zone plan those areas are designated which, from the point of view of avalanche risk, cannot be endorsed either conditionally or unconditionally as regions suitable for building. As a rule, there are three different zones. The red zone is characterized by a general building prohibition. Its boundary follows essentially the boundary lines of the largest known avalanches. The drawing of boundaries is supplemented by the avalanche dynamic computations which have been mentioned and by means of which the possible extents of catastrophic avalanches can be determined. No exceptions should be allowed for construction in the red zones unless the building can be used without risk to men and animals (e.g., an alpine hut used only during the summer and provided with correctly dimensioned protective equipment).

The blue zone comes next to the red zone. A certain degree of avalanche danger exists also in these regions. However, the possible avalanche forces can be sustained without damage, as a result of reinforcement or in consequence of special arrangement and improvement of the structures. Hence, dwelling houses are permitted in the blue zone provided certain safety specifications are met. Exceptions are buildings which give rise to a high degree of traffic or to unusually large assemblages of people (churches, schoolhouses, hotels).

In the blue zone, the danger diminishes with increasing distance from the red zone. Hence, it can be subdivided into subzones having different safety specifications (Figure 2). Evacuation duty must be imposed upon the entire blue zone and this requires the organization of an avalanche service. The latter must be sure that in the event of avalanche danger, the inhabitants of the blue zone shall be warned and when necessary evacuated. In this way it will be possible to at least avoid personal damage in the event of an avalanche descent.

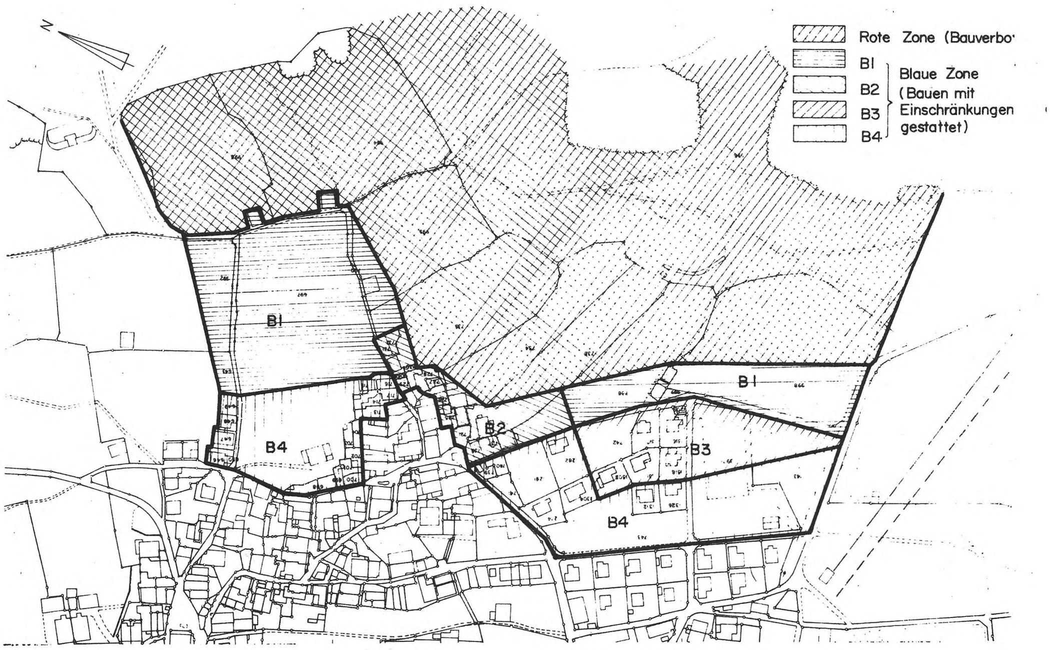
In the white zone, no avalanche danger exists. These regions are left open to settlement. During extreme snow and avalanche conditions, the avalanche service must provide for this zone also a continuous evaluation of the situation so that the inhabitants may be promptly warned of any unforeseen dangers. Under certain circumstances, parts of white zones are also cut off from their environment by interruption of transportation routes.

Avalanche zone planning is primarily the concern of the political precincts and they must also make the decisions regarding admissible risks for the various zones. The creation of avalanche zone plans must be made possible on the basis of legal principles. Up until the present in most cantons, there is a lack of proper planning laws which would provide for the introduction of the avalanche zone plan within the framework of local and regional planning. However, many building laws contain regulations designating building-prohibition zones so that on the basis of these regulations it is possible to designate avalanche zones. In exceptional cases, a precinct can also appeal to the "general police clause" according to which the precinct authority is responsible for undertaking all measures required for protection of the community from dangers in the form of floods, fire, landslides, avalanches, or epidemics.

The avalanche zone plan creates public law limitations which relate to the right to freely dispose of real estate. From this no compensation claims can be inferred since the agencies involved are forces of nature.

The avalanche zone plan must be approved by the precinct. The cantonal specifications also require as a rule approval upon the part of the federal government. The presence of a piece of property in either the red or the blue zone is to be recorded in the property register; for endangerment from avalanches is an important constituent of the real estate description. Only by the notation in the property register can unsuspecting prospective purchasers be made aware of this danger. In this way, the avalanche risk may be considered to be known to everyone.

Figure 1. Excerpt from the "Sernftal" Avalanche Survey, in the District of Matt and Elm, Cantonal Forestry Office of Glarus, National Map 1:25,000, reproduced with the permission of the Federal National Topographic Office, 31 October 1972.



N
Rote Zone (Bauverbo
BI
B2
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Blaue Zone
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3.3 Structural Avalanche Protection Measures

Corresponding to their nature and mode of action, two different types of structures are distinguished: structures in the starting zone which prevent avalanches, and structures in the track and runout zones which reduce the damaging effect of descending avalanches. In the starting zone, support structures (Figure 3) and drift structures (Figure 4) are introduced while deflection structures (Figure 5) and retarding structures (Figure 6) take over direct protection of the object in the track and in the runout zone. Both types of structures are also distinguished with regard to their form. They can be set up as massive installations (Figure 7 and 16-18) in the form of heavy structures without perforated surfaces (walls, terraces), as articulated installations (Figures 7-15), composed of various self-contained structural elements (snow bridges, snow rakes, snow nets) and as combined installations consisting of one massive and one articulated component (Figure 7).

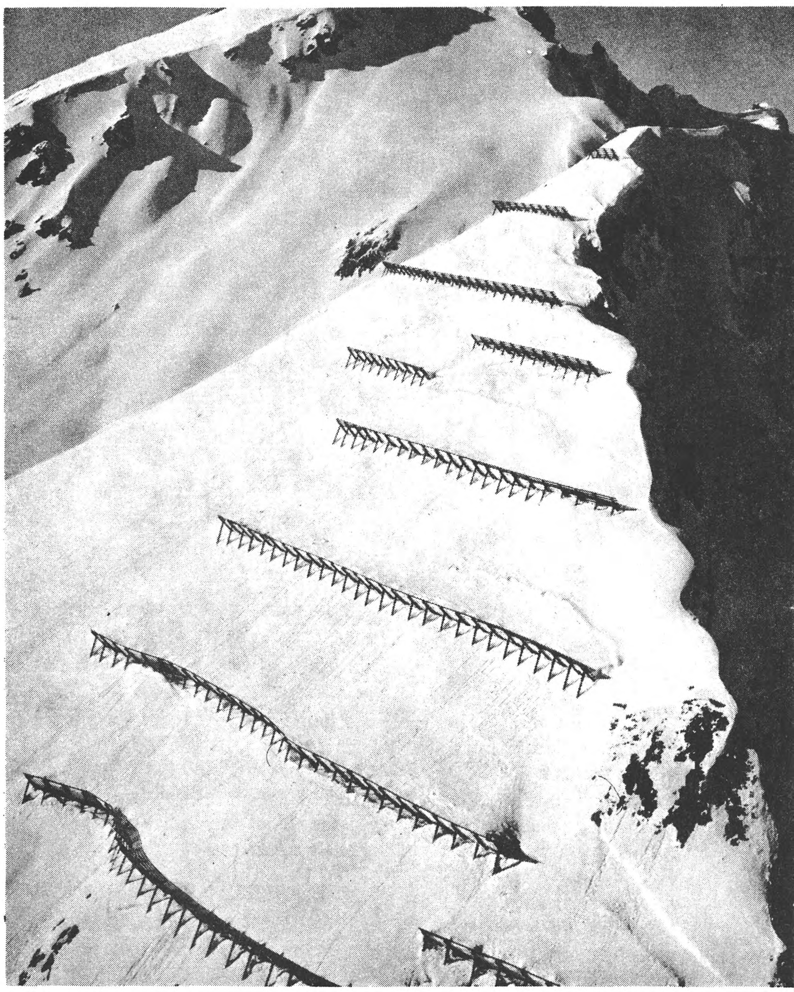


Figure 3. Control structures in the starting zone of avalanches Section 3.3.1); continuous arrangement of articulated supporting structures (photo E. Wengi).

Figure 2a. "Aetzgen" avalanche zone plan of the Ennenda Precinct, H. Oppliger, Cantonal Forestry Office in Glarus, property register plan: the blue zone is subdivided into four subzones having various safety regulations.

Figure 2b. Aerial photo of the "Aetzgenlaui" with plotted avalanche zones (photo E. Wengi).

Key: 1. Red zone (construction prohibited)
2. Blue zone (restricted construction permitted)

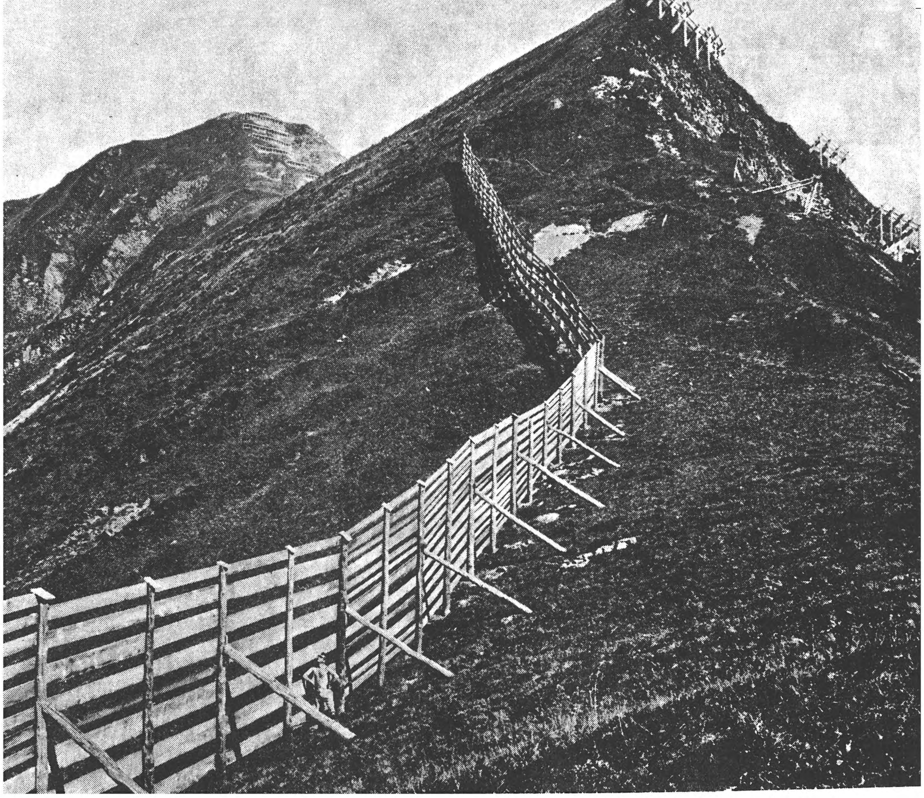


Figure 4. Structures in the starting zone of avalanches (section 3.3.1); snow fence with horizontal boards. When the boards are vertical, one uses the term "snow drift fence" (photo EISLF). [In the United States, there are no simple terms to differentiate between snow fences with vertical boards and snow fences with horizontal boards.]

3.3.1 Structures in the Starting Zones of Avalanches

Supporting Structures

Supporting structures support the snow cover in such a way that there can arise either very little snow movement or none at all. Assuming correct dimensioning of the structures, avalanches are prevented in the starting zones. A fully developed avalanche generates forces which, as a rule, cannot be sustained by a support structure. In control-structure regions above treeline, permanent installations are set up which consist of materials having as long a service life as possible (steel, concrete, aluminum). Within the tree zone, where the structure surface can be surrounded by forest, the requirements for durability of the materials are less stringent. It is temporary construction. Immediately after setting up the installation, consisting generally of impregnated wood, the area is afforested with suitable types of trees. After a certain time, the newly established forest prevents the onset of avalanches. In many construction projects we find permanent and temporary installations next to one another: above treeline there are installations of steel and concrete, while in the forest region wood grates and earth terraces are combined with afforestation.

A distinction is drawn between continuous (Figure 3) and broken (Figure 8) arrangement of supporting structures.

Continuous arrangement consists of long, horizontal series of structures which extend over the entire breadth of the terrain which is to be controlled. The lines of structures are interrupted only by parts of the terrain which are safe from avalanches. The broken arrangement displays intermediate spaces in the horizontal lines of structures. Depending upon the arrangement of the structures, a distinction is made between broken-interrupted and broken-staggered or a combination of these two possibilities. The arrangement of the structures is guided by topographic conditions in the construction region, the types of structures and the significance of the objects to be protected, taking into account the admissible risk.

Figure 5. Measures taken in the track and in the run-out zone of avalanches (section 3.3.2). Guidance and deflection walls of back-filled dry masonry for the protection of a dwelling (photo E. Wengi).

Figure 6. Measures taken in the runout zone of avalanches (section 3.3.2) retarding mounds with trap-dike; the retarding mounds divide th avalanche into many small arms and thus reduce their energy of motion so that the avalanche is brought to a standstill by the trap-dike (photo E. Wengi).

The types of supporting structures are: snow bridges (Figures 9-12), snow rakes (Figures 13, 14), snow nets (Figure 15), avalanche fences[1/] (Figure 7), walls (Figures 7, 16, 17), and terraces (Figure 18). The most varied materials are suitable for construction of these installations, such as steel (Figure 9), concrete (Figure 11), wood (Figures 10, 14), wire cable (Figure 15), aluminum (Figures 12, 13), natural rock (Figures 7, 16), wire gravel baskets in conjunction with natural rock (Figure 17), and earth (Figure 18).

Snow Drift Structures [wind-blown snow]

By utilizing wind forces, snow deposits can be influenced so that the formation of great mounds is hindered and the snow cover is favorably influenced mechanically (formation of pits, snow deposit outside starting zones). In exceptional cases, the break-up of snow mounds can be the impulse which triggers avalanches. When the formation of such a mound has been prevented by a snow drift structure, the avalanche path is thereby rendered safe. However, as a rule, drift structures are combined with support structures to modify the snow deposit in the starting zone of an avalanche by introducing snow drift installations in the form of massive snow drift walls and snow drift dikes or by means of articulated types of installation such as solid snow fences (Figure 19), wind baffles, snow fences with horizontal boards (Figure 4), or snow fences with vertical boards. In this way under certain circumstances, extreme depths of snow, for which it would hardly be possible to construct supporting structures, can be reduced to a controllable magnitude.

1/ The term Schneehaege refers to a vertical fence-like supporting structure. Hereafter, we will call it an avalanche fence and reserve the term snow fence for structures used to control blowing snow.

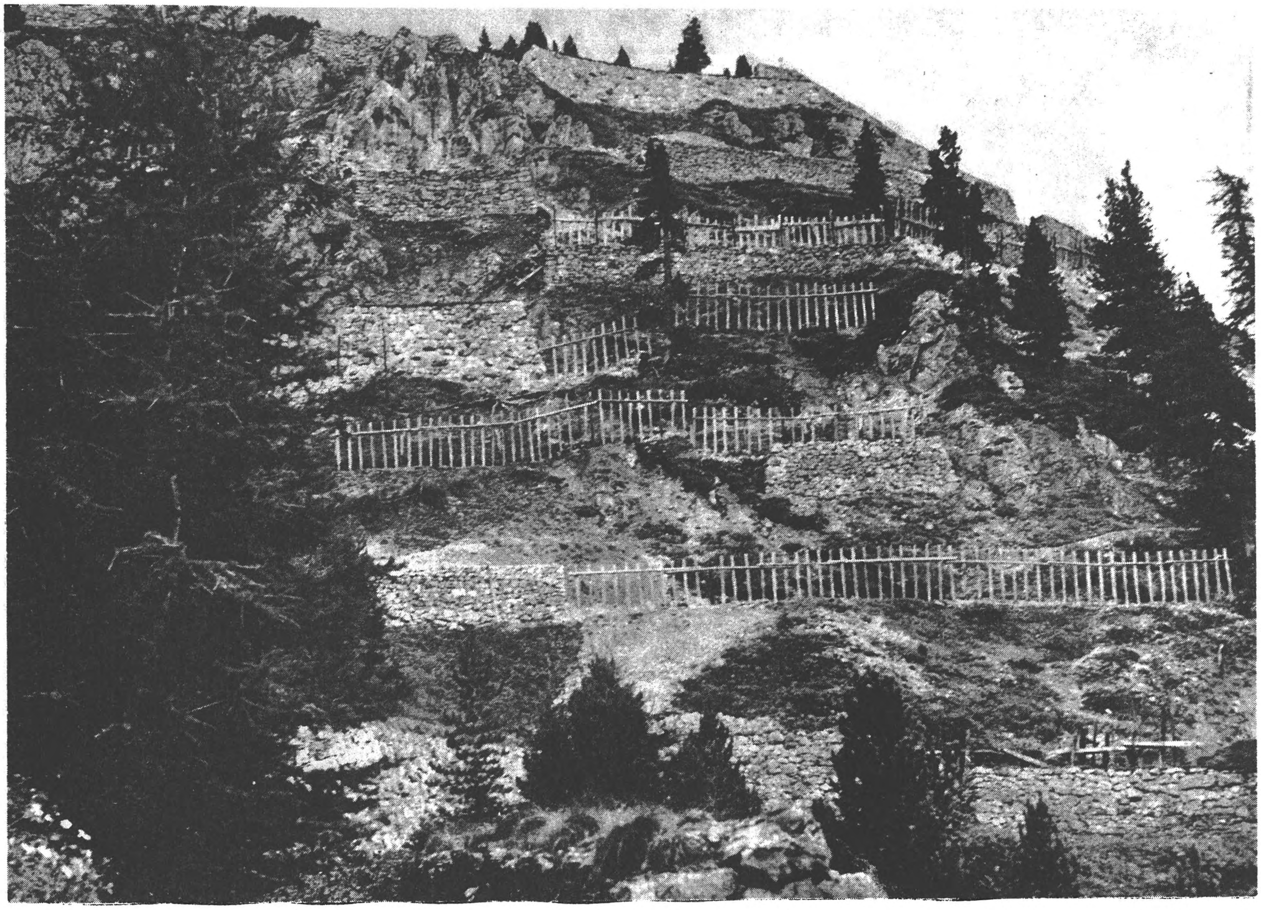
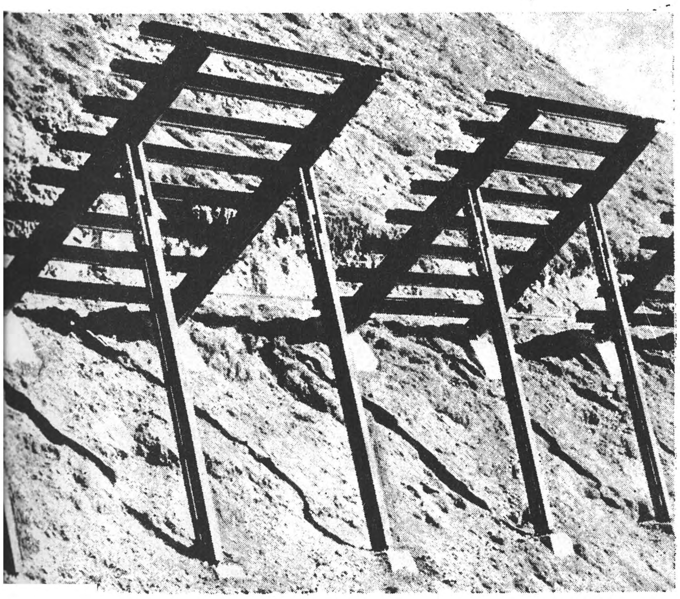


Figure 7. Distinguishing structures according to their form; walls are massive installations without perforated surfaces, avalanche fences are [vertical] articulated installations; in part both forms are combined: walls with superimposed avalanche fences (photo EISLF).

Figure 8. Structures in the starting zone of avalanches (section 3.3.1); broken arrangement of articulated supporting structures (photo E. Wengi).

Figure 9. Snow bridge; the beams of the compression grid are horizontal, supports and joists are anchored in the ground (concrete foundations installed on the spot or prefabricated elements, called base plates, are buried in the ground). Steel work of the Austrian-Alpine Montan Company (photo H. Oppliger).



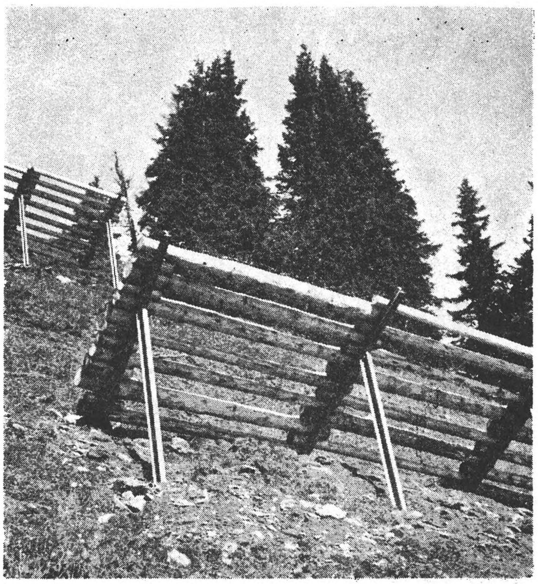


Figure 10. Three-element snow bridge; supporting structures made of railroad rails, grid consists of impregnated fir wood (photo E. Blumer).

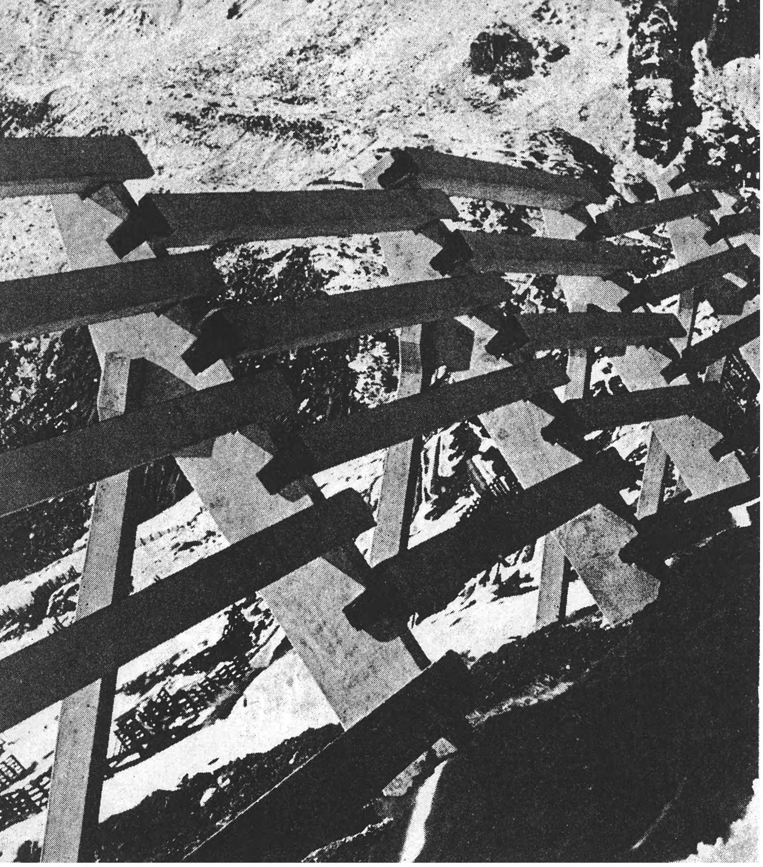
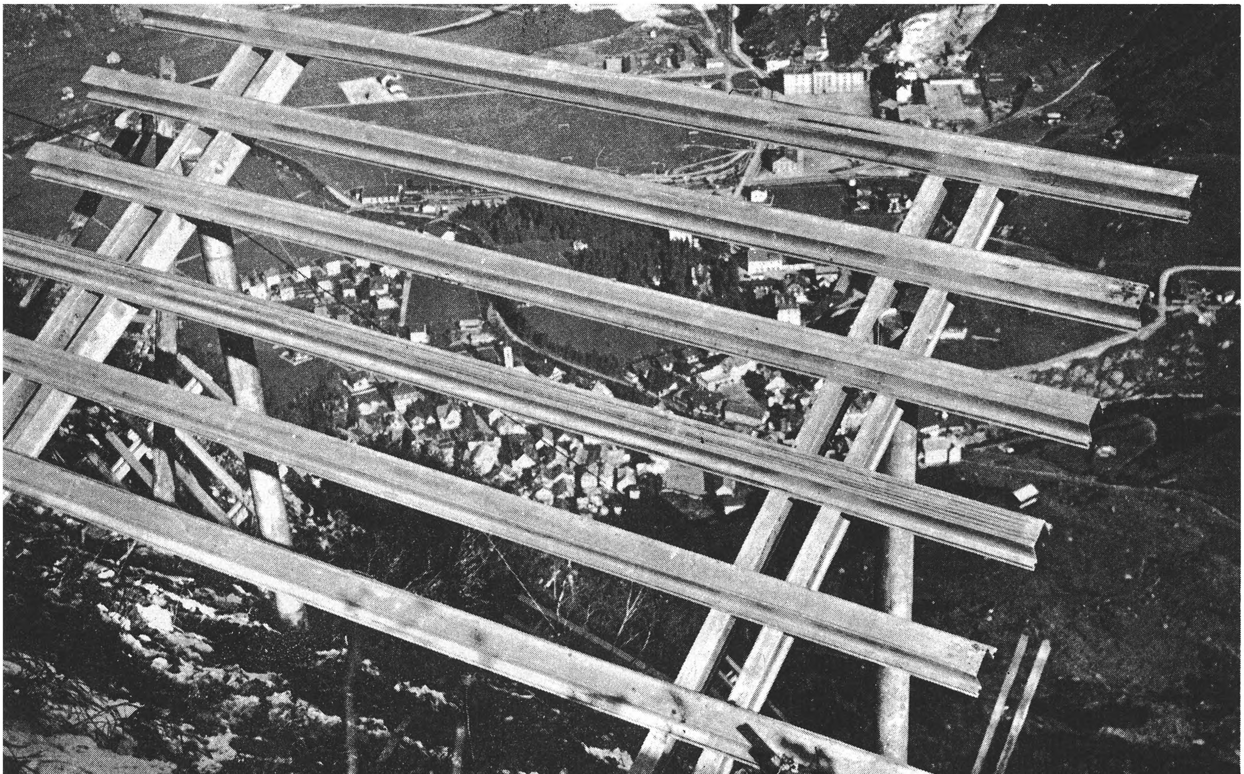


Figure 11. Multi-element snow bridge of prestressed concrete produced by the Prestressed Concrete Company (VOBAG) (photo A. Roch).

Figure 12. Single-element light metal snow bridge of the Aluminum Industry Company (AIAG) (photo H. Frutiger).



3.3.2 Measures To Be Taken in the Track and Runout Zone of Avalanches

In many cases, the onset of an avalanche cannot be prevented or can be prevented only at disproportionately high cost. Here deflection and retarding structures make possible the protection of important objects. Deflection structures consist of walls (Figure 5) or dikes which change the direction of the moving avalanche and deflect it from the object to be protected. Also included among deflection structures are galleries (Figure 21), splitting wedges (Figure 22), and inclined terraces (Figure 20) which lie directly in front of the protected object. Retarding structures shorten the extent of the avalanche and thus prevent the avalanche from penetrating into the endangered zone. This purpose is served by trap-dikes (Figure 6), trap-walls, retarding mounds (Figure 6), and retarding wedges.

Figure 13. Snow rake; the beams of the supporting grid are perpendicular to the slope, aluminum rake of the AIAG. [Beams of a snow rake are usually erected 15° downhill from the perpendicular to the slope] (photo H. Oppliger).

Figure 14. Snow rake of wood; temporary supporting structures; grid, supports, pinscers [Zangen], and swiveling beams consist of chestnut wood, the stringers of fir wood covered with aluminum sheet and the ties lying on the ground are made of railroad rails (photo H. Oppliger).

Figure 15. Multi-element snow net of the Brugg cable installation; the "compression grid" consists of wire cable nets hanging on swivel supports. Snow nets are light and capable of resisting rock impact (photo H. Oppliger).

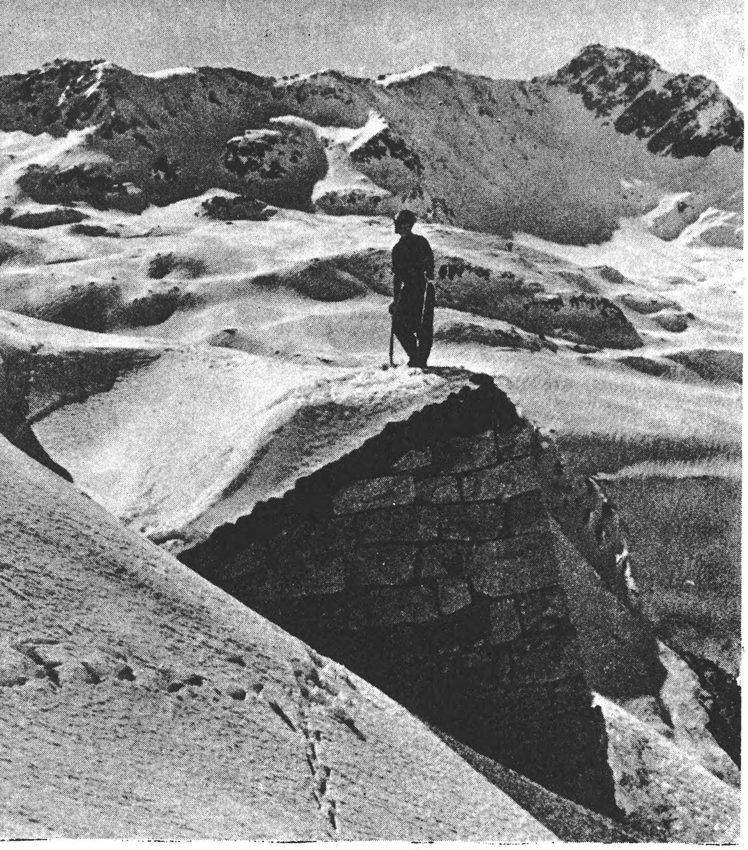


Figure 16.

Back-filled wall of broken stone covered with earth (photo P. Nipkow).

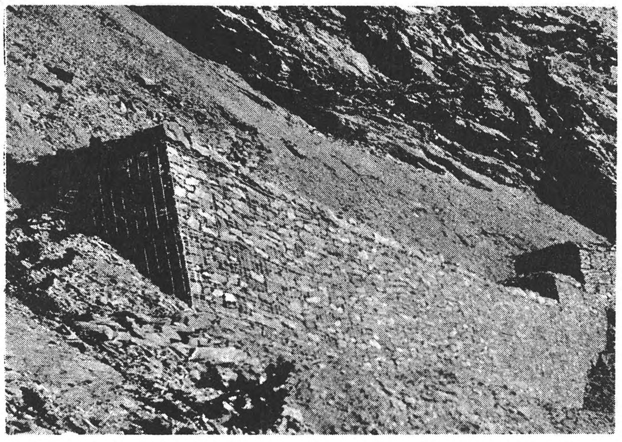


Figure 17. Wall consisting of broken stone and wire gravel baskets [Gabion]; by using woven wire containers it is possible to employ the rock material which often becomes available in great quantities (excavated in the construction of articulated supporting structures) for the construction of walls and wall terraces (photo E. Schildknecht).

Figure 18. Securing a steep slope with earth terrances in an old project; today earth terrances are introduced mainly to protect afforestations against creeping and gliding snow (photo R. Fehr).

In inhabited avalanche zones, which cannot be effectively protected by supporting structures or by direct protective measures, avalanche bunkers or avalanche cellars take over the protection of the endangered inhabitants. These are avalanche-proof rooms which may be resorted to in the case of acute avalanche danger when an evacuation is no longer possible. These dugouts must be so constructed that they also guarantee survival in the event of complete burial. It must also be possible for all endangered persons to reach them rapidly and without risk. Often avalanche cellars are created as additional or quickly available measures in combination with structures in the starting zone or in the track.

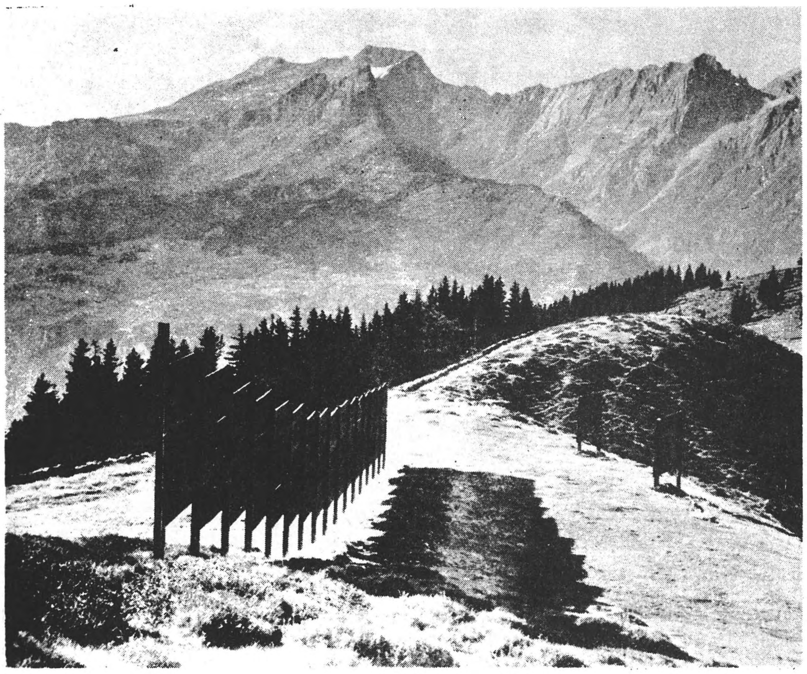


Figure 19. Snow drift structures; solid snow fence consisting of concrete-covered railroad rails and impregnated fir boards (photo E. Blumer).

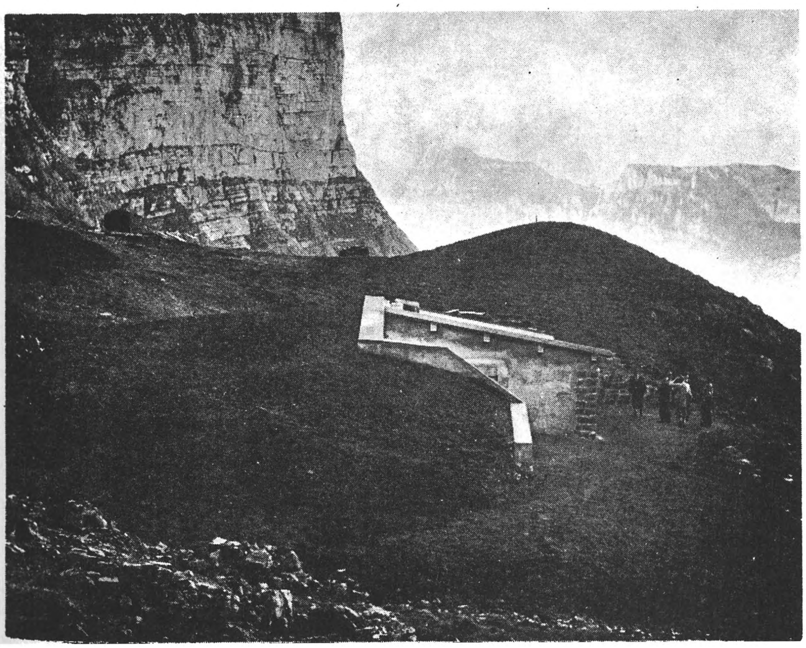


Figure 20. Inclined terrace; the back wall and the roof of the building are reinforced; the avalanche flows over the terrace and the building (photo E. Blumer).

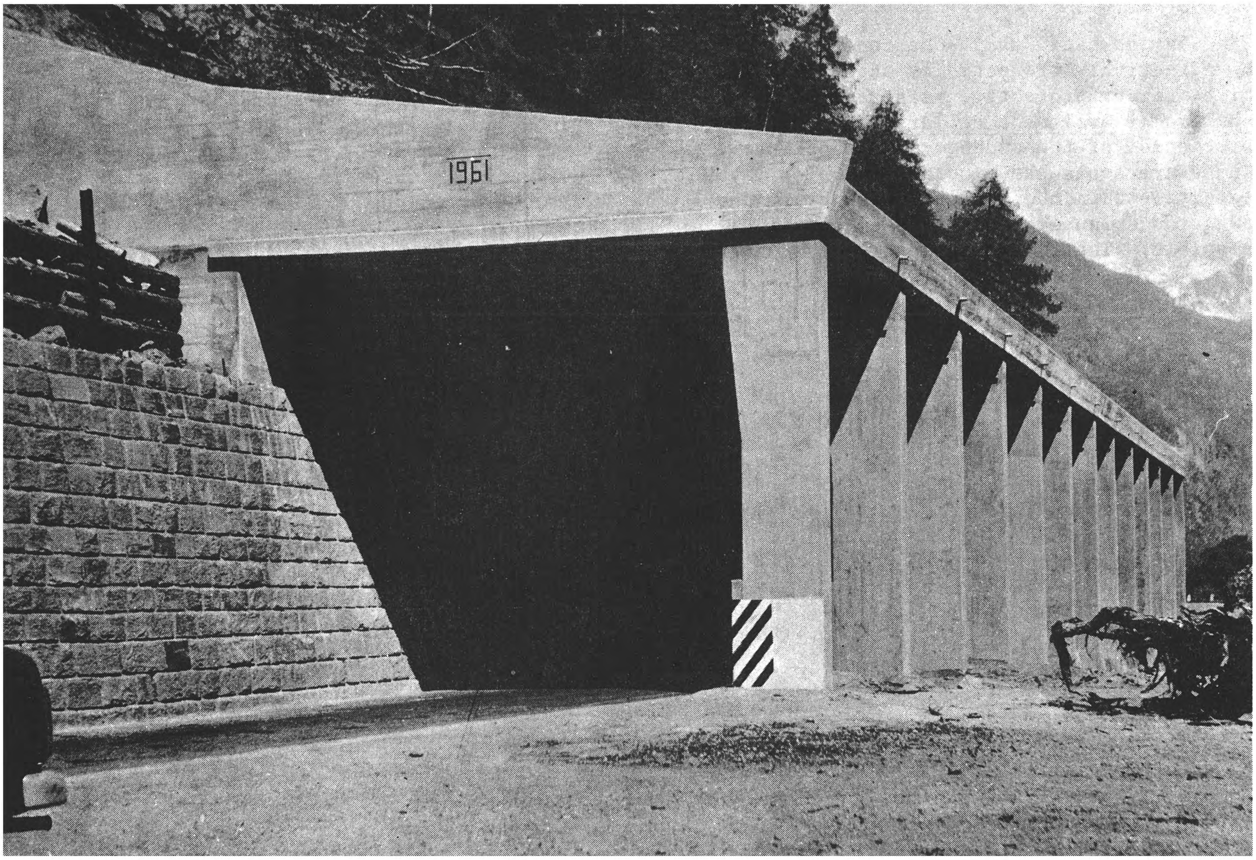


Figure 21. Avalanche gallery of reinforced concrete to protect a road (photo EISLF).

Figure 22. Splitting wedge; reinforced concrete wall with wedge-shaped earthen backfill protecting a stable (photo E. Blumer).

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[10] Documentation for an Introductory Course on the Avalanche Cadastral Survey, Davos, July 1962 and April 1967; Documentation for an Introductory Course for Those Preparing Avalanche Zone Plans, Davos, November 1962; Documentation for a Course in Avalanche Control Structures, Davos, June 1969; Documentation for a Course in Avalanche Safety Service in Communities, Lucerne, November 1970.

[11] Regulation Concerning Avalanche Service in the Community of Trun.

[12] Regulation Concerning Avalanche Service in Davos.

IV. HISTORICAL BACKGROUND OF SWISS AVALANCHE CONTROL CONSTRUCTION (Hans Frutiger, Weissfluhjoch/Davos)

There are several reasons for illustrating the development of Swiss avalanche control projects by the example of Davos. Here may be found a great selection of various types of control structures. In addition, the most varied forms of avalanche protection are placed at the service of the safety of this tourist center. These include not only structural protection, but also other possible measures such as the avalanche zone plan, warning service, closures, and artificial triggering of avalanches. In Davos, the development from a mountain farming hamlet to health resort and later into a winter sports center began somewhat more than 100 years ago. The stretch from Landquart to Davos was the first subsection of the Rhaetian railroad and several large mountain railroad projects coincide in time with the beginnings of so-called "technical" avalanche control construction. The development of the latter was strongly influenced by the avalanche problems of these railroads. Moreover, the activity of important pioneers in avalanche control construction was closely bound up with Davos. Since 1934, avalanche research has been conducted on the Weissfluhjoch in the region of Davos so that naturally it has also been possible to study the problems of control structures more thoroughly than might have been possible elsewhere.

There exist numerous indications that in the course of the 17th to the 19th centuries, because of increasing deforestation, there was a sharpening of avalanche endangerment in the valleys. Among other evidences, there is a hint of this in the very old edicts designed to protect forests above settlements. The Davos interdicts cover the period from 1535 to 1777. In the regions of the Valais, which also includes Davos, the decimation of the forest can be proven with specially good reliability. It is not an accident that valleys settled by Valaisans frequently have the reputation of being avalanche valleys. A classic example is St. Antoenien where on the deforested sunny side, without exception, every individual farm has its own avalanche protection usually in the form of a splitting wedge. A well-known example of direct avalanche protection is the Lady Chapel at Davos. The chronicler Flury Sprecher reports: "In 1602 on 16 January, on a Saturday night, at 2400 hours, after it had been snowing for 3 weeks and the snow had reached a depth of over 12 shoes [sic], all at once powerful snow avalanches broke loose in Davos in several locations so that mountain and valley trembled and roared. Entire larch and pine trees with their roots, much earth, and stone were torn away, the Lady Chapel with 70 houses and farm buildings were demolished or carried away and buried with all the inhabitants in the snow." And Jakob Gaudenz: "Anno 1817, on 28 February, here near the Lady Chapel, a frightful snow avalanche came down from the Stafflerberg, covering and surrounding the church with snow up to the roof, so that it was necessary to enter through the window near the organ." Apparently the church had been equipped with a splitting wedge after the accident of January 1602. The latter withstood the Frauentobel avalanche of 25 January 1968 again, but did not prevent a crack in the long side of the building. We do not know how far back in time this type of avalanche protection -- known in modern terminology as "direct object protection" -- extends. It must be assumed that structural control of avalanches had its inception with the settlement of the mountain valleys. Numerous haystacks, herdsmen's huts, and stables had to be protected from the outset by means of inclined terraces at the back and by splitting wedges. Such types of avalanche protection may be found in most alpine valleys. Correspondingly great, too, is the number of variety of names such as "Ebihoech," "Ueberhoh," "Lauistock," "Schanze," "Pfeil," "Abwurf," "Triangel," "Spiessegg," "Pfanneir," "Schneefirst," and "Schirmmauer."

Also, modern designs for direct object protection such as avalanche dugouts and galleries have been known for a long time. In Saas Grund, probably after the avalanche disaster of 1849, so-called avalanche crypts were introduced. These are underground chambers in which the inhabitants find safety during avalanche danger. Between Lavin and Guarda, vaulted niches were constructed along the old road as avalanche dugouts for travelers. Also, galleries have been constructed in early times for the protection of alpine streets and roads. In the beginning of the 18th century, gallerys were introduced into the most avalanche-exposed parts of the mule track over the Spluegen in the Val Cardinello. The Bernhardin route which had been built in 1823 from the very outset was furnished with avalanche galleries on the south side in the Val San Giacomo. Around the year 1805, the Kaltwassern gallery was constructed on the Simplon. This beautiful masonry structure was compelled to yield in the sixties to the modern enlargement of the pass highway. In the year 1871, the Davos community obtained the first avalanche gallery in a place called Brombenz on the Zuegen road, which had been built between 1870 and 1873. In a report from the year 1899 we find: "At each heavy snowfall the snow slides off and then frequently fills up the road on both sides of the gallery. The place also has a bad name with the drivers." Eighteen years earlier Coaz had written: "In constructing galleries care should be taken to make them long enough because otherwise they give poor protection and, whenever both ends are buried, cannot be used or can be used only after the entrance and exit have been opened." Both these observations have been cited here because even in the most recent times, the same old mistake has been repeated.

In March of the year 1818, the silver mine was leased to Johann Hitz of Klosters. Before renewal of the lease in 1822, the Bernese forester Karl Albrecht Kasthofer was commissioned to give an expert opinion regarding the Davos forests. This was the immediate occasion of the mountain journey which he carried out in the interest of forestry science in 1821 over the Gotthard and Bernhardin [passes] to Davos. In the year 1816, he had published the "Notes on the Forest and Ranges of the Bernese Oberland." There he also speaks of avalanche control projects: "In the neighboring Valais here and there on steep mountainsides, where snow avalanches form readily, the country people have fixed posts of larch into the ground and this simple device prevents the development of avalanches." Also in other localities, early attempts were made with very simple equipment to prevent the onset of avalanches. On the Piz Cluenas, after the disaster of the year 1817, horizontal ditches were also excavated in order to anchor the snow cover. We also know that after the avalanche disaster of 1756 in Geschinen in the upper Valais, permission was granted by the bishop for work to be performed on Sundays and holy days to renovate the ditches in Birch, which therefore must have been built earlier. Evidently at that time, this form of avalanche control was not yet known in the Bernese Oberland, for Kasthofer continues: "The inhabitants of our valleys have suffered for centuries from this frightful natural phenomenon without ever having sought a means of preventing its occurrence. The maintenance of those forest districts which are designed to oppose the development of the destructive natural phenomena which have just been described, and the cultivation of forests to this end is one of the most difficult tasks of forestry science in the mountain highlands and indeed this is not only because of the great obstacles which are presented by the very nature of these rough regions and which not infrequently render any kind of forest cultivation or careful forest preservation impossible; these obstacles are made still greater as a consequence of the claims made by private persons upon the ownership and use of those mountain slopes which must be at the free disposal of forestry police and water police for the purpose of preventing avalanches, rock falls, and earth cave-ins." Thus, Kasthofer invokes the prevention of the occurrence of avalanches -- which in today's terminology is called "structural control of avalanches in the starting zone." Kasthofer together with a well-known Graubuenden forester, thereby introduces a new epoch in avalanche control construction. Since in the beginning it was primarily a matter of maintaining and reconstructing the protective forest, avalanche control became the task of the Forest Service and has remained so to the present.

About the middle of the 19th century, some events occurred which were of importance for the science of forestry and for avalanche control. The year 1834 brought devastating inundations of water. The consequences of forest destruction, which was in turn a consequence of salt-works operations, smelters, and overgrazing of mountain pastures, were now becoming apparent. In 1843, the Swiss Forest Association was formed; its foundation goes back to Kasthofer. One of its leading members was Elias Landolt. As the first professor of forestry science at the newly founded Swiss Federal Institute of Technology, in 1858 he was commissioned by the Federal Council to give an expert opinion regarding the state of the mountain forests. The comprehensive final report was printed in 1862 and disseminated in large numbers. On 27 October 1864, the forest association submitted to the Department of the Interior the following request: "It is recommended that for the promotion of forestry science an annual credit of 20,000 francs be introduced into the federal budget." On 12 March 1865, the forest association was able to declare in a letter to the governments of the mountain cantons: "The Federal Parliament has recognized the efforts of the association and their economic significance and has reserved for the association, with the given object, a credit of 10,000 francs for the year 1865." In this we recognize the antecedent of federal subsidies without which today's avalanche control would be unthinkable. The second great water emergency of the autumn of 1868 triggered action in this area. Forester Emil von Grayerz write in November 1868; "Now or never the federal government and the cantons will lend a hand to put a stop to the further devastations which threaten us from the mountains. There really remains no other hope and source of aid other than the federal government and we would really be astonished if this federal government, despite the cantonal sovereignty, had not the force, the power, and the will to undertake something which could protect the whole country from further devastation and impoverishment." Another 2.5 years passed before on 21 July of the year 1871, there was formulated the "Federal Resolution Concerning Approval of a Federal Contribution for Torrent Control and for Afforestation in the Alps."

The year of 1871 is also significant for our study in still another respect. In the period from 1851 to 1873, Johann Coaz was the forest inspector of Graubuenden. Building on the preliminary intellectual work of Tschokke, Kasthofer, and the forest association, he was able to convert many ideas into actuality. He went to work with unheard of energy. He had already had supporting structures built in 1868 on Motta d'Alp in the lower Engadine, and he himself called it the "first structural control of avalanches carried out under engineering supervision in the Swiss Alps."

On 26 July 1870, the Alberti Torrent, which was at that time still without any structures, produced a great flood and devastated the surroundings of the cemetery. Coaz, presumably still in the year 1871, had urged the federal district forester to notify him of places where afforestations were necessary or desirable and had submitted to the government a tabulation of such places. Davos is represented there by two projects, namely, with the afforestations of the Alberti Torrent and of the avalanche path in St. John's wood. With its 56 hectares the Alberti is the largest afforestation in the area. There soon followed a further afforestation project for the watershed of the Gugger Torrent with 36 hectares. How great the afforestation activity at that time was can be gathered from the figures for the upper Engadine where in the years 1875 to 1934, on an area of 681 hectares, 5.34 million seedlings were set out. Table 1 shows what was accomplished in Davos.

In these projects, the starting zones of avalanches were built up almost exclusively with terraces and post installations. Figure 1 shows the standard procedures at that time.

With the help of these installations, numerous afforestations were promoted. But it had long been recognized that it was not the case that "this simple means prevented the occurrence of avalanches," as Kasthofer had expressed himself in 1816. Today, terraces and post installations are merely an auxiliary device for the protection of afforestation, particularly as a protection against gliding snow. Since 1955, their suitability has been under test on extended experimental areas of the Federal Institute for Snow and Avalanche Research on the Dorfberg near Davos.

The avalanches which devastated Davos on 23 December 1919, were the occasion for further construction projects. For the most part, these extended far above the upper tree line where afforestations were no longer possible.

Table 1. Afforestations and Construction Projects in Davos 1874-1920

Name of Region	Area ha,	No. of Seedlings	Earth Terraces, Length, m	Rows of Posts No. of Posts	Rows of Posts Length, m
Albertitobel	55.8	331,000	7,398	?	?
St. Johannwald	2.8	5,220	437	729	510
Brombenz	1.5	5,300	--	75	44
Haehlzuegli	2.2	9,100	183	1,130	792
Schatzwald	36.3	103,315	980	1,971	1,380
Waldenmaehder and Hohruefeli	3.3	6,600	--	7,227	5,060
	101.9	460,535	8,998	11,132	7,786

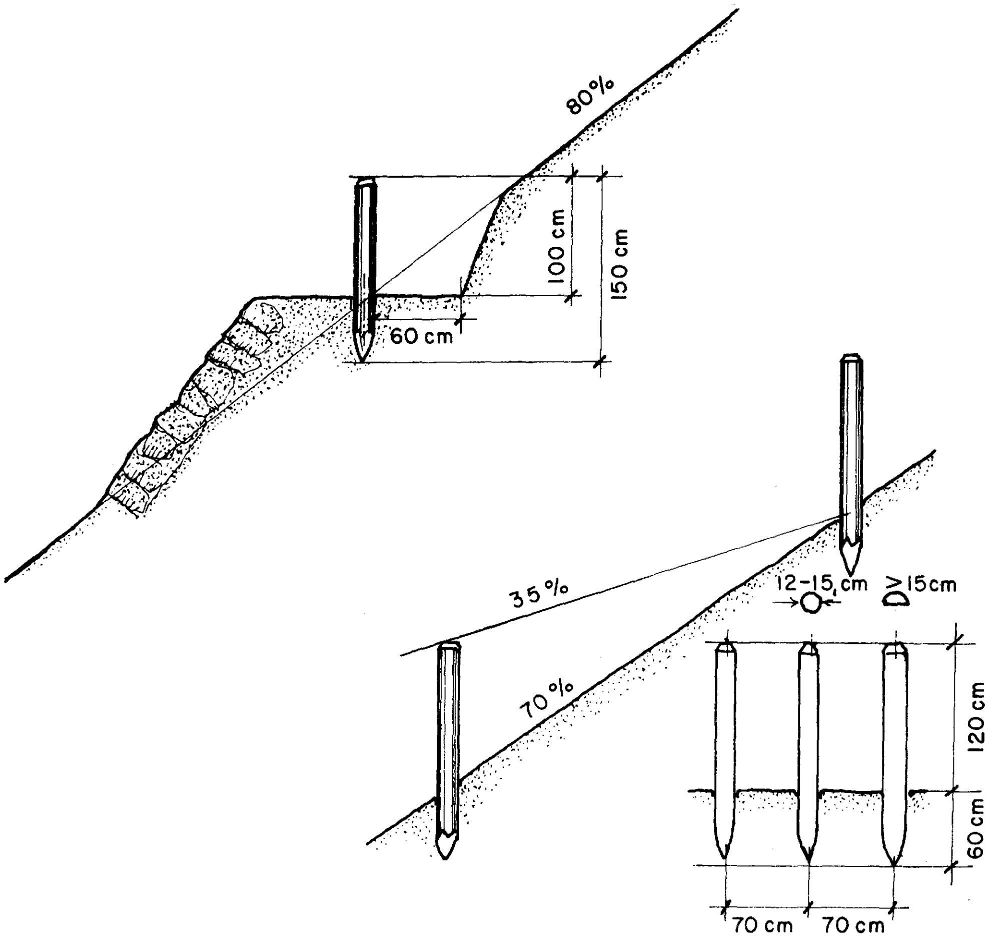

Figure 1. Top: standard procedures for earth terraces (beams) and rows of posts for the "Guggerbach-Schatzalp" afforestation near Davos; autumn 1901. Below: standard procedures for rows of posts for the "Waldenmaeder" afforestation near Davos; August 1910.

On the Schiawang and Dorfberg in the years 1920 to 1924, a total of 7,217 running meters of supporting structures were erected, predominantly walls, wall terraces, mixed terraces, and earth terraces. The building material, broken stones and earth were obtained on the spot or in the vicinity. Wood or even steel was employed only exceptionally for a few snow rakes in narrow couloirs. The structures, consisting principally of hewn stone, are called massive structures to distinguish them from the articulated type, e.g., the snow rake. In Switzerland between 1876 and 1938, about 1,000 km of supporting structures were erected, of which 95 percent were massive structures.

It soon became apparent that the broken stone wall construction was less durable than had been assumed. On the Schiawang and Dorfberg, after only a few years, substantial signs of disintegration appeared, particularly in the mixed terraces. Only 6 years after what had been thought to be the conclusion of the construction work it was necessary to set up a project for the alteration of the mixed terraces into wall terraces and for more extensive repairs on the walls. Improvement and enlargement operations extended into the year 1944.

A further inadequacy became apparent: the terracing of the slope did not suffice as a support for the snow cover whenever unfavorable conditions were present. Sufficient thought had not been given to the leveling effect of the wind upon the snow deposits and to the differential snow cover build-up (compare Figure 2); avalanches broke loose also in the defense areas.

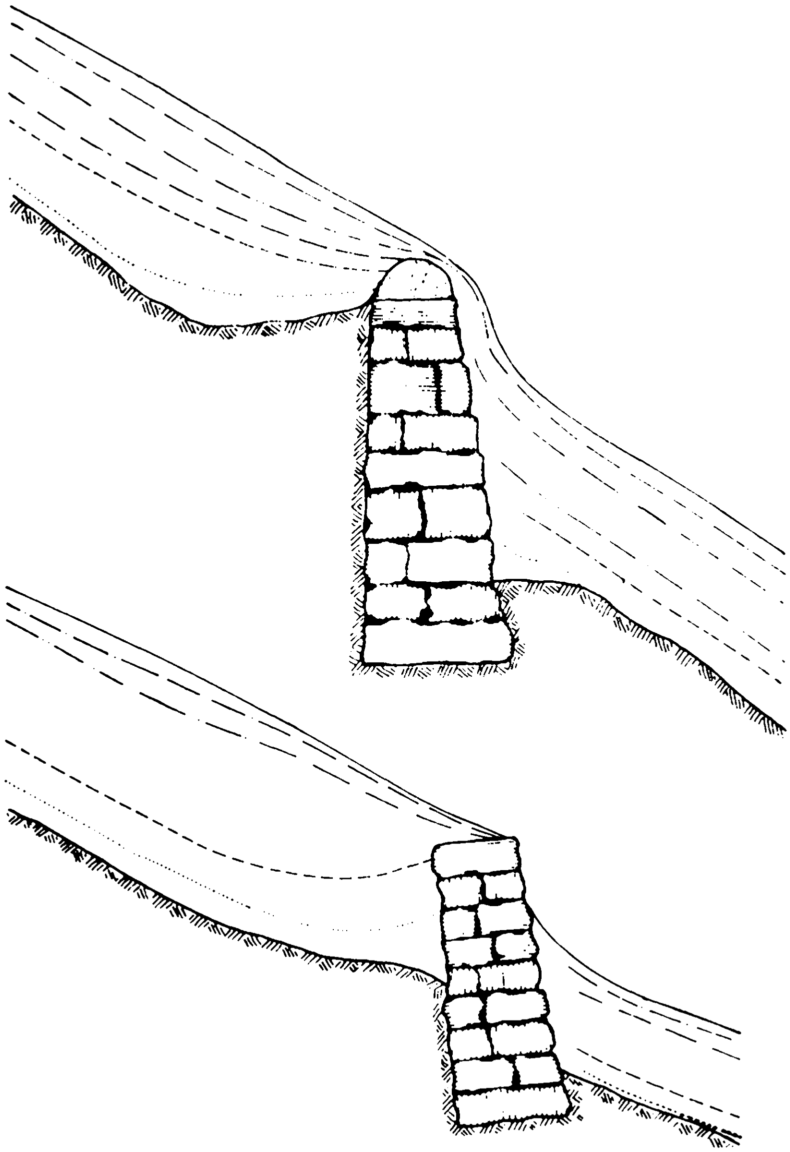

Figure 2. Leveling effect of the wind upon snow deposition among massive supporting strucures (after F. Eugster, 1938, p. 72). Top: wall terrace Alpetta, 2,230 m above sea level; 30 January 1930. Bottom: free-standing wall, Alp Gruem-Cavaglia, 2,100 m above sea level; 21 January 1930.

The years between 1920 and 1940 are characterized by a new pioneering development. The federal forest inspector F. Fankhauser II had continued in the twenties to be a zealous proponent of avalanche control by means of terraces, although Vincenz Pollack, who had made penetrating and thorough studies of avalanche construction projects along the Arlberg road, had already in 1907 cast considerable doubt upon the effectiveness of such "earth banks and stone banks" and "stepped excavations." Coaz was also aware of the inadequacy of such structures, for in 1910 he wrote: "The so-called 'surface layer avalanches' constitute one of the greatest dangers for any control construction, and hence we have every reason to prevent the development of such avalanches. One method of doing this is to erect the installations taller than usual so that wherever possible they extend into the upper part of the snow cover. This can be accomplished to a certain degree; however, the associated costs should not be allowed to range too high." Knowing this fact, progressively taller structures have been built in the Obergesteler Galen. Hess wrote in 1936: "When these installations, too, turned out to be inadequate and snow slides recently ran over them, it became necessary to build still more effectively. The last wall type attains a total height of 8-9 m, of which 6-7 m of useful height extend above the slope."

A certain malaise became evident in structural control of avalanches. This becomes clearly evident in the "Experiences With Structural Control of Avalanches," which Emil Hess, who was then forest inspector, published under contract to the forest inspectorate in 1936. In the introduction he asserted: "Considering the importance and the many-sidedness of the problems and their effect upon the public economy of the mountain regions it would have been worthwhile, even a long time ago, to gain closer knowledge of avalanche formation by means of systematic observations and experiments, in order to obtain generally valid principles for the installation of structures." He remarks further that Switzerland, with respect to exact snow research, had stayed behind the neighboring countries and that means were lacking for large-scale research studies. However, the latter were already in progress. In the year 1931, the Federal Snow and Avalanche Research Commission had been founded, and in 1935, a team of researchers had started the work in Davos. In the first winter, the work was still carried out down in Davos and after 1936 up on the Weissfluhjoch. As early as 1939, results of decisive importance for avalanche control construction were published in in a comprehensive work entitled "Snow and Its Metamorphism." R. Haefeli had succeeded in carrying out a snow pressure computation which became the basis for the design of modern, articulated supporting structures. In the region of the Weissfluhjoch, it was possible to check the theory by means of snow pressure measuring devices in the form of snow bridges. At the same time, the avalanche-control structures in the vicinity offered ample opportunity to continue intensively the winter observations which had already been begun earlier in other localities. The already mentioned inadequacies were also confirmed in the Dorfberg project which had been strengthened in the years 1947 and 1948 by the erection of snow fences and snow rakes between the terraces. During the supplementary operations on the Schiawang, the idea was conceived as early as 1935 of replacing the wooden beams of the snow rakes, which at that time had an almost horizontal supporting plane, with prefabricated, armored concrete beams. Experiments were also carried out with woven wire coverings on the support grates.

In 1942, snow research set up shop in the newly erected institute on the Weissfluhjoch. Its first director, E. Bucher, in 1947 published the "Discussion of Avalanche Defense Works"[1/] and in 1948 there followed the "Contribution to the Theoretical Foundations of Avalanche Defense Construction."[2/] It would take us too far afield here to describe in detail the investigations and conclusions of Haefeli and Bucher, although in certain respects they exercised a great influence upon the technology of the practice of avalanche-control construction. For the further development of structural control of avalanches, there was importance in the requirement that the supporting structures should be built high enough so they would not be covered by snow. In the case of massive structures this was possible only with disproportionately high costs. Bucher came to the conclusion, "that the rake structure erected approximately perpendicular to the slope may be considered a very useful construction element."

There soon followed the avalanche winter 1950/51 and the federal law of 19 December 1951 which brought with it an extraordinary subsidy over a 30-year period in the form of increased federal contributions to afforestation and structural-control of avalanches. For operations in the starting zone and for the restoration of protective forests, up to 80 percent of the cost was borne by the federal government. There were new allocations, over a period of 10 years, of contributions of up to 50 percent to galleries protecting highways and roads and up to 30 percent for the relocation of avalanche-endangered buildings [sic]. This unleased a veritable flood of control projects. The development proceeded with unexpected speed. In the "Contribution to the Study of Structural Types in Avalanche-Control Projects" of the Federal Institute for Snow and Avalanche Research (EISLF) of 1951, the building materials considered were steel, concrete, and wood. In late fall of the very same year the first light metal snow bridges were installed in the "Mattstock"/Amden project and almost simultaneously in January 1952 the Prestressed Concrete Company (VOBAG) made its first contacts with snow research for the purpose of producing snow bridges. In August 1952, there began the installation of the

1/ In English as: Technical Translation TT 66 National Research Council of Canada, 6 April 1948.

2/ In English as: Translation 18 U.S. Army Snow, Ice, and Permafrost Research Establishment [now called CRREL] Hanover, New Hampshire, February 1956.

first VOBAG snow bridges in the "Milez"/Tavetsch project. Along with the snow bridges there then came a basically new type, the snow net. In the fall of 1951, square nets of wire cable from the Brugg Cable Works Company (KWB) were set up in the "Schafberg"/Pontresina project and for the protection of the Maloja road in Sils-Baselgia. In December of the same year, the KWB proposed to the snow researchers that investigations be conducted regarding the suitability of the wire cable net for avalanche defense works and that the design proposals be checked. In the study "Proposals for the Design and Calculation of Net Installations," R. Haefeli in 1954 proposed the triangular snow net and extended the snow pressure calculation to the latter. He saw in the slack trapping surface a particular advantage in contrast to the conventional rigid supporting plane. Within a few years the open structures had developed from the ponderous wall to the extremely slender and light snow net. Now open structures are employed almost exclusively.

In the spring of 1955, E. Hanausek encouraged the Austrian-Alpine Montan Company to develop a steel snow bridge. In late fall of the same year, the first 50 bridges were delivered for avalanche control on the Heuberg near Haeselgehr/Tirol. In close cooperation with the EISLF, which supplied the design criteria, the steel structures were further developed and were soon employed generally in Switzerland also.

In the year 1952, the EISLF installed the experimental project on the Dorfberg near Davos. This permitted continuous observation of the various types of structures with regard to their effect upon the snow cover and with regard to the effect and stability of the various building materials. Here, gathered into the most restricted space, all possible types of structures can be examined.

In response to this rapid development, regulatory measures soon asserted themselves. The federal forest inspectorate, as the supervisory organ of the federal government, which had to carry the major part of the costs of structural control of avalanches issued various directives with the purpose of creating uniform principles for planning structural control of avalanches. On 30 November 1953, the "Table of Technical Terminology for Structural Control of Avalanches" and on 20 May 1955, the "Provisional Guidelines for the Design of Permanent Supporting Structures" were published. In the beginning of 1961, the latter were given definitive form. The use of these guidelines is binding upon all avalanche structural control projects subsidized by the Swiss Federal Government.

Table 2. Comparison of the Lengths of Massive and Open Supporting Structures

Period	Massive Structures m'	Massive Structures %	Open Structures m'	Open Structures %
Davos 1920-1924				
Schiawang-Dorfberg	7,045	98	172	2
Switzerland 1876-1938	990,500	95	50,000	5
Switzerland 1938-1966	20,800	18	96,700	82

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V. PRINCIPLES OF STRUCTURAL CONTROL OF AVALANCHES (Bruno Salm, Weissfluhjoch/ Davos)

1. Introduction

"If one compares the relatively short development time of structural control of avalanches with that of other areas of construction, then it is not surprising that structural control in the starting zone, with which we are exclusively concerned here, is still in its period of stormy youth." It was thus that the respected pioneer of snow and avalanche research Prof. Dr. R. Haefeli described the situation in structural avalanche control in the year 1951 [1]. In the meantime, some things have changed. The "storms" have in great part subsided and we have moved into a rather "classical" period. In the past 21 years, the investigation of fundamentals regarding the material properties of snow has been intensively pressed forward not only in Switzerland but also in many foreign research institutes. At the same time, the behavior of avalanche control structures was continuously observed by the practitioners and from this it was possible to draw useful conclusions. The development manifested itself for example in the "Guidelines of the Federal Forest Inspectorate for Supporting Structures" [2], where all insights and experiences accumulated in the course of time are summarized. These guidelines were already in their fifth edition in 1968.

It is not, however, our intention to leave the impression that all problems of avalanche structural control have been solved. There continue to be gaps; occasional, often heatedly conducted discussions among specialists attest to these gaps. Nevertheless, it may be contended that today it has become possible to set up avalanche structural control which guarantees a very high degree of safety. Often the problems now lie more on the political and financial plane and no longer on the technical plane.

2. The Material Properties of Snow

Combating avalanches presupposes a knowledge of the material properties of snow which is as comprehensive as possible. One should clearly understand why avalanches occur, why at this particular slope and not at another. Further, one should also understand how they move, what velocities are attained, and what sort of dynamic effects are to be expected, etc.

First a distinction must be drawn between snow which has retained its original structure, or in other words, as it occurs in the naturally deposited snow cover, and snow whose original structure has been, at least partially, destroyed by fracture processes. The first kind shall be called "natural snow" and the second "avalanche snow," where the latter may be understood to be a thorough mixture of the smallest snow particles with air into a so-called aerosol (compare de Quervain 2, 3).

2.1 Natural Snow

The behavior of natural snow is similar to that of a tough, compressible fluid. In contrast to a rigid body, snow therefore deforms even under the very smallest loads and modifies both its shape (shearing and extension deformation) and volume (volume changes). It is one of the most important problems of snow mechanics to find a relation which shall be as general as possible between stresses and deformation velocities. The very simplest relation between these two quantities is given for the Newtonian fluid in a one-dimensional state of stress by

$$\sigma = \frac{1}{a} \frac{\delta u}{\delta x} \qquad (1)$$

where σ denotes a tensile or compressive stress; a is a constant of viscosity which depends upon the nature of the snow; and u is the deformation velocity in the direction x. Thus the stresses are proportional, not to the velocities themselves but to their changes in the direction of one axis. Hence, we would have to look for the highest stresses in a snow cover wherever the velocities change most markedly. Tests have shown that relation (1) is valid only for very small stresses and deformations. The quantity "a" increases substantially as the stresses increase; in addition, it also depends upon whether σ involves a tensile or a compressive stress (being substantially greater in the case of compressive stresses). Nevertheless, equation (1) is entirely sufficient for our considerations. In addition, it is also valid for pure shear deformations perpendicular to the x-axis whenever the shear stress and shear deformation are substituted in place of normal stresses and normal deformations.

Naturally, relations like (1) are not valid for arbitrarily high stress magnitudes; here the strength of the material sets certain limits. As was the case with viscosity, this strength depends very much, in the case of snow, upon various factors and correspondingly varies between very wide limits. In general, the strength also increases with increasing specific weight. Besides, the compression strength of one and the same variety of snow is just about twice as great as its shearing and tensile strength (the two latter being about equally large). Finally, strength drops off all the more sharply, the more rapidly a load is applied. One obtains the smallest values for shock-type stresses. As is well known, the naturally deposited snow cover has a distinctly stratified structure, so that each stratum has a different strength value.

2.2 Avalanche Snow

The motion of a flowing avalanche -- a predominantly flowing motion on the ground, in which the individual snow particles remain in contact with one another -- is decisively influenced by the frictional forces occurring between the ground and the moving snow. If the velocity of the snow is v, then for a turbulent form of motion the effective frictional force W per unit length may be formulated as follows [3], [4]:

$$W = \mu N + \frac{\gamma}{k^2} U v^2. \qquad (2)$$

Thus there is a first component which is independent of the velocity and proportional to the force N which acts perpendicular to the surface of deposit. The proportionality factor μ is the coefficient of friction. The second component increases as the square of the velocity and is in addition dependent upon the specific weight of the moving snow γ, upon a coefficient k^2 (often also denoted ξ) which primarily characterizes the roughness of the underlying ground, and finally is dependent upon U which is the contact length between snow and underlying ground measured in cross section. A direct measurement of these factors is not immediately possible; hence they have been in part computed backwards from observed avalanches. For the coefficient of friction today, one assumes values from 0.15 to 0.5 depending upon the nature of the snow and the underlying ground conditions. For the roughness coefficient, one assumes a value of 400 to 600 ms^{-2}. The mean specific weight of a flowing avalanche is estimated to amount to as much as 300 kp m^{-3}.[1/]

In the case of powder avalanches -- predominantly a motion of particles suspended in the air -- the velocity-independent component in (2) can be omitted and hence the resistance at the avalanche front becomes substantially dominant. For this type of avalanche, the avalanche snow, in the form of an aerosol, displays very small mean density values. They probably lie somewhere in the range from 2 to 30 kp m^{-3}.

3. Avalanche Dynamics

To the extent that it is important in the structural control of avalanches, some additional remarks should be introduced into this section on the subject of avalanche dynamics. The destructive effect of avalanches is a consequence of their force effects. The latter, if one disregards short-term shock effects, are essentially dependent upon the product of the specific weight and the square of the velocity. In this connection, it is also an important question whether, or under what circumstances, a specific location can be reached at all by avalanches -- which leads to the problem of the run-out distances of avalanches. This distance, over which the originally present kinetic energy is completely consumed, is sharply dependent upon the square of the velocity and upon the coefficient of friction but, on the other hand, only slightly dependent upon the total mass of the descending avalanche. Hence, the velocity appears to be the most important factor in judging the effects of avalanches. On the one hand, this velocity is determined by the material properties occurring in relation (2), and on the other hand, by the local terrain and snow conditions. If a snow stratum breaks off, it then accelerates thanks to its own effective dead weight. But at the same time, the frictional forces become effective in accordance with equation (2). The acceleration continues until the driving force and the braking force are equal; from this moment on, the velocity can no longer increase. The acceleration phase is relatively short. Ninety percent of the constant terminal velocity has been attained in a path length of about 40 times the flow

1/ kp = kilopond force: 9.806 kp = 1 newton. The magnitude of kp measurements is the same as for kilograms.

height. But with loose-snow avalanches, this period lasts substantially longer since the flow heights and hence the driving forces at the outset are very small and diminish only slowly. In general, it may be said that the terminal velocities are greater, the greater the slope inclinations and the magnitude of the broken-off snow stratum (or the flow height).

In certain cases, the size of the fracture area can influence the velocities, too. It is without influence -- this must be repeatedly emphasized -- on even, open slopes where there is no channeling by gulleys. Hence, in the case represented in Figure 1a, the avalanche velocity in the cross section b-b (terminal velocity) remains independent of whether or not the entire region above b-b breaks loose or only that lying above a-a. Also, the run-out distance s remains substantially the same. On the other hand, if channeling exists, then the shape of the starting zone is significant. In Figures 1b and 1c, there are shown schematically two cases which must be differently evaluated. The quantity which is decisive for the velocities is the mean quantity of snow Q_m descending in unit time, for example, in the cross section a-a. It can be estimated by

$$Q_m = \frac{K}{\Delta t} \qquad (3)$$

where K is the volume of the snow masses released and Δt is the time which the snow most distant from a-a required to arrive there; in other words

$$\Delta t = \frac{\ell}{v_m} \qquad (4)$$

Here ℓ denotes the distance covered and v_m the associated mean velocity. If one assumes that in both cases the slope of the terrain and the magnitude of the released snow layer are the same, then it is immediately clear that the case in Figure 1c, owing to the greater volume, gives a higher value of Q_m and hence a higher velocity in section b-b. If in Figure 1c only the right portion of the surface breaks loose, then the volume is only about half as great and the velocities will diminish correspondingly.

These ideas, which have been but briefly sketched, are of some significance in drawing up avalanche risk maps and in planning structural control of avalanches, and they give some leads for evaluating the protective effect which may be expected. In the following sections, this topic will be considered further.

4. Principles of Supporting Structures

4.1 The Problem and the Mode of Action

In the guidelines [2] which have already been mentioned, the task of supporting structures is defined as follows in Article 4.1: "It is the task of supporting structures to prevent avalanches or at least to limit snow motions -- they cannot be completely restrained -- to a harmless magnitude. Fully developed forces as a rule cannot be sustained by supporting structure installations."

Thus, the problem is a double one: the main problem is to produce an overall increase in the stability of the sloping snow cover -- understanding here by stability the ratio of strength to the existing stresses. The secondary problem consists in limiting the size of the snow masses which have been set in motion and in retarding and catching them.

How then can a higher stability be attained in the sloping snow cover? The existing stresses arise in the case which we are considering exclusively from the dead weight. On a smooth slope, this is transmitted from layer to layer by normal and shear stresses to the ground. Under more complicated topographical conditions, a part of the weight is also carried off parallel to the slope and reacts to anchorages such as rocks, trees, or flatter places. In the case of a snowfall on the existing old snow cover, the stresses increase at a rate which corresponds to the intensity of the precipitation. If the stability does not become critical (in other words approach the value 1) the strength must also increase. Experience shows the factors which decide how this development will end, i.e., whether or not there will be a fracture, are usually the shear strengths and shear stresses which arise parallel to a layer. Individual snow strata (snowed-in surface hoar, depth hoar) can often be much weaker in this respect than the preponderant remaining portion of the snow cover. An improvement in stability is brought about here by the normal stresses which by themselves increase the shear strengths and at the same time produce an increase in density (see Section 2.1). If, in spite of this, a shear crack occurs locally, then it will propagate until it reaches a place of higher stability, in other words, a place where the slope inclination is less or where the shear strength is sufficiently high. A slab avalanche produced in this way can therefore attain very great size in the case of a slope whose stable spots are spread widely.

With the installation of rigid support surfaces, conditions in the inclined snow cover are decisively changed. The movements

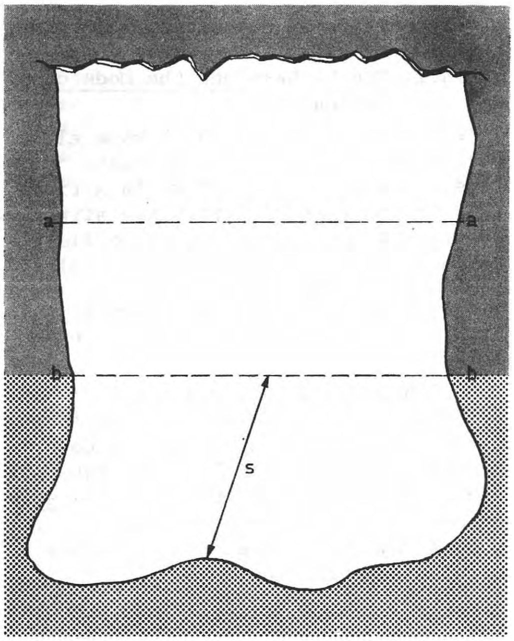

Figure 1a

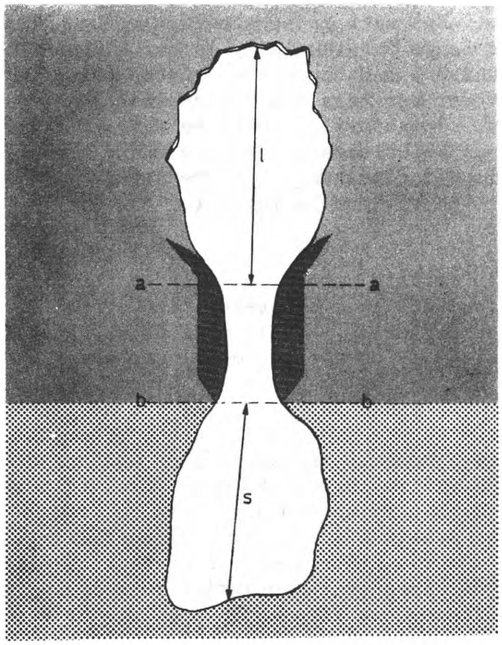

Figure 1b

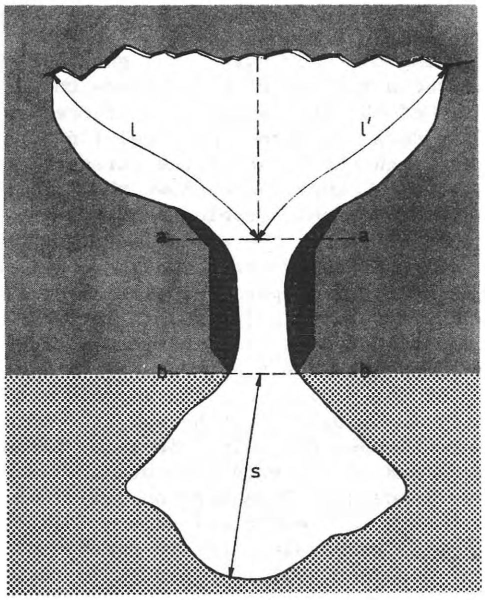

Figure 1c

Figure 1a, b, c, Various forms of starting zones and the track of avalanches.

in the direction of the valley -- ever present, owing to the fluid characteristics of snow described in Section 2.1 -- are held up by these walls with the consequence that in the up-slope direction additional compressive stresses arise over a certain "obstructive region" in accordance with relation (1). These compression stresses absorb part of the dangerous shear stresses (Figure 2). The principal effect of supporting structures therefore consists of a rearrangement of shearing stresses into compressive stresses or under some circumstances also of tensile stresses into compressive stresses. In accordance with Section 2.1, this brings about the desired higher stability: for this type of stressing the strength is substantially greater and the increased densities contribute to a temporally accelerated increase in the strength. If nevertheless, a local fracture takes place, then the propagation of the fracture process is limited by the rows of installations lying above and below, thus there is a limitation also of the size of the snow mass in motion. In such cases, the retarding and catching capability of the support installations also comes into play. The retarding capability is based upon the motion-limiting forces which arise from the rebound. In relation (2), this state of affairs manifests itself in that it is necessary to add a third component which is dependent upon the square of the velocity. It should also be noted that the unpleasant snow motions within the controlled area arise principally as a result of loose-snow fractures. These are not a consequence of the above-described stress phenomena and therefore cannot be prevented by the type of stability increase which has been mentioned. Rather, they are formed in a very small space as a result of the occurrence of instability in small snow particles. Thus, a supporting structure can be effective here only by its retarding and catching capability. In the following section, it is shown that the greatest degree of attention should be given to this aspect of the matter in arranging the installations.

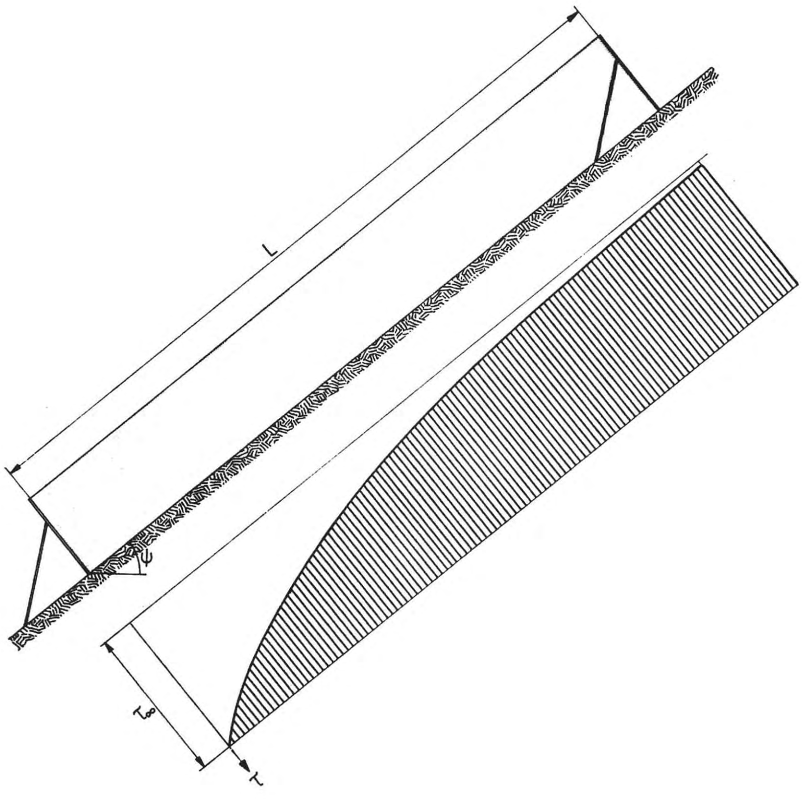

Figure 2. Mode of action of a supporting structure, with the shear stresses acting on the surface of the ground; τ_∞ is the shear stress which is reacted by the ground on a, uniformly inclined slope, with no structures.

4.2 Arrangement and Design

The arrangement and design of supporting structures must be inferred from the assigned tasks of these installations and from their mode of action. The problem is to express the described relationships and requirement in numerical values which can serve as a foundation for a planner. This is a multiform problem. In addition to the already described effects of the material properties of snow and of the topography, there are also those of a generally climatic nature such as precipitation, wind, radiation, and temperature conditions. Further, there are such very important factors as the nature of the ground surface (including vegetation) and the foundational properties of the ground. A further complication here is the fact that in part, scientific investigations which might have served as a basis are lacking and they must be replaced by accumulated experience. But in addition, the planner must consider a feature which has thus far not been mentioned, namely the cost of such a construction. In general, this is very high and hence one is compelled to adapt structural avalanche control to the demands of the objects to be protected or to the acceptable risk. In other words, high cost should not be avoided if the value of the area to be protected justifies it. Half measures would in such a case be the worst possible course and in addition would detract from the reputation of supporting structures. However, for the ratio of cost to reliability obtained there is also an upper limit which it would be wise not to exceed. Figure 3 shows schematically how the cost increases ever more sharply with higher reliabilities. The precise form of the curve depends, among other things, upon the terrain and snow conditions. Two possibilities are represented by a solid line and by a dotted line. With the solid curve, a cost increase of ΔK_1 produces a much higher reliability increase [or "safety increase"] than one of ΔK_2. In the case represented by the dotted line, the relationships are somewhat different, but there too, the curve flattens out considerably for high safety values. Hence, the optimum of an arrangement or of a design is obtained whenever an adequate safety is formulated in such a way that the sharply increasing portion of the cost-reliability curve is fully utilized without at the same time moving into the slightly inclined and therefore uneconomic range. In what follows we shall discuss three features of arrangement and design of supporting structures; these are features which quite substantially influence safety, namely the extent of a supporting structure, the heights of the structure, and the spacing of the structures along the fall-line [line of steepest gradient].

In the "Guidelines," 30° to 50° are given as the inclination range which justifies structures, but here the possibility must not be excluded that in exceptional cases it will be necessary to exceed these limits. As to where the upper boundary of a construction area should lie, there is usually no problem; it should be placed immediately below the highest avalanche starting points. More discussion is provoked by the lower boundary. Since, according to the preceding section, it is the primary shear crack which predominates in the fracture and since this can propagate over very great areas, it is not sufficient to place structures only in the upper parts of a slope. Further, it has been shown in Section 3 how in many cases (e.g., that shown in Figure 1a) the destructive effect of avalanches is practically independent of the size of the fracture area. For example, if one were to halve the cost by putting structures in only half of the fracture area, one would be far from gaining a corresponding increase in safety. In Figure 3, this would correspond to the dotted profile among the shown curves. Hence, structures should extend toward the valley far enough for the terrain inclination to diminish definitively below about 30°. Deviations from this should be considered to be exceptional cases and require precise clarification.

With regard to the height of the structures, there is a fundamental requirement upon which both the degree of avalanche safety in catastrophic situations and also the process of designing the supporting structures rest. This requirement is: structure height must correspond at least to the extreme snow depth to be expected at the site of the structure. By "extreme snow depth" we understand the highest value of the maximum snow depth during a long series of years. If this requirement is not fulfilled, then supporting structures can fulfill their task only partially or not at all. If structures are covered with snow, then at the upper edges of the structure there arises additional shear stresses which are known to promote the formation of avalanches. The retarding and catching capability is then completely lost. In order to have any chance of fulfilling this requirement, one must assume a detailed knowledge of the snow depth distribution over the project area. A merely general knowledge does not suffice, because the snow depths are also subject to sharp variations in small areas. For an adequate determination, one must have about 25 to 100 samples or depth readings per hectare. If possible, the measurements should be carried out during several winters. How extreme snow depths can be inferred from measured depths is explained in the "Guidelines." Here it is important to know that the result obtained will be all the more reliable the closer the measured values are to the extreme values.

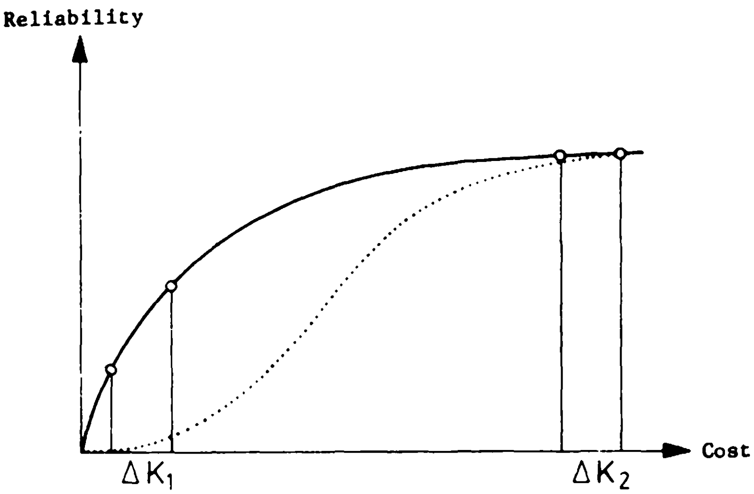

Figure 3. Schematic representation of the relationship of the relationship between cost and the resulting reliability of supporting structures.

The determination of the height of a structure, denoted H_K, at the same time largely determines its dimensions. As has been shown in Section 41, the main task which this dimensioning must fulfill is that of arresting the slow movements of the snow cover in the direction of the valley. The forces resulting in this process determine the dimensions and hence are considered to be the decisive factor. All other stresses, e.g., the dynamic ones, may therefore not be any greater -- which is something that can be achieved by a suitable arrangement. The slope-parallel snow-pressure component S'N (which is the most important factor) in the region which is free of boundary effects amounts to

$$S'_N = \gamma \frac{H_K^2}{2} K N. \qquad (5)$$

per length unit of support surface. Here γ denotes the mean specific weight of the snow cover, K the creep factor which is dependent upon the nature of the snow and the inclination of the slope, and N is the glide factor which is influenced by ground roughness and slope exposure. The values of K lie between 0.7 and 1.05 and N can vary from 1.2 to 3.2. This latter factor takes into account in principle the increase in snow pressure which results from the gliding motion of the snow cover upon the ground surface.

Structure spacings in the fall-line [line of steepest gradient] must be so designed that three conditions are simultaneously fulfilled:

a. The structures must be undamaged by the maximum snow pressure acting statically.

b. In the same way, it must be possible to react without damage to those dynamic stresses elicited by movements of the snow.

c. The velocity of snow movements inside the control area may not exceed a certain limiting value. Thereby the energy of motion which is decisive for damage action is reduced to a harmless magnitude.

If these relationships are presented as a function of the spacing factor -- defined as the ratio of structure spacing to structure height -- and of the slope inclination, then one obtains the three families of curves which correspond to the above conditions and which are shown in Figure 4. For a specific case, one then employs that condition or curve which gives the smallest spacing.

For calculating the family of curves arising from the first condition, the unfavorable assumption was made that the snow lying between two rows of structures has lost its cohesive bonding to the ground and at the same time has slid away, in the form of a rigid slab, somewhat in the direction of the lower structure. The friction forces which in this process relieve the installation of load are looked upon as being velocity independent and are taken into account by the three friction coefficients 0.50, 0.55, and 0.60 given in Figure 4. The curves were obtained by equating the "slab pressure" -- it contains the structure spacing -- resulting from the slippage of the rigid slab, to the snow pressure given by equation (5). Of the three curves, it is the middle one which is taken as the normal curve;

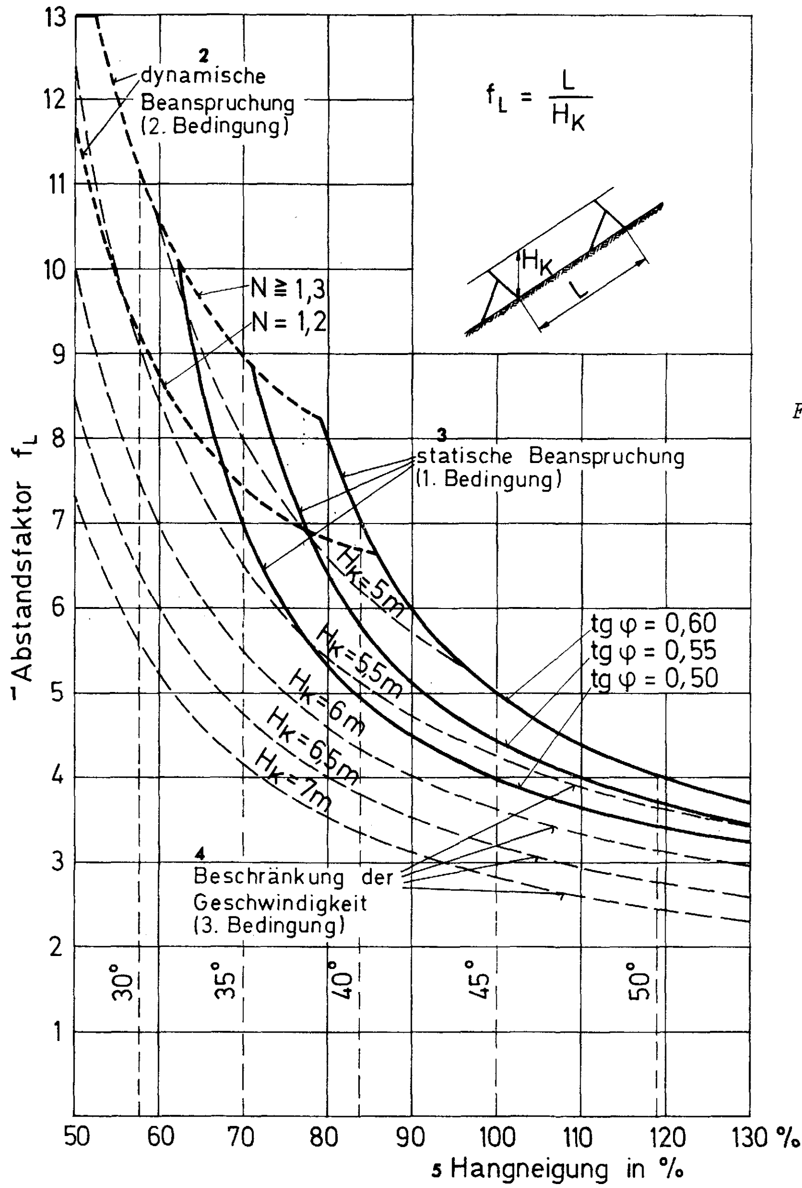

Figure 4. Determination of spacings of structures in the fall-line L.

Key:

1. Spacing factor
2. Dynamic stress (second condition)
3. Static stress (first condition)
4. Restriction of the velocity (third condition)
5. Slope inclination in percent

however, with smooth ground having high glide factors or also in the case of high safety requirements, it is the lower curve with $tg\,\varphi = \mu = 0.50$ which should be used. This statement is to be interpreted as meaning that this lower curve should be used, for example, also in the case of rough ground and high safety requirements.

On the other hand, the upper curve may be used only for rough ground and simultaneously low safety requirements.

The second and third conditions have to do with dynamic stresses or with velocities. Hence, a relation must be sought which displays as a function of structure spacing the degree to which supporting structures are capable of reducing the velocities. For this purpose, there has been introduced into equation (2) a third term which is proportional to the square of the velocity and which represents the retarding effect and on the other hand also represents the dynamic stress.

The initial slab thickness -- which according to Section 3 has an essential effect upon the velocity -- has been assumed to be proportional to the extreme snow depth. The proportionality factor has been at the same time assumed to be still greater in the case of small slope inclinations than in the case of large inclinations (0.25 and 0.20, respectively), with an increase in shear strength, accompanying increased load, being included in the calculation. If then an overstressing of the structures by snow slides is to be avoided, then the latter must produce forces which are no greater than the snow pressure in equation (5). The equating of both quantities then leads to the curves which correspond to the second condition. Substitution of a constant velocity magnitude (10 ms^{-1}) into the relation between structure spacing and velocity leads finally to the quantitative formulation of the third condition. Attention should now be drawn to the fact that the retarding capacity of the supporting structures depends much upon the deflection angle α, i.e., upon the angle through which a displacement, originally parallel to the slope, is deflected by the obstacle. The smaller this angle, the smaller is the effect. Thus the avalanche structure builder is justified in fearing the so-called revetment formation (shaded part in Figure 5). But it cannot ever be entirely avoided; nevertheless, the situation is most undesirable in which the natural snow cover is deposited in this way, even though the snow depths may be small. The avoidance of grid-beam spacings which are too small prevents such unfavorable depositions of snow. Of course, one must remember that gaps between the beams which are too large also reduce the retarding capacity. Hence, in construction locations where loose snow slides occur very frequently, this group of problems must receive the closest attention.

5. Principles of Deflection and Retarding Structures

5.1 Deflection Structures

By deflection structures, we understand structures designed to oppose avalanche forces and having the purpose of transforming, deflecting, splitting, or preventing lateral extension of a moving avalanche. What is involved here are galleries, terraces, dikes, walls, or wedges. The principles underlying the calculation of such structures follow immediately from the preceding sections. Here it should be noted that in the velocity calculation, it is better to assume small coefficients of friction in order that the decisive extreme conditions will be included. The conventional values lie between 0.15 and a maximum of 0.30. In computing the friction forces operating on the structures, usually only the velocity-independent term is taken account of in relation (2). This is done for the sake of simplicity, but also because normally in making field measurements, it is possible to determine only the ratio of the maximum total normal and shear stresses (mechanical maximum

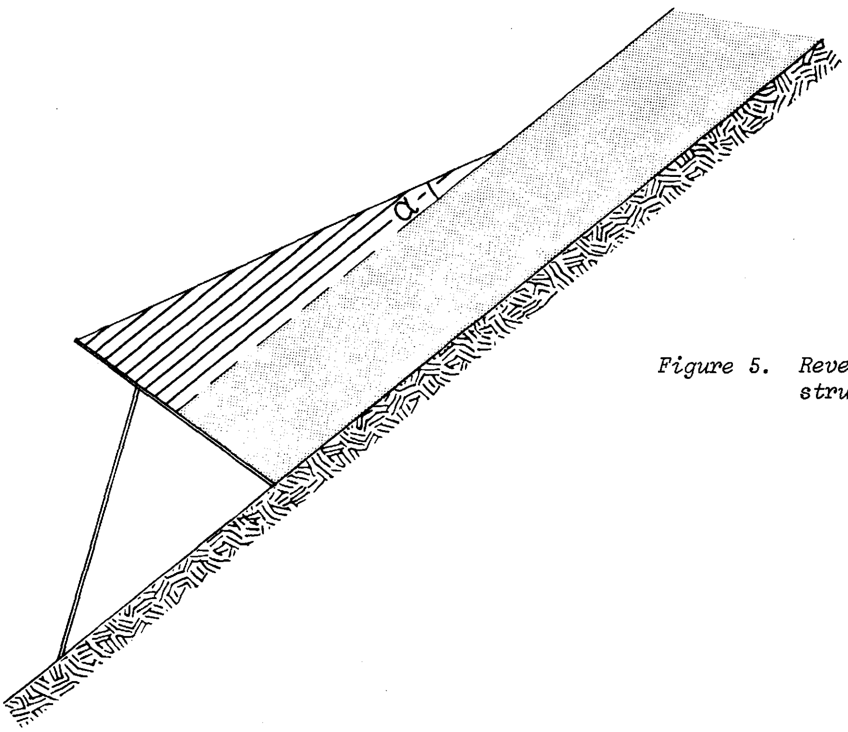

Figure 5. Revetment formation for a supporting structure.

force measurement). Thus, one must be content with a "lump sum" coefficient of friction. Hence, these coefficients must here be set rather high; as a rule, one selects values between 0.30 and 0.50.

A certain degree of care is in order in the case of structures which aim at a lateral change of direction. It is not possible for any arbitrary avalanche to be deflected through any angle, at least if one wants to remain within the range of reasonable dike or wall heights. In general, the rule holds that the possible deflection angle becomes smaller, the more rapidly an avalanche flows. Therefore, in the case of very rapid powder avalanches, such measures have little prospect of success. What is most likely to have success is the case when the natural terrain itself causes a substantial deflection. It is also true that in an extreme case, an artificial strengthening of the terrain can be used to guide the avalanche flow into the desired direction.

5.2 Retarding Structures

Retarding structures are designed to deal with avalanche forces and which are opposed frontally to the avalanche with the object of arresting its mass or of shortening its run-out distance. This involves arresting [catching] dikes, and retarding mounds, wedges, and blocks. As in the case of a lateral deflection, here, too, the principle holds that not every avalanche motion can be slowed in any location and arrested, but rather the natural terrain must be of such a nature that in the normal situation an avalanche comes to a halt there. Then measures which artificially strengthen the terrain produce an arrest of the extreme avalanche also.

The retarding of an avalanche by means of artificial measures is based primarily upon the two following effects:

The obstacles, by being arranged in such a way as to be mutually displaced relative to the flow direction produce a lateral distribution of the avalanche flow so that compared to the undisturbed state, a substantially greater flow breadth is attained. Because of this magnification, however, the flow height and hence also the velocity must diminish. From this it follows that the obstacles should be so arranged to produce as uniform a distribution as possible of the avalanche flow over the available terrain. In addition, the obstacles must also be sufficiently high, relative to the expected flow heights. Further, the terrain should display a certain minimum breadth transversely to the avalanche direction if there is to be any effectual broadening at all. Therefore, narrow, deeply cut gullies are not suitable for retarding structures.

The subsequent mode of action in retarding is immediately evident from relation (2). The second term in this relation is dependent upon U which is the contact length between snow and underlying ground, this length being measured in a transverse section perpendicular to the motion of the avalanche. This length is magnified by the installation of artificial obstacles. But in addition, there also come into operation (see Section 4.2) the rebound forces which are responsible for the retarding capacity of supporting structures. From what has been said, it may be inferred that artificial obstacles are all the more effective the more they elongate the transverse cross section line of the ground surface relative to the original state and also the greater the area which these artificial obstacles oppose to the avalanche. Hence, the most effective procedures should be the retarding mounds made of earth. To arrest an avalanche means to bring it completely to a standstill with the aid of an artificial obstacle (dike or wall). This is accomplished by forcing the avalanche snow to flow upward to such an extent that its kinetic energy is completely dissipated. The decisive quantity here is the so-called energy-line elevation; in hydraulics it is given by the Bernoulli equation and consists of the sum of velocity head, flow head, and height above a reference plane. However, this equation requires adaptation to such a medium as avalanche snow since in contrast to something like water, internal friction forces are activated during deformation [5]. For a rough estimate of the required structure height H_D, this effect, however, should be neglected and one obtains as the condition:

$$H_D \geqq \frac{v^2}{2g} + H_L + H_S \quad (6)$$

The first term on the right represents the velocity head. v is the velocity immediately in front of the obstruction and g is the gravitational acceleration (9.81 ms^{-2}). H_L denotes the flow height of the avalanche measured vertically, and H_S represents the maximum depth of naturally deposited snow which in the extreme case exists in front of the structure. From relation (6) it is immediately apparent that an avalanche can be arrested at reasonable cost only if the velocity in front of the obstruction is not too great. But this is in general the case only when the avalanche has previously traveled through a run-out terrain and lost a corresponding amount of energy -- an effect which, if possible at all, should be amplified by artificial means. Hence, the normal case is a combination of retarding structures and arresting construction, with the arresting installation being installed at the lower end of the run-out terrain. A run-out terrain is distinguished from the track in that the slope inclinations of the former are on the average no greater than about 12° to 15°. Further, the length of this terrain must correspond roughly to the run-out distances of normal (i.e., not extreme) avalanches.

6. Concluding Remarks

Within the limits of this work, it has been possible to deal with only a few problems of structural avalanche control. In this choice, the attempt has been made to treat such questions as have perhaps more often than others been an occasion for discussion or whose aspect has been subjected to a marked modification by the progress of research and experience in the past 20 years.

Rigid schemata should definitely be avoided in structural avalanche control. Rather, those who build avalanche control structures, on the basis of his evaluation of the ever-changing conditions on the one hand, and on the basis of the requirements on the other, must reach solutions which are economically balanced in proportion to the values protected.

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[1] Recent Developmental Tendencies and Problems of Avalanche Control Structures in the Starting Zone.

[2] Avalanche Control Structures in the Starting Zone, Guidelines of the Federal Forest Inspectorate for Supporting Structures.

[3] On the Destructive Force of Avalanches.

VI. PERMANENT SUPPORTING STRUCTURES

(Walter Schwarz, Interlaken)

This article does not form a comprehensive and finished account of permanent supporting structures. Rather, in addition to general data, various special problems are treated which confront the avalanche-control builder.

1. General Remarks

A distinction is made between temporary and permanent supporting structures in the starting zone. Temporary supporting structures aim at a provisional stabilization of the snow cover.

This temporary protection can be achieved by

a. permanent supporting structures which are taken out after their protective purpose has been achieved; in this manner, for example, power plant construction sites have been temporarily protected by means of light metal snow bridges, or in the case of other construction sites, with snow nets.

b. temporary supporting structures with a limited lifetime (principally of wood), which support the snow cover provisionally until the growing afforestation can take over this function after on the average 20-40 years.

Up to now, in temporary supporting structures, very often too low a degree of safety has been accepted; in future this should be avoided.

Permanent supporting structures in most cases strive for a high degree of safety and assume a permanent or long-term protective effect. Hence, they must employ durable building materials.

Permanent supporting structures will always be the appropriate choice wherever

a. it is not an individual object which is protected but an area (e.g., protection of a town, protection of several traffic arteries one above the other);

b. the high cost of the supporting structures bears a carefully weighed ratio to the value of the objects protected and where

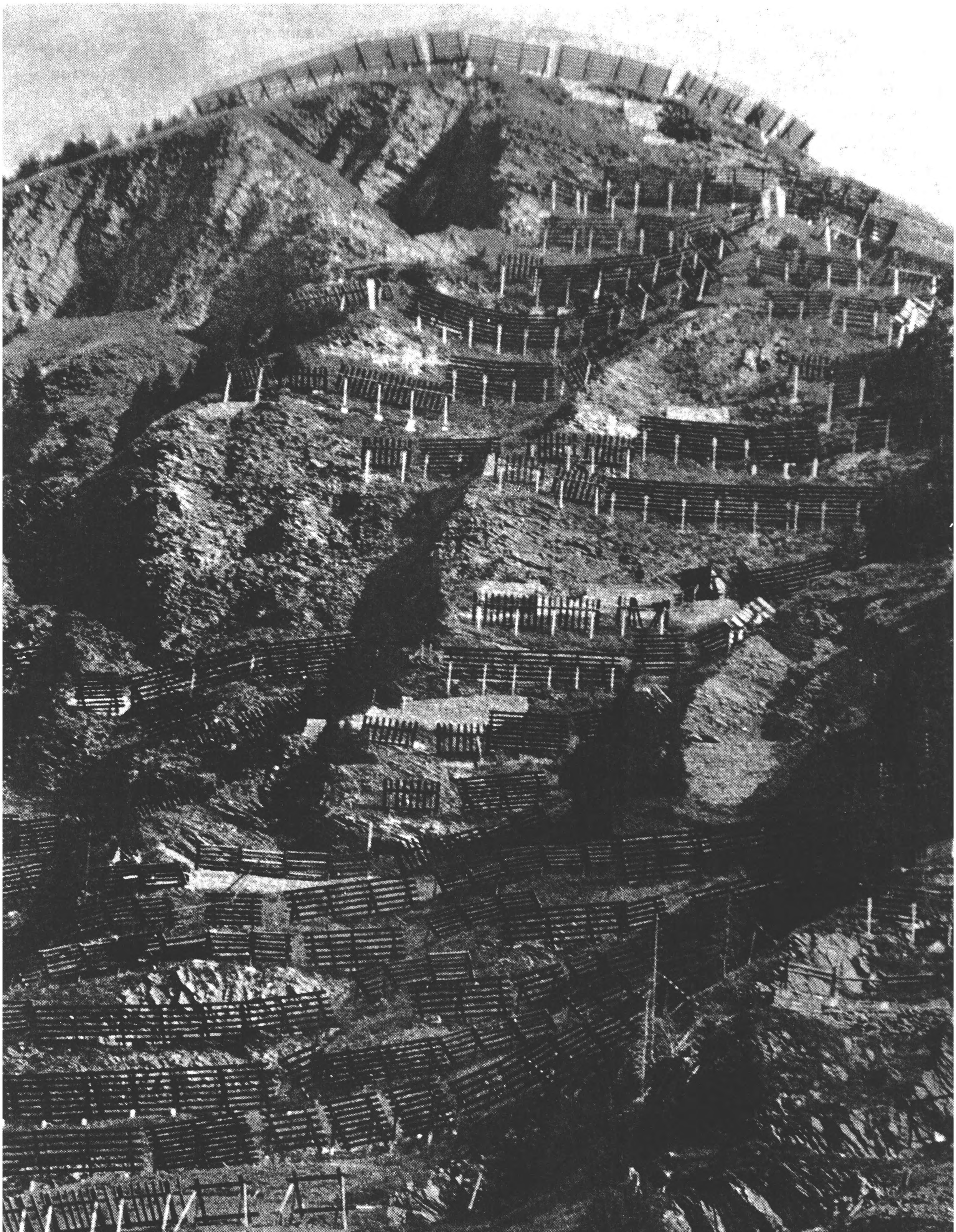
c. overall treatment of an entire region occupies the foreground.

The potentialities of the use of permanent supporting structures and their limitations, as compared with other types of structures, will be shown in the following by means of the example of National Highway N 2 through the Reuss Valley from Amsteg to Goeschenen. This illustrative project is unique in the alpine region both with respect to the great variety of its features and with respect to the concentration of the measures employed. Its various constructive measures protect 5,250 running meters or 37 percent of the 14.2-km-long distance against avalanches. Its individual, permanent structural measures are distributed as follows:

Table 1. Nature and Extent of Permanent Avalanche Control Structures Along National Highway N 2 Between Amsteg and Goeschenen

Type of Structure	Protected Distance [m]	Fraction of the Total Construction [%]
Tunnels	1,250	23.8
Avalanche galleries	1,880	35.8
Avalanche guiding structures (lateral)	210	4.0
Avalanche arresting spaces	160	3.0
Retarding structures	50	1.0
Supporting structures combined with afforestation	1,700	32.4
Total	5,250	100.0

Tunnels have been built under numerous deeply channeled avalanche paths; in cases when there is a purely linear protection requirement and when simultaneously the costs of supporting



structures would not be financially tolerable, galleries suggest themselves; avalanche-guiding structures serve for deflection, channeling, or constriction of lateral extension (shortening of the gallery lengths!) of flowing avalanches. In addition, outside the stretch from Amsteg to Goeschenen, N 2 must be protected in the Silenen area against the well-known Wiler avalanche (27 January 1968, seven avalanche dead) and the Opplital avalanche. Against these avalanches from very large and hence uncontrollable starting zones with areas of about 100 and 27 hectares, respectively, the following measures have been provided:

Against flowing avalanches:

Creation of large arresting spaces (can also be combined with lateral guidance structures and retarding structures) by the removal of material amounting to some 100,000 cubic meters, which has been used in the construction of N 2.

Against powder avalanches:

Frontal avalanche guidance dikes having a length of about 800 m and height of 8 m measured from the highway level immediately on the mountain side of the highway route in order to conduct the powder avalanche component over the highway. The effect of these dikes is similar to that of snowdrift walls; the highway is located in the protection range of the dikes. The compression shock of the powder avalanche is absorbed by the dike and the avalanche jumps over the highway.

Supporting structures should be mentioned as the only construction measure which prevents avalanches. This type of structure, in the case of the N 2, accomplishes the following protective tasks:

Steintal/Hustal (Gurtnellen) project:

a. Surface protection of the N 2 and of the Gotthard highway for about 1,000 m against actual and potential avalanches;

b. Simultaneous protection of the settlements of Wiler as well as a group of buildings in Alphorn and Alpenroesli/Kirche.

Entschigtal (Wassen) project:

a. Protection of the SBB [Swiss National Railway] (twice), of the Gotthard highway, and of the N 2;

b. Protection of the southern boundary of the town of Wassen.

Laubzuege (Wattingen) project:

a. Protection of the tunnel portal of the SBB, of the N 2, and of the Gotthard highway;

b. Protection of the arsenal and the settlements of Wattingen.

2. <u>Supporting Structures and Their Protective Effect</u>

The protective effect of a supporting structure in accordance with guidelines [1] depends upon

a. the position of the object to be protected: for example, the same degree of safety cannot be obtained by supporting structures for a railroad running through a steep slope as for a village at the bottom of a mountain valley;

b. the topography of the starting zone: for example, the effectiveness of supporting structures on a steep lee slope is more doubtful than it would be on the windward side of a convex and smooth mountain ridge;

c. the nature, especially, of the new snow masses: thus in the case of very loose snow masses which have fallen at a low temperature, limited snow movements can occur throughout the entire protected area as the result of widespread avalanche fractures;

d. the types of structures employed and the method of construction: a broken arrangement of snow nets having low retarding and arresting capacity will not

Figure 1. Partial view of the permanent supporting structures Wilerhorn/Brienzwiler (1,700-2,004 m above sea level) in sharply eroded terrain invaded by rock falls; snow bridges, snow rakes, and avalanche fences in continuous and broken arrangement, depending upon terrain conditions; supplementation of the articulated supporting structures by massive dry walls, mainly as protection against rock impact; on the left portion of the summit knoll (windward side) snow bridges OeAM having a high degree of filling (65 percent) functioning to reduce the amount of drift snow in the uppermost right-hand portion of the area (lee side); true snow fences OeAM (bright band) behind the above-mentioned snow bridges with a high degree of filling (photo W. Schwarz).

Figure 2. *Avalanche structures Tanngrindel/Brienz in the run-out zone [Ausaperungsphase]: the portions of the slope with no structure have discharged their snow masses; the stabilization of the snow cover by means of supporting structures is evident. In the lowest right-hand part of the protected area, glide cracks have been able to form. In later years these could be prevented by the installation of glide-protection bridges OeAM. A snow-drift structure with a length of about 100 m and OeAM walls is located on the summit field of the project (photo W. Schwarz).*

be able to meet the same high safety requirements of a continuous arrangement of snow bridges or snow rakes;

e. the position and configuration of the boundary of the protected area: i.e., partial protection of large starting zones can loose a great part of their effectiveness with respect to preventing avalanches if, as a consequence of unwise location of the structure and inadequate boundary protection, avalanches can break into the protected area from other parts of the slope.

From the dependence of the attainable safety upon various factors, it follows that supporting structures cannot provide an almost absolute safety, as is the case with an avalanche gallery, but instead most of the time, additional precautionary measures are to be recommended, such as, for example:

a. The snow deposits near supporting structures should be continuously observed in winter in order to correctly estimate the level of effectiveness of the structures, especially in situations of general avalanche danger and in order to

Figure 3. A concrete guiding wall of 2.5-5.0 m height here protects the supporting structures against heavy and frequent avalanches from adjacent unprotected regions (Wilerhorn/ Brienzwiler, photo W. Scharz).

be able to promptly institute possible safety measures (e.g., closure of certain regions).

b. In avalanche zone planning, one may not always count upon complete protective effect from the structures; hence, regions bordering on steep slopes with structures should be classified with the highest degree of caution.

c. In protecting highways and railroads along the base of slopes or through steep slopes, additional arresting spaces should be created as close as possible in front of the object to be protected, for example, by shifting the route in the direction of the valley, erecting true arresting structures in some form (avalanche fences, snow bridges, etc.) and by covering the lowest structures with diagonal weaving.

d. It is always possible to combine structures with afforestations. As the protecting forest grows, the level of safety increases.

The problem of zoning must still be briefly discussed in relation to what has been said above. The main object of avalanche zoning is to prevent further occurrence of new settlements (dwelling houses together with all possible transportation arteries) in avalanche-endangered zones if there is a possibility that

Figure 4.--Additional snow bridges with a minimum length of 10 m and at half the installation spacing (middle) together with a guiding wall of steel OeAM (bottom) keep surface slab avalanches from entering the built-up area from adjacent slopes. The snow bridges OeAM (above, with D_K = 4.0 m and below, with D_K = 3.5 m) are protected against the edge effects by means of double boundary blocks and concrete disks (Wilerhorn/Brienzwiler, photo W. Schwarz).

these might later necessitate new and expensive structural control. In order to gain one square meter of new building land, it is possible for several hundred francs worth of supporting structures to be required. Private means are scarcely available for such operations and the means of the federal government and of the cantons must be predominantly reserved for the protection of existing settlements.

3. Planning Supporting Structures

Before starting to build supporting structures, all other construction and combination possibilities must be checked out (guidance installations, galleries, retarding structures, and arresting structures, direct protection structures, snow-drift structures). In this way, it is often possible to achieve not only a substantial saving of cost, but also to achieve effective protection more rapidly.

The planning of supporting structures must be preceded by as thorough a determination as possible of the avalanche history, climate, topography, geology, and vegetation as well as by a clarification of the transportation possibilities; observations of snow depth distribution and avalanche conditions are especially important.

The designation of the most important construction areas is of decisive importance in large construction regions and can be undertaken only on the basis of the above data. At the same time, one must adhere to the principle that a project should not be limited only to the most important, already observed, or potential starting zones, but also that these areas must be protected as much from above as from the side. Hence, a construction project always begins at the highest starting zone, even if the most important fracture areas lie further down.

Slopes from 30° to 50° are today considered generally to be in the range which justifies construction. Of importance in connection with these limiting inclinations is the determination of the downhill extent of a project. Projects which have been made too small -- whether because of an alleged lack of money or because the danger coming from outside the protected area was wrongly estimated -- necessarily lead to reverses and bring discredit to supporting structures.

Where a lasting protective effect is sought there arises the need to decide whether structures should be temporary or permanent and in particular as to the possibilities for afforestation and their chances of success. Permanent structures, except in treeless regions, should be erected anywhere a natural avalanche protection, in the form of reforestation, requires a longer span of time than the maximum lifetime of temporary supporting structures (compare H. in der Gand, Article 7). This applies especially to the upper tree line and at lower elevations to unfavorable locations. In such zones, supporting structures can be erected with permanent foundations and a temporary grid (e.g., using impregnated wood).

The layout of the structures in the terrain is accomplished in accordance with the "Guidelines for Supporting Structures" [1] (compare B. Salm, Section 4.2). In these guidelines, structure spacing in the fall-line is arranged according to structure heights H_K. Since the effective grid heights D_K in practice amount to 2.0 to 5.0 m with staggering of the structure sizes at 0.5 m intervals spacings based upon H_K are only conditionally suitable for the structure layout. Therefore, in Table 2 for the normal cases, the spacings in the fall-line have been arranged according to the slope inclination and the effective grid height.

In setting up the provisional cost estimates, the number of running meters of supporting structure represents the most important cost factor. For small areas it is best to use the layout in the terrain to determine the required number of running meters of supporting structures. For large areas, this method is not usable; instead one must resort to a computational method which helps avoid erroneous evaluations and thus bad cost estimates.

The number of running meters may be reliably estimated by the following formula:

$$LZ = \frac{F}{f_L \; D_K} \alpha \; [m'] \qquad (1)$$

Here: LZ = number of running meters
F = construction area in m^2
f_L = spacing factor according to guidelines
D_K = effective grid height (2.5/3.0/3.5/4.0/4.5/5.0 m)
α = gap factor of the structural arrangement, which assumes the following values:

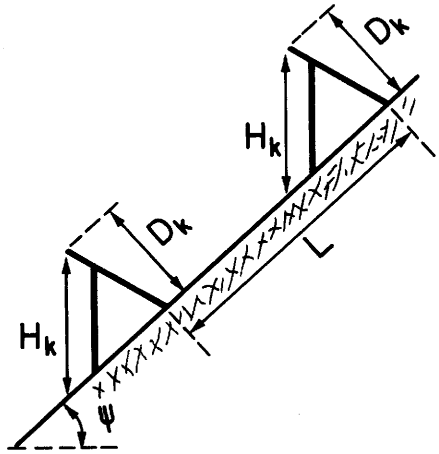
Gap	Gap Factor
4-2-4-2-4 m	0.68
10-2-10-2-10 m	0.84
22-2-22-2-22 m	0.92
Continuous	1.00

The numbers 4/10/22 m denote the structure lengths and 2 m denotes the gap between structures in the same line.

Table 2. Structure Spacings [L] Down the Fall-Line According to D_K (for notation see text)

ψ [°]	D_K [m]	H_K [m]	L [m]	ψ [°]	D_K [m]	H_K [m]	L [m]
30	2,0	2,31	25,6	45	2,0	2,83	12,6
	2,5	2,88	32,0		2,5	3,54	15,8
	3,0	3,46	38,4		3,0	4,24	18,9
	3,5	4,04	44,8		3,5	4,95	22,0
	4,0	4,62	51,3		4,0	5,66	22,9
	4,5	5,20	50,1		4,5	6,36	21,3
	5,0	5,77	47,9		5,0	7,07	19,8
35	2,0	2,45	21,9	50	2,0	3,11	11,7
	2,5	3,05	27,1		2,5	3,89	14,6
	3,0	3,66	32,6		3,0	4,67	17,5
	3,5	4,27	38,0		3,5	5,44	20,4
	4,0	4,88	40,0		4,0	6,22	18,7
	4,5	5,49	35,7		4,5	7,00	17,2
	5,0	6,11	33,6		5,0	7,78	15,6
40	2,0	2,61	15,1				
	2,5	3,26	18,9				
	3,0	3,92	22,7				
	3,5	4,57	26,5				
	4,0	5,22	30,3				
	4,5	5,87	26,4				
	5,0	6,53	24,8				

Note: Structure spacings have been derived using spacing factors f_L for a gliding factor, $N \geqq 1.3$ and a coefficient of friction for snow on ground of $tg\,\psi = 0{,}55$



Illustrative calculation

To use formula (1), it is necessary first to determine the construction area (74,000 m^2), the average slope ψ (40°) of the area, and an estimate of the average extreme snow depth $\bar{H}_{ext}$ (350 cm). In this way, the spacing factor f_L^{ext} (5.8 according to the mean guidance curve $tg\,\psi$ 0,55) can be derived. By means of the average extreme snow depth and average slope, one computes the associated snow cover thickness [⊥ to slope] [maechtigkeit] ($D = \bar{H}_{ext}\cos\psi = 350 \cdot 0.766 = 268$ cm) and then one selects the corresponding, next largest installation size setting D_K = 3.00 m.

From this one gets:

$$LZ = \frac{74\,000}{5{,}8 \cdot 3{,}00}\,\alpha = 4253\,\alpha$$

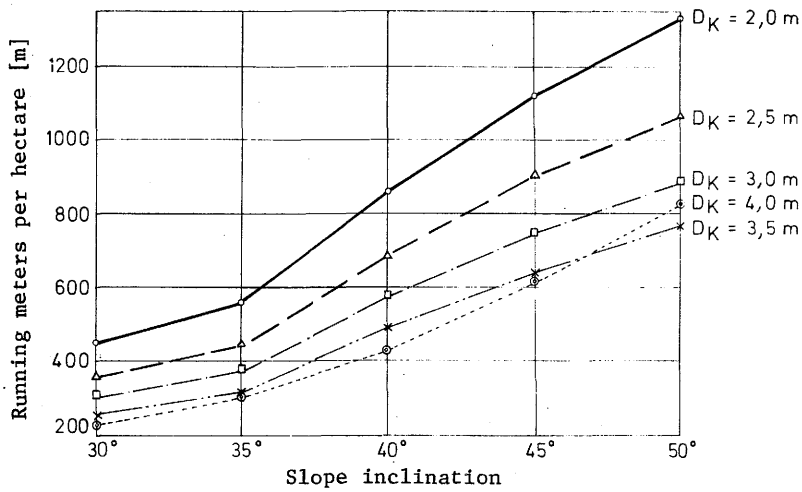
The choice of the gap factor is left to the planner:

For continuous arrangement with α = 1.00 we have LZ = 4,253 m, for broken arrangement 4-2-4-2-4 m with α = 0.68 we have LZ = 2,892 m.

The families of curves of running meters per hectare for the most conventional D_K are plotted in Figure 5 for continuous arrangement. These running meter figures can be multiplied by the appropriate gap factor α to get the desired value for broken arrangement.

No attempt is made to present the running meter figures per hectare for structures having a D_K of 4.5 and 5 m since such structures occur only as individual structures and never for entire projects. Already in the uppermost range of the curve for 4-m installations it is evident that the rule of thumb "the taller the structure the bigger the structure spacing and the smaller the running meter figure per hectare" is no longer valid for the greatest H_K. Thus, the curves for structures having D_K = 4.5 and 5.0 m run substantially above the curve D_K = 4 m -

Figure 5. Running meters of supporting structures per hectare for continuous arrangement, N ≧ 1.3 and tg φ 0,55.



which is related to the assumed fracture heights of unavoidable snow movements and to the design velocity limitation (compare B Salm, Section 4.2).

With the gap factor α of a project, it is also possible to directly derive the reduction in the number of running meters for broken arrangement as opposed to continuous arrangement (α = 1.00). This reduction amounts to 32 percent for broken construction having alternately 4 m of installation and 2 m of gap and for 10/2 m it amounts to 16 percent and for 22/2 m it amounts to 8 percent.

Since the costs per meter of intermediate tie-piece fittings for bridging the gap between structures amounts to only about 60 percent of the cost of the structures themselves, there is no significant savings from leaving gaps. In addition, the installation of intermediate tie-piece fittings is associated with no additional foundation costs. It is therefore not logical economically to strive for as large a gap as possible in the line of structures when, at the same time, one perhaps obtains a significant reduction in the degree of safety.

More important than the question of gaps is constructing the entire project in accordance with the guidelines. If one investigates the number of running meters per hectare of supporting structures for existing projects, one discovers surprisingly small values in some cases.

4. Running Meter Costs as a Function of the Grid Height D_K

At the present time, for completely installed steel snow bridges (slope inclination ψ = 45°, glide factor N = 2.5, height factor f_c = 1.1, structure lengths of 22 m) one must figure on prices up to 850 francs per running meter for structures having D_K = 3.0 m and 1,400 francs per running meter for structures having D_K = 4.0 m.

Since above prices depend sharply upon transportation costs which vary from project to project and therefore upon the required volumes of concrete (0.15 m^3 up to 1 m^3 per foundation), for the following analyses just the costs for the superstructure, which are substantially fixed, are included. The costs and weights of the superstructure, per running meter, in Figure 6 are understood to be for steel snow bridges of the Austrian-Alpine Montan Company (OeAM) having normal design pin-jointed foundation bearings and with delivery costs prepaid. Figure 6 shows the marked dependence of the running meter prices upon the effective grid height and the steep rise in these prices for structures having a high D_K.

The purchase of a steel snow bridge with D_K = 5.0 m is 75 percent more expensive than one having D_K = 4.0 m; in addition, on a hectare at a slope inclination of 45° and using the continuous form of construction, the corresponding snow depths require 700 running meters of support installation with D_K = 5.0 m in contrast to 600 running meters with installations having D_K = 4.0 m. Thus, the largest installation types should be employed with some restraint and it is preferable to be on the lookout for possibilities of snow depth reduction by means of snow-drift structures or, for example, one might put supporting structures of D_K = 4.0 m on walls in order to gain height.

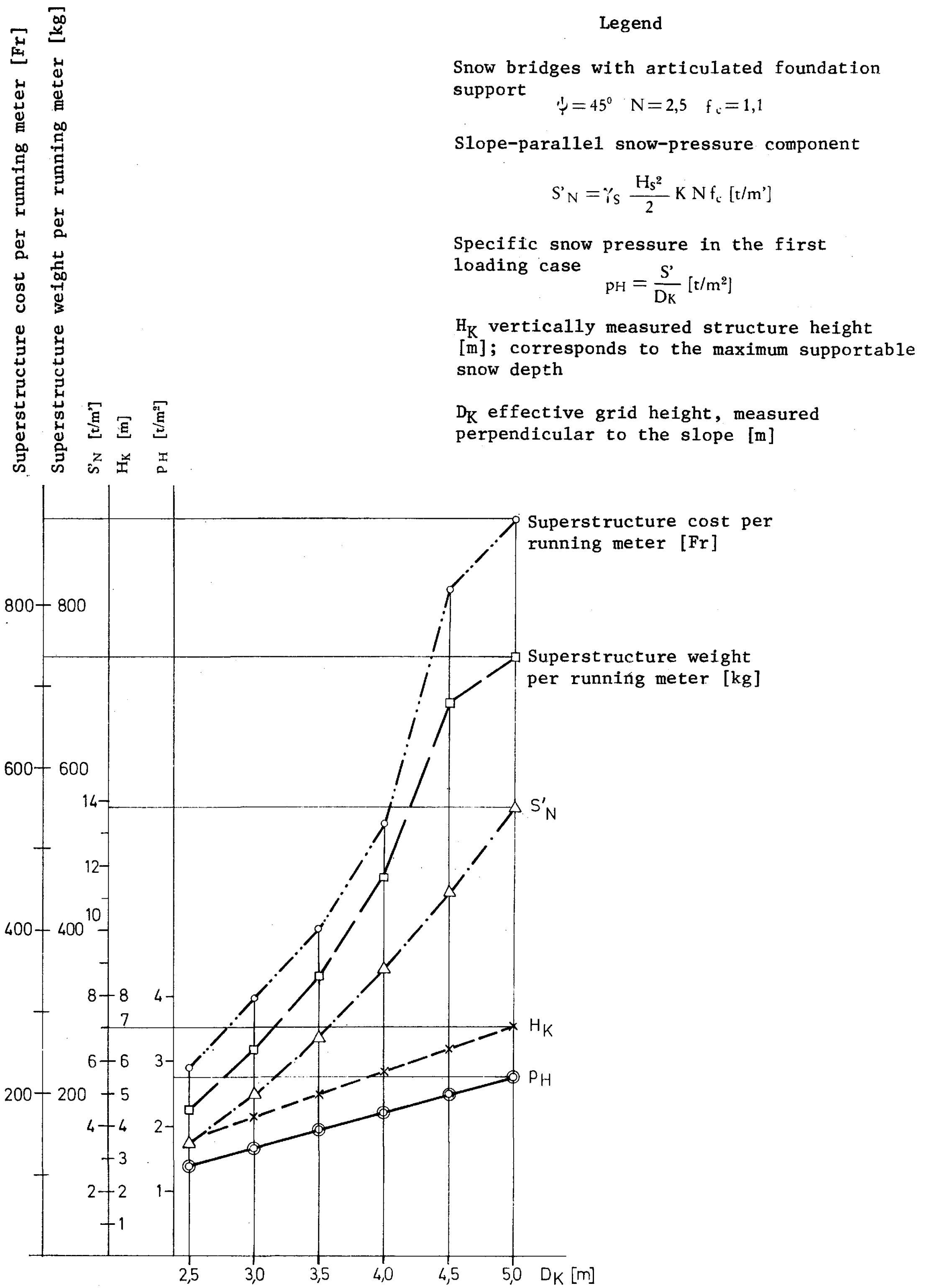


Figure 6. Structure heights and snow depths, snow pressure magnitudes, running meter weight, and costs, illustrate by the example of steel snow bridges OeAM of various installation sizes.

5. Checking the Supporting Structures

During construction, it is well to provide the construction superintendent annually with a sketch of the arrangement of the operations (compare Figure 7) in order to orient him with regard to the installation layout. When combined, these annual structure layouts provide a survey of the entire project. In addition, these plans can be employed for the winter observations (plotting the descents of avalanches into the structures, glide cracks, snow drifts in the area, etc.), for recording damage, for the organization of operations (e.g., designation of areas for afforestation, terracing, etc.), and quite generally for recording the operations which have been carried out. It is precisely the latter which is missing today in many old projects.

When costs are as great as 0.5 million francs per hectare for permanent supporting structures, it is also advisable to have the completed structures and all their details photogrammetrically recorded; the corresponding costs for a 1:500 scale plan are about 500 francs per hectare -- for an area of 5 hectares (more expensive for smaller areas).

Plans with structure layouts and photogrammetric detailed plans of a completed project should also be supplemented by a construction cadastral survey. In the latter, which is best in tabular form, in addition to the structure number, size, and type, all worthwhile data concerning each individual structure should be recorded, such as data regarding building material, foundation, spacing, slope inclination, glide factor, episodes of damage, etc.

6. Construction Materials, Structure Types, Overall Running Meter Figures, and Manufacturers of Supporting Structures

Up until the end of the fifties, modern supporting structures were principally the following types of articulated and mass prefabricated units:

Expensive but easily transported supporting structures having light metal connections (Aluminum Company of Switzerland, Zurich, and the Aluminum Works Company, Rorschach) as well as those made of elements which are heavy but cheaper to procure, made of prestressed concrete (the Prestressed Concrete Company, Adliswil

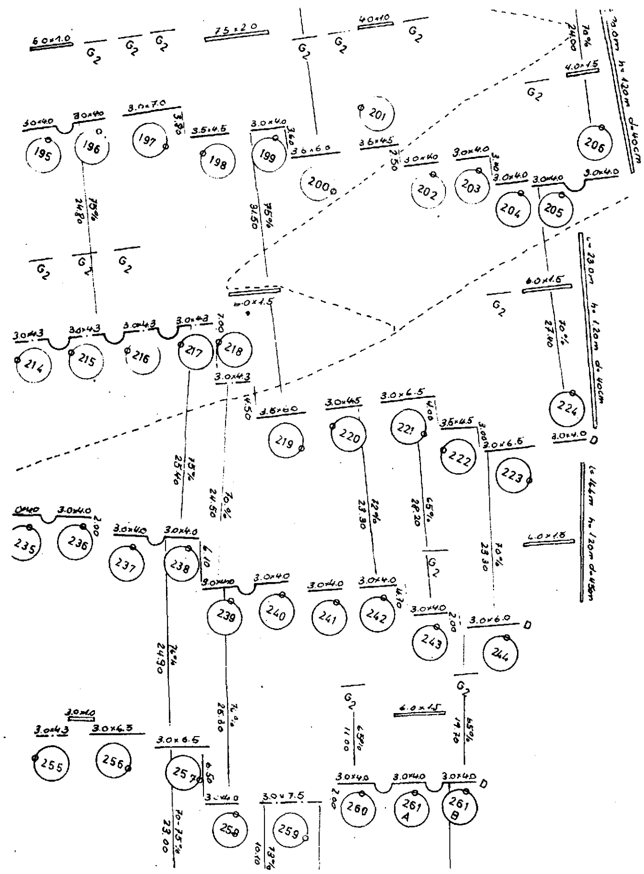


Figure 7. Excerpt from a sketch, "Installation Layouts 1:500," for the Tanngrindel/Brienz avalanche control project.

Legend

201	Structure number with data regarding supplying company
	Snow bridge
	Snow rakes
3,0 × 4,0	Grid height x structure length
	Intermediate beam fittings
	Dry wall
G2	Anti-glide bridge
D	Double end beam and support
L=20m h=1,2m d=40cm	Concrete separating wall

Zurich). These two materials have the essential disadvantage of displaying sensitivity to rock impact. Since the beginning of the sixties, the superstructure building materials have tended to be exclusively steel.

The most widely used type of structure today is the snow bridge. Usually the snow rake is unable to compete with snow bridges, primarily for manufacturing reasons and therefore also for reasons of cost.

The use of avalanche fences -- today principally made out of old railroad rails and a net grid -- is usually limited to old projects having walls which are made higher by a means of this type of installation.

The use of snow nets (the Brugg Cable Works Company, Brugg) has diminished because of [high] maintenance costs and deficient retarding effect and arresting capability. The introduction of loose stone anchors could augment the possibilities for employing this type of structure and together with various improvements (a different form of the compression grid), its employment could again become interesting.

In Switzerland, between 1939 and 1970, a total of 160,394 m of articulated supporting structures (including wooden structures) were constructed. In the period from 1964 to 1970, the figure was 74,843 m or about 10,700 m per year; here the quota of snow bridges and snow rakes in steel amounted to more than 6,000 m per year. Of these steel designs, the greatest part were snow bridges of the Austrian-Alpine Montan Company (OeAM) represented by Carl Stuerm and Company, Rorschach.

In addition to the manufacturers already mentioned, today the following Swiss firms are also producing permanent supporting structures:

Snow bridges: Giovanola SA, Martigny
Snow rakes: Zuellig and Company, Goldach
Snow bridges/snow rakes combined: Belloli/ Donatsch (BEDO), Cama and Landquart

7. Problems in the Boundary Zones

Boundary structures are required to support static end-effect forces which, depending upon the existing glide factor, can amount to two to five times the slope-parallel snow-compression component. In addition, there are dynamic forces which can stress the boundary of the construction area because of avalanches from adjacent uncontrolled areas.

Hence, one should strive to cover entire terrain hollows with structures and extend them laterally up to terrain ridges. But this is not always possible, and by itself is often insufficient. When it is not possible to attach the structures to a natural boundary line, protection of the construction boundary is often still not achieved by back-staggering the next lower row of structures. Instead, additional measures must be considered.

In practice, the end-effect forces are usually counteracted by installing an additional beam and support on the boundary side of the original beam and support. In the case of high glide factors, this measure by itself is often insufficient; it is necessary to build longer concrete separating walls having a height of about $H_K/2$ or concrete block of equal height must be inserted from beam to support. The separating walls substantially reduce the end-effect forces and definitely prevent the entrance of ground avalanches into the construction area.

In Austria, for relieving the boundary structures, small gliding snow bridges having a D_K = 1.0 m are also employed. In the Bernese highlands, large earth terraces are also employed for anchoring the snow cover to the surface of the ground, or niches are blasted out of the rock.

In the case of open construction boundaries there is the danger of slab fractures extending from the unconstructed zone into the constructed zone. This danger can be dealt with by building additional structures of normal size at half spacing. A possible approach, and one particularly to be recommended when there is risk of damage to the supporting structures is the construction of avalanche guidance structures (steel walls and concrete walls or earth dikes). Under some circumstances the construction of such dikes or walls can create the disadvantage of increased snow drifts in the boundary zone of the construction area.

When there is a possibility of dynamic stressing of the supporting structures in the boundary zone, it is advisable, in addition to the measures which have already been discussed, to install an additional beam and support in the middle of the compression grid in order to prevent damage to the latter.

Besides the "separation constructions" which have been mentioned and which primarily relate to the lateral boundary zone, some remarks must be made regarding the design of the lower project boundary. At least in the case of protected objects which lie near the construction area, e.g., in the protection of roads and railways, the lowest row of structures must in any case be installed continuously and with an increased grid height; in addition, thought should be given to the intro-

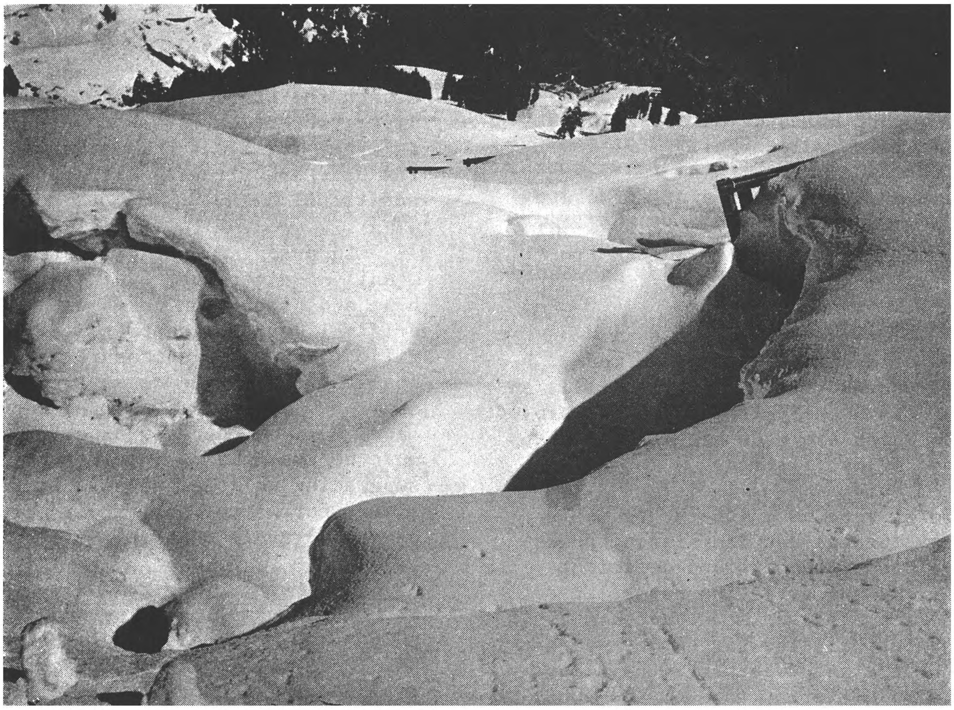
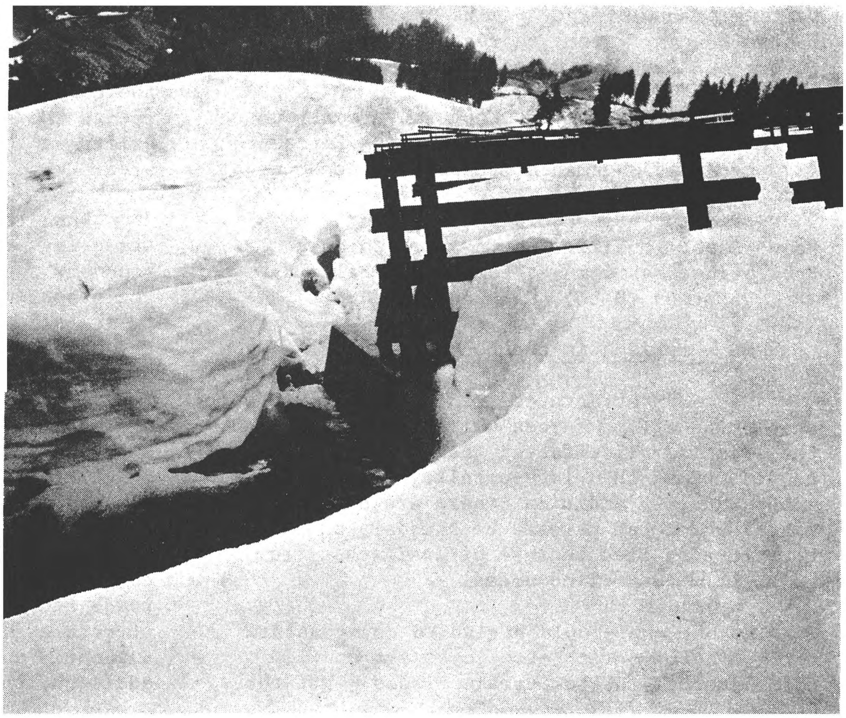


Figure 8. The gliding motion of the powerful snow masses demonstrates the great edge-effect forces which must be restrained by the supporting structures along the edge of a construction area (Tanngrindel/Brienz, photo W. Schwarz).

Figure 9. An OeAM snow bridge protected from edge-effect forces by means of a concrete block and a double end beam and support (Tanngrindel/Brienz, photo W. Schwarz).



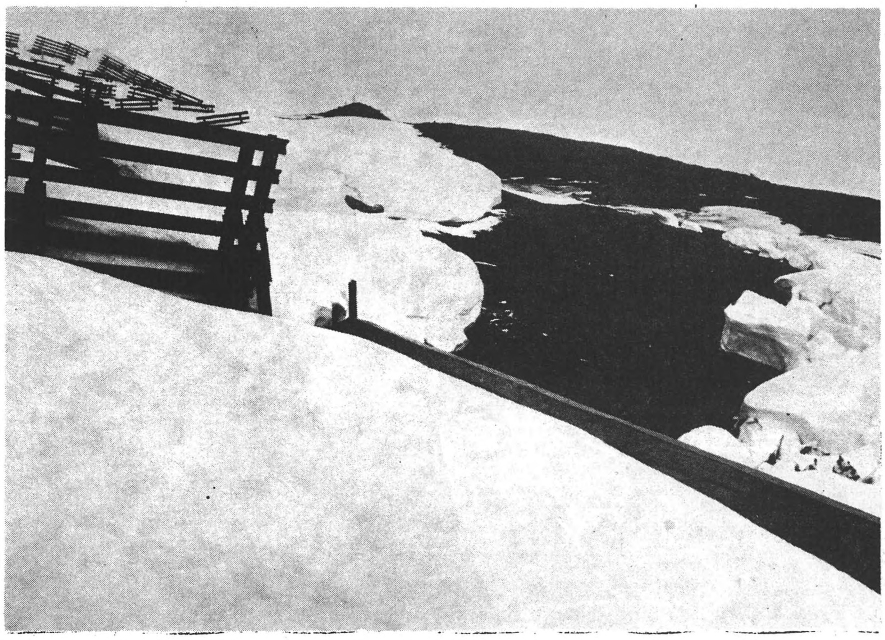


Figure 10. Concrete separating walls prevent entrance of ground avalanches and extension of gliding motions from the unconstructed into the constructed zone (Tanngrindel/Brienz, photo W. Scharz).

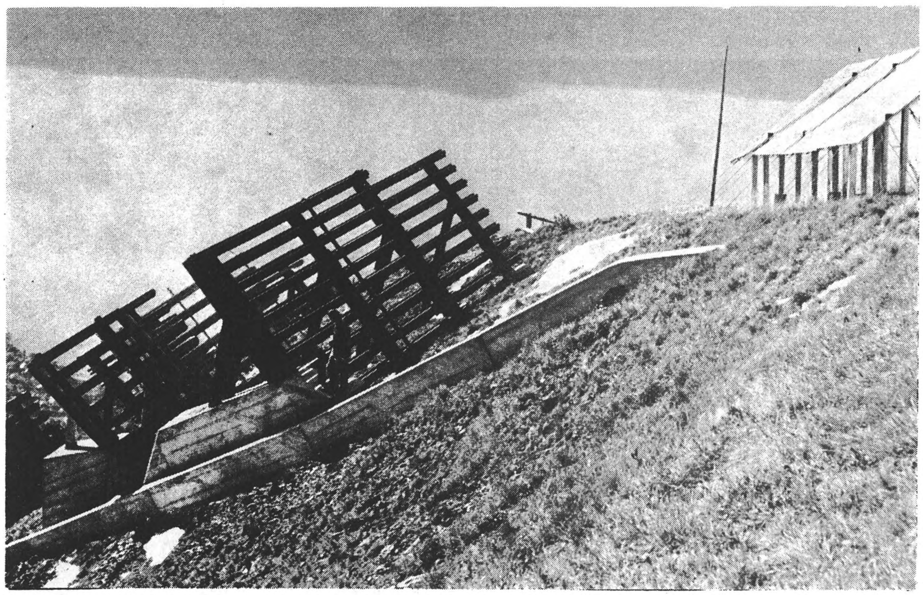


Figure 11. Concrete separating walls, concrete block, double beams and supports at the end of the structure, additional snow bridges at half spacing protect the uppermost part of the Tanngrindel/ Brienz construction area from [snow movement in] the unconstructed region. Separation of the constructed from the unconstructed zone is reinforced by a jet roof (photo W. Schwarz).

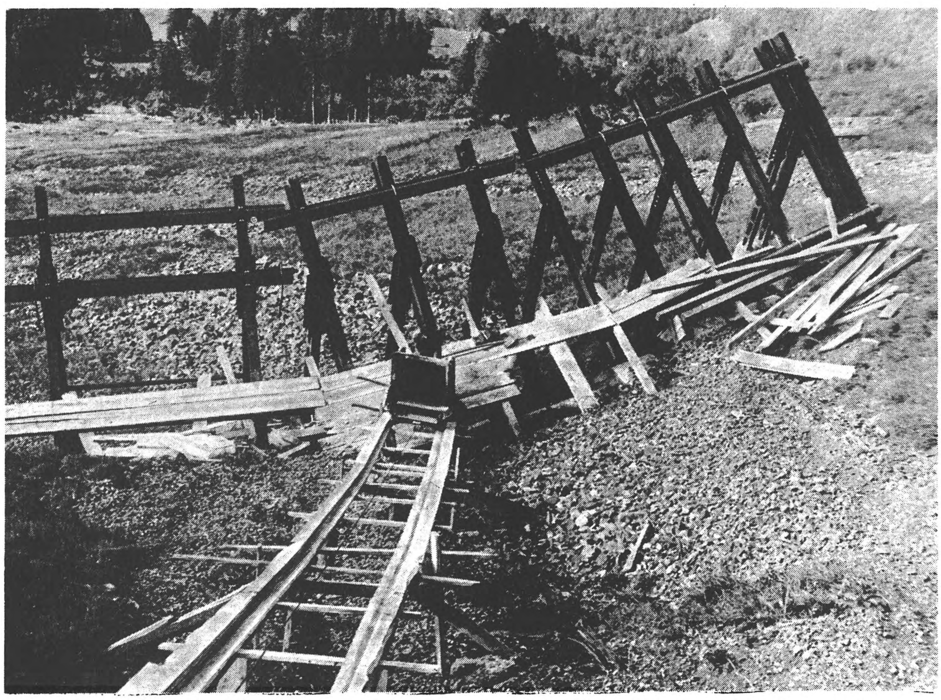


Figure 12. *In construction area boundary zones, which are exposed to dynamic stressing, the endangered structures must be strengthened by installing additional beams and supports in the center of the field or be protected by other suitable measures (Wilerhorn/Brienzwiler, photo W. Schwarz).*

Figure 13. *Snow nets (Brugg Cable Works Company), with a continuous row of steel snow bridges OeAM below (Tanngrindel/Brienz, photo W. Schwarz).*

duction of a diagonal weave on the compression grid. Snow net projects are often satisfactorily closed off below by means of a row of rigid supporting structures (e.g., a continuous row of snow bridges) in order to retard and arrest any snow movements.

8. Permanent Protection Against Gliding Snow

Permanent snow glide protection is intended, in grassy southern locations having flat ground and also in locations of similar exposure having smooth superficial rock faces, for the protection of permanent structures against damage produced by gliding snow forces, and is also intended to permit afforestation on flat ground sites.

From this description, it is clear that gliding snow protection whenever possible, should be based upon conventional, temporary, cheap measures, such as flat or dished terraces, and wooden posts (compare H. in der Gand, Section 2). These latter methods assume good solid ground and are not usable in flat rocky situations. For these cases, the following two procedures have been developed for permanent gliding snow protection:

a. construction of dry walls, in some cases by resorting to wirebound stone boxes (the system employed by Hutter-Schranz, Fratelli Albertolli, Avi, etc.), having a height of about 100 cm;

b. installation of antiglide bridges OeAM with D_K = 0.6 m and 1.0 m.

For example, in the Tanngrindel/Brienz project (glide factor N = 2.9) 350 running meters of dry wall with wire-bound boxes (which simultaneously served as deposit locations for rocky excavation material) and about 500 running meters of OeAM antiglide bridges were installed for permanent gliding snow protection.

These permanent antigliding structures are placed in such a way that the spacing of the supporting structures in the fall-line is approximately halved, taking into account the shape of the terrain. In this way, in the above project, it was possible to prevent the occurrence of glide cracks.

In a number of antigliding installations, it has been established empirically that the horizontal spacing should not exceed 2-3 m since otherwise new glide cracks arise and in particular the corners of the dry walls are damaged.

Permanent gliding snow protection using dry walls and antiglide bridges is capable of reducing the movements of gliding snow within the limits of a construction area to such an extent that no further glide cracks arise. The resulting force peaks applied through the antiglide structures have not, on the basis of observations thus far, had a disadvantageous effect; it has not yet been possible to detect any slab fractures across these installations.

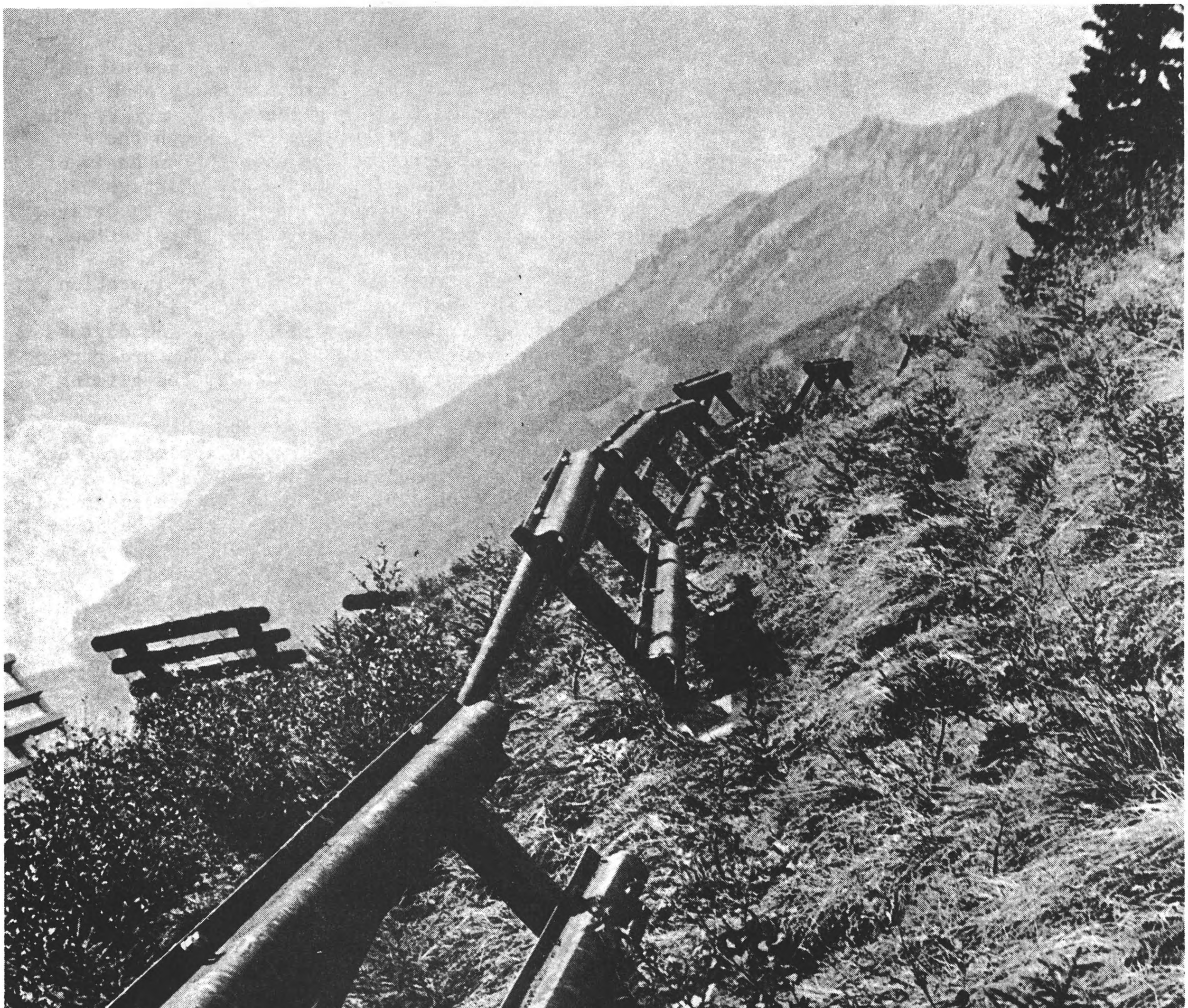
In constructing dry walls, consideration should also be given to a tapering in the direction of the valley and at the foundation, amounting to at least 25 percent, in order to avoid overturning of the walls by the gliding snow forces.

The OeAM antiglide bridges are manufactured for concrete foundations as well as for those employing ground plates, in structure lengths of 3 m and grid heights D_K of 0.6 m (one beam) and 1.0 m (two beams). From 1963 to the end of 1971, the OeAM produced 4,038 running meters of antiglide bridges of which 630 running meters were assembled in Switzerland. The costs today per running meter for the purchase of superstructure of the type 1.0 x 3.0 m with concrete foundation run to about 120 francs -- including freight, import charges, and sales tax, and for the completely installed structure, the cost is about 200 francs -- without material transport.

The antiglide structures 1.0 x 3.0 m having a concrete foundation have shown themselves, despite great deposits of snow, to be astonishingly resistant to damage. Of the 492 running meters of antiglide structures in the Tanngrindel/Brienz construction, since 1962 only 1.2 percent have been damaged and this was only because the rock anchorings had been torn out along with entire slabs of rock.

The employment of types having base plates is to be avoided since in the case of deep soils the protection of afforestation and the load relief of the supporting structures is more successfully accomplished by large-area terracings (stepped terraces, dished terraces, earth terraces, posts).

Figure 14. OeAM gliding snow bridges 1.0 x 3.0 m permit afforestation in sites having high glide factors and flat-ground soils and also relieve the actual supporting structures. Important for antiglide bridges is the existence of a large taper in the supports amounting to at least 35 cm/m (Tanngrindel/Brienz, photo W. Schwarz).



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English Translation of German Titles

[1] Avalanche Control Structures in the Starting Zone, Guidelines of the Federal Forest Inspectorate for Supporting Structures.

[2] Avalanche Control Structures.

[3] Avalanche Control Structures in Steel and Reinforced Concrete, Use of Steel, No. 316.

[4] The Limits of Modern Avalanche Control Structures in the Starting Zone.

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VII. TEMPORARY SUPPORT STRUCTURES AND GLIDING SNOW PROTECTION (Hansruedi in der Gand, Davos)

1. Temporary Supporting Structures

1.1 General Remarks

A temporary supporting structure is an anti-avalanche protective measure having a short-term period of effectiveness. In Switzerland, this type of structure is primarily employed in conjunction with the afforestation of avalanche regions. The supporting structures must, in this case, fulfill their purpose only until the growing afforestation functions independently for avalanche protection, i.e., on the average 20-40 years. Occasionally, it is necessary to provide temporary facilities (construction sites, barracks, transport facilities, etc.) with temporary avalanche protection by means of supporting structures.

The considerable reduction of required permanency for temporary supporting structures in contrast to the requirements of permanent avalanche protection structures permits the choice of cheaper and less durable building materials and more economical designs. Because of the high costs of permanent support structures (compare W. Schwarz, Section 4), this is a decisive feature for the short-term protective measures needed in regions of afforestation.

Up to now in Switzerland, it has been necessary for the majority of protective structures to be permanent. From 1939 to 1966, the 31,600 m of temporary supporting structures built amounted to only 25 percent of the total support construction [for the period] [1]. Within the framework of future installations in mountain forests and in new afforestations, temporary supporting structures will increasingly come into use (compare C. Ragaz, Article 16, and M. de Coulon, Ausblick). The limitations imposed upon the building costs of temporary support installations will thereby attain still greater economic significance.

In the pursuit of price-favorable solutions, one must not be misled into sacrificing the necessary quality of construction. The past has shown often and clearly that makeshift and unsuitably designed structures are in the long run unable to meet the severe demands of the avalanche regions. Such provisory structures easily give rise to failures and also to excess costs and in this way damage the image of temporary support construction. Practitioners -- partly on their own and partly in cooperation with the Federal Institute for Snow and Avalanche Research (EISLF) -- have repeatedly sought to construct more resistant, standard types of structures. Important principles for this purpose have been communicated to us by Prof. Dr. Haefeli in his snow engineering and avalanche construction lecture at the Federal Technical Advanced School of Zurich. Nevertheless, the development of temporary supporting structures, from the engineering point of view, did not progress very far. The practitioner had at his disposal neither the necessary principles nor the time to solve the various material, engineering, and design problems; and the EISLF was fully occupied with permanent support construction after the avalanche catastrophes of the winter 1950/51.

Therefore, it is not surprising that with the development and industrial manufacturing of prefabricated, standardized permanent supporting structures, temporary support construction suffered a certain loss of confidence. This was apparent when permanent support constructions were erected instead of temporary ones, in many places even in afforestation regions. The marked rise in cost for permanent structures, caused in part by more rigorous guidelines and in part by rising costs of material, has recently brought a halt to this uneconomic procedure. But at the same time and with good reason, there was also a call for more resistant and more economical types of structures.

The EISLF, within the context of afforestation experiments being carried out in the avalanche starting zones of the Stillberg in the Davos Dischma Valley in conjunction with the Swiss Forest Research Institute (EAFV), was confronted with the task of erecting temporary supporting structures in which the structures would have to satisfy (Figure 1) precisely these requirements: high resistance and durability at the least possible construction costs. Admittedly the new type of installation still does not have its final long-term testing behind it; but is has already proven itself in two important cases:

Figure 1. Experimental region EISLF/EAFV Stillberg (Dischmatal/Davos), temporary supporting structures with round-wood snow rakes; left subarea with ready-made continuous arrangement, right subarea with discontinuous arrangement; 9 March 1972 (photo E. Wengi).

a. in the snowy midwinter and later winter 1969/70, over a several months time span with high snow pressure, there was not a single instance of deficiency in over 300 m of supporting structures; also, slab fractures occurred only in the surrounding zones but not in the controlled region itself (Figure 2).

b. the structures survived undamaged despite high shock loadings from a wet, ground avalanche which broke loose during the extremely warm days of Easter 1971 (Figure 3).

Hence, because of the urgent need for temporary supporting structures for future afforestation and forest restoration projects, this type of structure will be employed as an example for illustrating the most important material, technical, design, and construction facts and principles which must serve as a foundation for the planning and erection of temporary supporting structures. This does not exclude future developments in temporary supporting structures.

1.2 Guidelines

The last edition (1968) of the Guidelines of the Federal Forest Inspectorate for Supporting Structures, designated "Guidelines" in the following paragraphs [2], sets the standard for both permanent and temporary supporting structures in the starting zones of avalanches. This is a consequence of the fact that both types of structures -- with the exception of the lesser durability required for the temporary support installations -- have basically the same task and effect. Therefore, temporary supporting structures must be calculated, designed, and dimensioned on the basis of the possible stresses and with attention to the material properties of the various materials employed. Thus, a

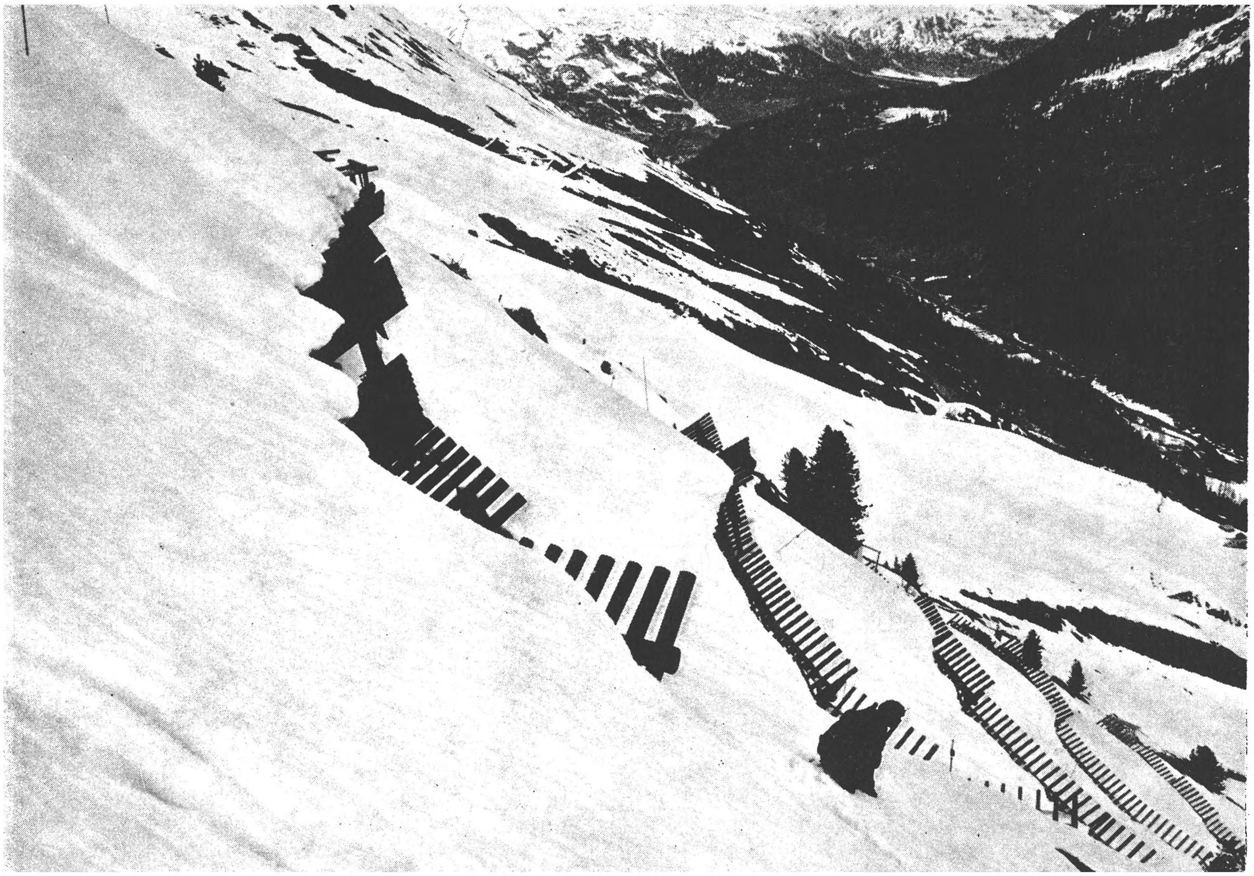


Figure 2. Experimental region in Stillberg with a continuous arrangement [of structures]: condition of the snow cover on the round-wood snow rakes on 29 May 1970 (photo E. Wengi).

temporary supporting structure is no longer, as previously, merely left to the distinctive capacity of the journeyman but properly and in analogy to permanent modes of construction, must be elevated to the rank of engineering construction. It is in this sense that the above-mentioned Guidelines now provide the principles necessary for the static computation and design of articulated, temporary supporting structures.

1.3 Building Materials

Up until today, for temporary supporting structures, wood has maintained its position as the most important and price-favorable building material. Fir, pine, larch, scotch pine, mountain fir, and chestnut are used both in the superstructure and in the lower structure, primarily in the form of round-wood. Where the wood supply is adequate, half and quarter timbers are also employed in the grids. On the other hand, so far square timbers have been used only in a few cases [3], among others in an experimental project carried out by the EISLF on the Dorfberg in Davos/Dorf, for the purpose of comparing round-wood structures. Square timber exhibits less strength than round-wood, owing to the unavoidable cutting of wood fibers during sawing [2, 4, 5, 6] and involves higher material costs. Therefore, it will probably not play a significant role in temporary supporting structures in the future as a construction wood although untreated, unsplintered square timber is less subject to rot than unimpregnated round-wood.

Figure 3. Experimental region on the Stillberg with continuous arrangement of structures: snow deposit by the wet, ground avalanche of 22 April 1971 on the uphill side of the lowest row of structures, 3 May 1971 (photo J. Rychetnik).

Wood is a naturally growing construction material whose material properties, depending upon growth conditions, can display a wide range even for the same species. Besides excellent structural characteristics, wood also possesses some deficiencies which limit its utility. Therefore, a fundamental knowledge of the material is a prerequisite for technically and economically correct utilization of wood. This applies particularly to the severe conditions to which wood is exposed in temporary supporting structures.

We shall briefly list [5, 6, 7] the essential structural advantages and disadvantages of wood with respect to temporary supporting structures.

Important advantages of wood:

a. relatively low material cost in comparison with other building materials;

b. high compressive and tensile strength under stress in the fiber direction;

c. good chemical corrosion resistance in soil compared with other building materials used for supporting structures. This is an advantage when construction components are installed in soil;

d. easy workability both on the workbench and at the building site, so that necessary adaptations of the structural elements may be carried out right on the site without great alterations and additional costs;

e. relatively low weight compared with its strength, which contributes to simplification and cheapening of transport and assembly operations;

f. simple and cheap assembly with nails as fastenings and the short construction time which is guaranteed by the dry mode of construction, all of which favor construction progress and construction costs especially in the mountains with their climatically short building periods;

g. in certain cases, the acquisition of wood in the vicinity of the construction site can also be advantageous with respect to transportation and with respect to scheduling procurement of the building material.

Structural disadvantages of wood:

a. possible destruction, especially by fungi, which necessitates improving the durability by special wood protective measures (compare Section 1.4);

b. the marked variability of strength and deformability of wood depending upon various factors such as growth conditions, volumetric weight, water content, wood defects, etc., which impose rigorous standards in establishing allowable stresses and, in the selection of the wood, to eliminate diseased, defective, contorted, boxy, and branchy material [2, 4-10];

c. the necessity of selecting and tailoring the required dimensions to the available assortments.

In addition to wood, one also finds other building materials in temporary supporting structures:

a. prefabricated, armored concrete plates and natural stone plates for the foundations;

b. iron pilings for anchoring structures to the mountainside;

c. nails, wood screws, bolts, and iron bands employed as fasteners.

1.4 Protection of Wood

Most of our wood varieties which are likely to be employed in supporting structures are attacked by fungi when left unprotected in the open. Insects, especially long-horned beetles [Cerambycidae] are occasionally secondary wood destroyers of subordinate significance. The wood-destroying fungi possess the specific capability of decomposing the skeletal substance of the cell walls (cellulose) and the lignin and using these as nourishment. This decomposition of the wood, known as rot, manifests itself in a sharp reduction of wood strength and ends with complete disintegration of the wood. Wood rot manifests itself far beyond the boundaries of the forest and can, despite reduced propagation rates in the high altitudes and under inferior living conditions for the fungi, still produce great damage in moist unprotected wood. On the Dorfberg in Davos and on the Schilt/Toggenburg, in avalanche structures and afforestation within and above the forest zone a total of more than 20 different varieties of wood-destroying fungi were observed in wooden protective structures [11]. Wood decay is also the chief reason for the complete displacement of wood as a building material from all permanent avalanche protective structures and it compels the use of special wood protective measures in temporary supporting structures. They all are designed to conserve the functional capability of the wood structures for a period of 20-40 years and therefore are of decisive significance [11-15] in temporary supporting structures.

The process of wood protection begins in the <u>selection of the construction wood</u>. Here it should be noted that the natural resistance of the wood to fungal attack can display considerable variability depending upon the type of wood and also depending upon whether one is dealing with heartwood or sapwood. Of better durability are the heartwoods of chestnut, oak, scotch fir, mountain fir, and larch. Spruce, pine, and scotch fir sapwood are less fungus resistant; larch and oak sapwood are highly susceptible to fungal attack. Snow rakes of spruce began to disintegrate owing to wood rot after as little as 5 years; this was on the Schilt/Toggenburg at 1,500 m on a north slope having heavy precipitation. On the southern exposure of the Dorfberg near Davos at an elevation of over 2,300 m, horizontal spruce beams rotted within 10 years to the point of being unusable. On the other hand, in the construction and afforestation region of Selva-St. Brida at an elevation of 1,800 m chestnut heartwood built into snow rakes in the year 1943 on a southeast slope were still functional even after a period of 25 years. Hence, for longer durability of the structures and for especially endangered structural elements, there is advantage is selecting more durable woods. It goes without saying that only healthy wood should be used. But without a detailed investigation, it is often impossible to establish the existence of fungal attack. For this reason, it is important to obtain assurance that the wood has been rapidly and expertly prepared and in certain cases, has been dry-stored after felling and up to the time of its inspection for construction purposes. In doubtful cases, sampling investigations should be carried out.

Additional important <u>wood protective measures</u> are of a <u>constructive nature</u>. Here it is a matter of excluding as much as possible the collection of water and of excluding the longer lasting increase in wood moisture, as compared with that of dry wood, by suitable arrangement of the wood elements and of the fastenings. High wood moisture is the essential prerequisite for the development of fungus. Optimal conditions, depending on the type of fungus, range from a water content of 20 percent to 60 percent of the dry weight of the wood. Below 15 to 20 percent, no growth of wood-destroying fungi is possible.

The most important constructive [design] protective measures are (compare Figure 4):

a. a predominantly standing or inclined arrangement of the supports, grid beams, and diagonal braces, so that rain and melt water remain for a lesser time. For the same reason, in wood structures, the snow rake with its inclined grid elements is to be preferred to the snow bridge with its horizontal grid elements.

b. an aluminum or sheet iron covering arranged over all horizontal wooden stringers that include corewood [1/] so that air can circulate between the metal and the wood in order to avoid as much as possible the penetration and stagnation of rain and melt water. These measures were applied, with good results, for the first time by Chief Town Forester J. Kuster, in St. Gallen. on the Schilt/Toggenburg.

c. the avoidance of unnecessarily large, wood pieces that include corewood by designing the wood elements in accordance with the results of the static calculation. Thicker wood pieces that include corewood are more markedly exposed to fungal attack than are thinner pieces that do not include corewood. This is related, among other things, to the fact that thinner wood dries out faster than thicker wood and that cross-sections without corewood are less disposed to the formation of dry cracks and hence are less inclined to water stagnation than is the case with cross-sections that include corewood. Therefore, to the extent that thicker pieces can be employed, it is advantageous to install them as half rounds or quarter rounds and moreover with their round sides downward in order that water shall be unable to accumulate in the cracks. In addition, the supporting capacity of the half rounds is better in this position than when the cut surface is downward because the stress distribution leads to larger tensile stress and smaller compressive stress which introduces greater load-carrying capacity in view of the much higher tensile strength of the wood.

d. it would also be advantageous to raise the entire wood construction above the ground in such a way that it lies outside the moister zone in the vicinity of the ground. But this is not realizable because of the substantial increase in the cost of the foundations which would be associated with such a procedure. But something like this cannot be avoided, without increasing costs, in connection with the stringer positions on the upper support end, which permits the penetration of water into the cross-cut end. In these

[1/] corewood: the juvenile wood immediately surrounding the pith.

cases, one must employ artificial protective measures to deal with the susceptibility of the components to rot.

A final important measure, which is very effective when properly used is artificial wood protection. This involves the introduction of fungicides into the wood structure so the development of fungi is prevented or adequately delayed. This wood impregnation must always be employed whenever the natural durability of the wood is too short compared to the required useful life. When spruce and pine are used, this may be necessary for a useful life of more than 5 years and in the case of chestnut, for a life of more than 20 years. In addition, wood must be impregnated in every case when it has not been adequately protected by design provisions in the construction itself. Depending upon the useful life of the supporting structures and upon the resistance of the wood, this [need for protection] applies to horizontal stringers, the lower part of grid beams and supports, as well as ties that are near or in contact with the ground, and moreover, applies to exposed locations where stringers are attached to supports, and to exposed crosscut ends of grid beams and diagonal braces.

In order to obtain an appropriate and economic wood impregnation, protective agent and mode of employing it should be selected in accordance with the time limits imposed upon the structures in the installation. There are available for the purpose of wood protection such agents as water soluble salts, oils, protective agents dissolved in organic solvents, oil-salt mixtures, and emulsions.

The wood protective agent should exhibit the following characteristics:

a. good fungicidal effectiveness against brown rot and mold rot; minimal toxicity for humans, animals, and the vegetation cover, during and after application;

b. good water solubility (salts) and diffusion capability as well as good storage capability and resistance to washing out;

c. good penetration depth for the existing water content of the wood, and low metallic corrosion.

Possible impregnation procedures:

a. manual procedures:

immersion soaking over several days
osmotic processes
salt wrappings or oil-salt wrappings as an additional protection for wood which is in contact with the ground

Charring, painting, spraying, and dipping give inadequate protection and therefore may not be considered for wood impregnation in supporting structures.

b. industrial procedures:

pressure kettle procedures
sap-displacement procedures (Boucherie technique, open-tank soaking, suction procedures, alternating pressure procedures)

Besides the nature of the wood and local conditions, the impregnation procedure is determined especially by the durability required of the supporting structures. Wood having inadequate natural durability, in order to attain a useful life between 5 and 15 years must be protected at least by means of a soaking over several days. A useful life of more than 15 years is obtainable by means of correct application of the manual osmotic process or of the industrial processes. For telephone poles, today it is expected that industrially impregnated wood will have a useful life of 33 years. In temporary supporting structures, it is probable that the durability of wood treated in this way, when subjected to less exacting elimination criteria, will be still higher.

But the effectiveness of wood treatment depends not only upon the quality of the protective agent and the method of introducing it, but also very essentially upon the state and the impregnability of the wood. Thus, oily protective agents should be applied only to air dried wood, while with water soluble salts, the best protective effect is achieved when they are introduced into sappy wood. In addition, air dried spruce and pine cannot be impregnated as deeply with oily protective agents as can sappy woods with salt agents. In this case, scotch fir and larch sapwood behave more satisfactorily. In addition, a marked tendency of air dried wood to crack improves the penetration of the protective agent.

In general, a good deep protection adequate for long-term useful life of the wood is obtained only by the osmotic, the industrial pressure kettle, and sap-displacement processes. Especial attention must be paid to adequate impregnation of construction components inserted into the ground. As experiments with telephone poles have shown, a substantial increase in protective effect is achieved by applying salt-wrappings and protective soakings for a reimpregnation of dry cracks. With the object of further improving the protection of specially exposed zones, when wood is cut to fit at supports and connection locations, these processes should be carried out before the impregnation or at least retreated with suitable protective agents [after they are cut].

The artificial protection of wood must, therefore, corresponding to the conditions and possibilities prevailing at the site, be thoroughly planned if there is to be an effective and economic selection of wood, protective agents, and protective procedures adapted to the duration of the structures. The costs of wood impregnation are not low. In the case of industrial processes, they can be as high as the price of the wood itself; manual procedures are on the whole substantially cheaper [15]. But, evaluated in terms of the protective function of a temporary supporting structure, it would be irresponsible to select the method of wood impregnation only on the basis of its cost. Similarly, under normal conditions deficient planning and hence lack of time should not be allowed to make it impossible to use the best protective treatment.

It is intended that this exposition of the most important principles of wood protection in temporary supporting structures should bring out with sufficient clarity the fact that a mastery of manifold material is of basic importance for the use of wood in open-air construction and requires a solid background of knowledge.

In order to enlarge our knowledge of the effectiveness of various types of wood protecting methods under natural environmental conditions and thereby to aid practical avalanche structural control, the EISLF, together with the Wood Division of the Federal Material Testing and Research Institute (EMPA) in Duebendorf and in conjunction with the Division of Material Biology of the EMPA in St. Gallen, instituted large-scale field investigations many years ago in order to determine the most suitable wood protection techniques for avalanche control structures. The first results of these experiments will be published elsewhere in the near future. In addition, the practitioner can get advice from the EISLF with regard to problems arising in wood protection, insofar as the state of knowledge permits.

1.5 Installation Type (Figures 4 and 5)

For a long time now preference has been given in articulated temporary supporting structures to round-wood snow rakes with their grid beams arranged perpendicular to the contours and having horizontal grid timbers. The reason for this lies in the simpler anchoring, on the uphill side, of the tie over the entire installation length. In the case of snow bridges, the snow-pressure forces are applied via the grid to two carriers and the process of anchoring these carriers with adequate tensile strength on the uphill side introduces more construction difficulties. In addition, the skew-standing grid timbers of the snow rake are substantially less exposed to rot than the horizontal grid beams of the snow bridge (compare Section 1.4). And finally, in afforestations, when small trees grow up through the snow rakes, less damage occurs to them than when the branches are bent over the grid beams of snow bridges.

In the following, we therefore limit ourselves to a discussion of the most important construction features of the round-wood snow rake, turning to the SLF type of structure for illustration. This type of structure has been further developed from traditional designs and has been conceived and designed on the strength of a statistical calculation based upon the Guidelines and also on the strength of the principles of wood construction engineering and the principles of wood protection [16, 17, 18].

The snow rake consists of the grid, the main framework, and the foundations on the uphill and downhill sides.

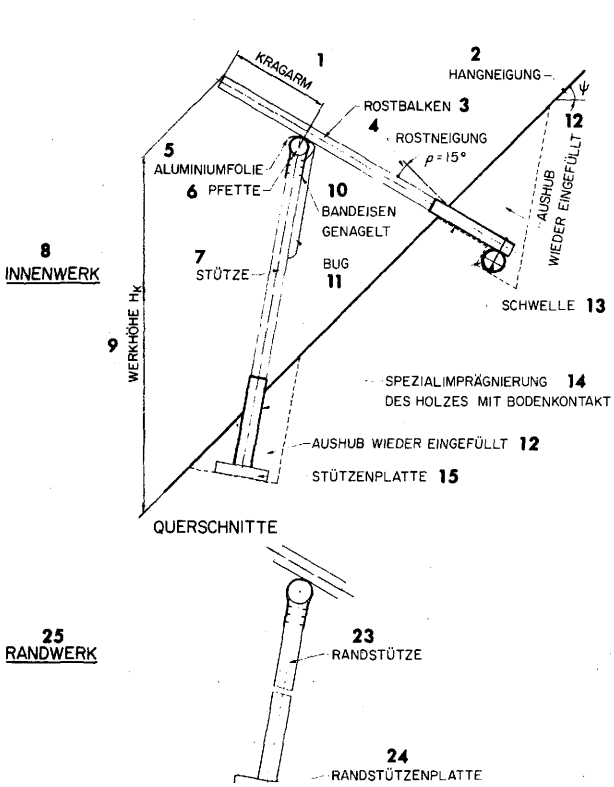
The grid (together with the grid beams, which as we have already mentioned, are perpendicular to the contours -- corresponding to the Guideline recommendation for rigid support surfaces) is inclined 15° downhill from the perpendicular to the slope. A sharply inclined grid, of the sort which was normally built in former times, displays the following disadvantages, some of which are serious:

a. with increasing downhill inclination of the grid, snow pressure increases.

b. snow rakes having a sharply inclined grid are more easily overrun by snow slides; this can also give rise to more extended avalanche invasions into a controlled area.

c. the snow overflowing the rakes transmits additional shear forces to the grid so that the foundation forces, particularly the tensile forces, are also increased.

d. with increasing grid inclination, the amount of wood in the structure increases (longer and thicker grid beams).



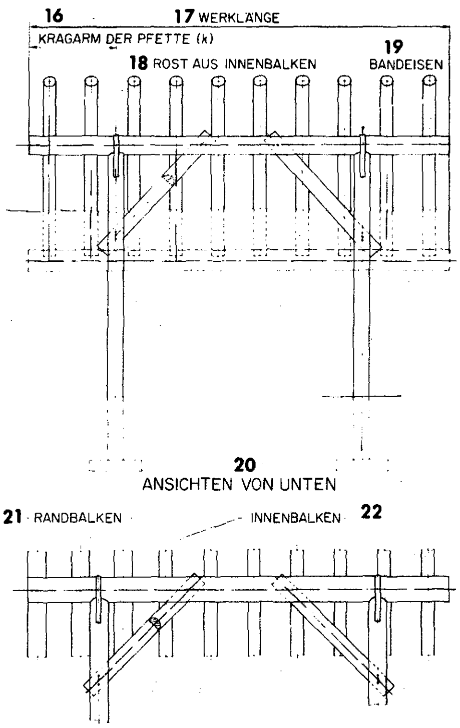


Figure 4. Round-wood snow rake SLF Stillberg/ Davos Construction glide factor 1.2 height factor 1.13

Key to Figure 4:

1. Cantilever [overhang]
2. Slope inclination
3. Grid-beam
4. Grid inclination
5. Aluminum foil
6. Stringer or Purlin
7. Support
8. Internal structure
9. Structure height
10. Nailed steel strap
11. Cross-brace
12. Refilled excavation
13. Tie
14. Special impregnation of the wood which is in contact with the ground
15. Support plate
16. Stringer cantilever
17. Structure length
18. Grid of interior beams
19. Steel straps
20. View from below
21. End beams
22. Interior beams
23. End support
24. End support plate
25. End or boundary structure

Opposed to these disadvantages, there is the insignificant advantage of a relatively small reduction in the tensile force acting on the uphill foundation. Hence, a grid inclination greater than that given in the Guidelines should be rejected.

The grid beams have been designed as freely supported carriers having a one-sided cantilever directed downhill. In order to obtain grid beam cross-sections which are as low as possible (wood protection), the design is based upon equilibrated bending moments. The grid transmits the forces of the snow pressure which act upon it to the main framework, i.e., uphill to the tie and downhill to stringers and supports. In the type of construction which has been conventional thus far, the tie -- both as a part of the main framework and at the same time as an uphill rake foundation -- lies in the open on a terrace which is at least 1 m broad and is anchored in the ground by wood pilings or iron pilings. The pilings are approximately perpendicular to the

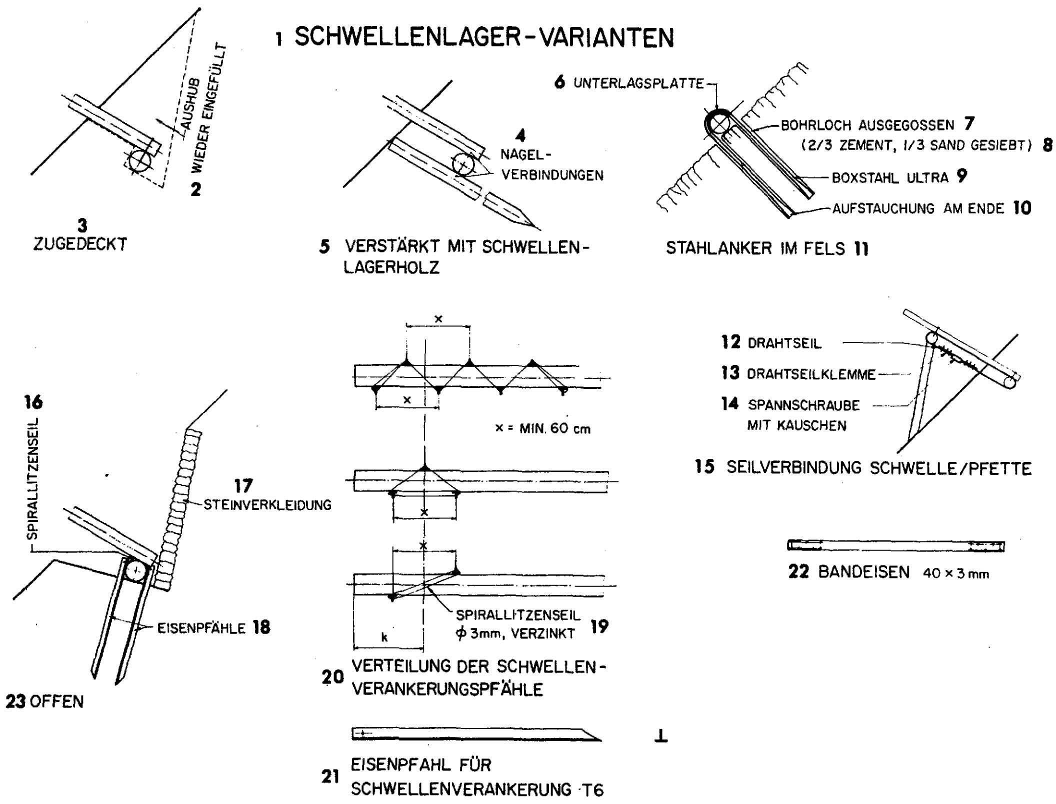


Figure 5. Details of the round-wood snow rake SLF Stillberg/Davos Construction.

Key to Figure 5:

1. Tie support variations
2. Refilled excavation
3. Covered
4. Nail fastenings
5. Strengthened with tie-support wood
6. Base plate
7. Drill hole filled with (See 8)
8. 2/3 cement, 1/3 sieved sand
9. Ultra-box-steel [Boxstahl ultra]
10. Edge-rolled on the end
11. Steel anchoring in rock
12. Wire cable
13. Wire cable clamp
14. Turnbuckle
15. Tie/stringer cable connection
16. Spirally stranded cable
17. Stone mantle
18. Steel pilings
19. Spirally stranded cable
20. Distribution of the tie anchoring
21. Steel piling for tie anchoring
22. Steel strap
23. Open

grid plane and driven at least 1 m deep into undisturbed soil and arranged along the tie, uphill and downhill, in such a manner that their ranges of effectiveness overlap on the ground as little as possible. In order to assure a distribution of the applied foundation forces that is as uniform as possible upon all pilings, the latter are connected to one another by a spirally stranded cable (compare Figure 5). Even in the case of careful design, this type of foundation has, in experience, had low tensile strength. It is the weakest part of the entire construction and has, in various ways, been the source of damage to the structures particularly when high snow pressures resulting from gliding snow action are applied over a long period of time or when high momentary shock loadings produced by snow movements are applied to such snow rakes. In addition, computation principles are lacking for designing the piling anchor in accordance with snow pressure and strength of the soil. Therefore, the Guidelines specify for this case that in localities having marked gliding activity the tensile force acting on a tie should be reduced by artificially increasing the ground roughness (terraces, pilings). Further, such installations should not be erected in terrain which is too steep and in excessively deep snow, unless the foundations have been specially designed for the tensile forces.

Such a possibility of installing uphill foundations strong in tension presents itself when the tie is placed in undisturbed soil at a perpendicularly measured foundation depth of at least 1 m and with replacement of excavated material into the foundation diggings, with the lowest part of the support grid also being covered (compare Figure 5, variants of covered tie supports). The foundation tensile force acting in the direction of the support grid plane and applied to the tie should, in this case, not exceed the strength of the soil. The Guidelines give the principles of computation for designing uphill foundations to resist ground tensile forces. Here it should be noted that it will in general probably be difficult to install the several-meters-long tie completely in undisturbed soil and hence in the interest of safety one should assign an admissible shear stress to the ground which is equal only to that of the replaced excavation material (0.50 t/m^2 in 1 m foundation depth).

Figure 6 compares the allowable tensile components of the uphill foundation force and the maximum values of the same as calculated according to the Guidelines -- in the form in which they arise for half boundary structures or interior structures of a 4-m-long snow rake having perpendicular height from 1.5 m to 4.5 m, and whose tie is installed for 0.8 m in the ground in the direction of the grid plane. The left part of the diagram is valid for the case without gliding of the snow cover on the ground (N = 1.2), the right side for that with moderate snow gliding, such as that which still occurs initially under average local conditions, for example, in an afforestation carried out with large planting holes (dished terraces, compare Section 2.3.2) (N = 1.8). The maximum perpendicular structure height H_K for end structures and interior structures is given at the intersection point of the corresponding maximum value curves with the associated curves of allowable tensile force. Table 1 also displays the most important results of this study.

Key:

1. Computed tension component for end (RW) and interior (IW) structures
2. Allowable tension component for end (RW) and for interior (IW) structures

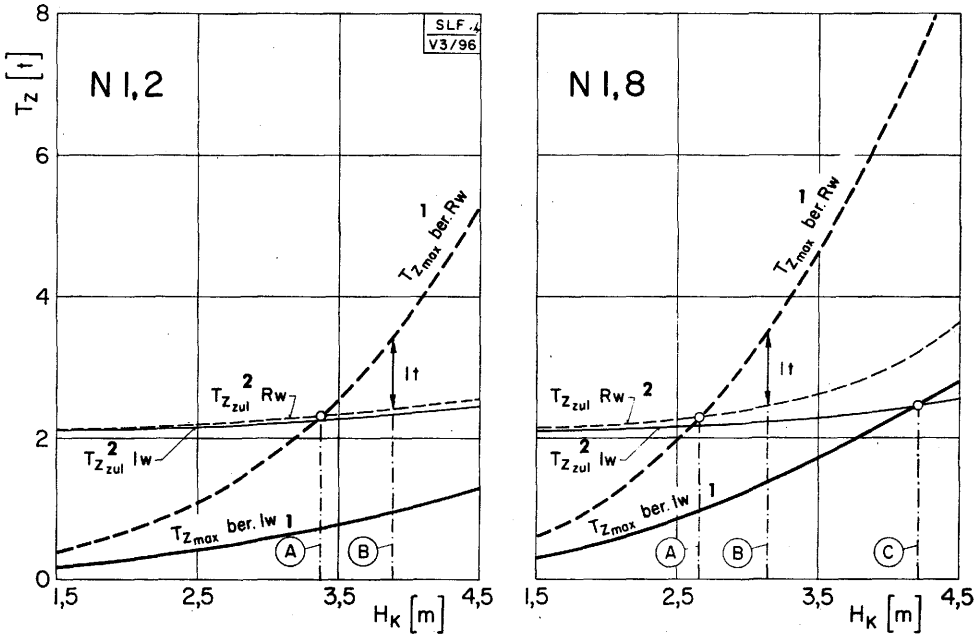


Figure 6. Computed maximum and allowable tension components T_Z of the foundation force T acting on the tie of a snow rake (tie installation in the grid plane to a depth of 0.8 m in the ground). This is shown for the half (1/2 = 2 m) end installations (RW) or for the inner installation (IW), for installation heights H_K 1.5-4.5 m and for glide factors (N)/height factors (fc) N=1.2/fc=1.13, N=1.8/fc=1.02

Table 1. Allowable Structure Heights H_K [m] for Snow Rakes of the SLF Type With Structure Lengths of 4.0 m in the Case of an Open Tie and in the Case of a Tie Introduced to a Depth of 0.8 m Into the Soil in the Direction of the Grid Plane, for N=1.2/fc=1.13 and N=1.8/fc=1.02; RW = end structures, IW = interior structures; assumed value of the admissible tensile stress of the piling anchoring = 1 t per 1/2 structure; ABC compare Figure 6.

Key:

1. Open tie, with piling anchor
2. Tie introduced into the soil
3. Without piling anchor
4. With piling anchor

N	Schwelle offen, mit Pfahlverankerung 1		2 Schwelle im Boden eingebaut			
			ohne Pfahlverankerung 3		mit Pfahlverankerung 4	
	RW	IW	RW A	IW C	RW B	IW
1,2	2,4	4,0	3,3	≧4,5	3,8	≧4,5
1,8	1,8	2,6	2,6	4,2	3,1	≧4,5

In summary:

a. By introducing the tie into the ground, one obtains in the case of snow rake construction not only a substantially stronger anchoring in tension than in the case of an open tie but one can also, as a consequence of this better tensile foundation, erect structural types having a greater height; and this is also the case when one takes into account the required wood cross-sections. Thus, e.g., a well constructed interior structure having height of 4.2 m and computed for a glide factor of N = 1.8 displays the following minimum timber diameters: grid beams 16 cm, tie 20 cm, supports (4 m long) 19 cm, stringer 24 cm. As the heaviest structural element of this assortment, the stringer weighs about 100 kg.

b. The decision as to whether a snow rake should be designed with a tie built into the ground or with an open tie which has been anchored with pilings is a decision which can be made only on the basis of a computation of the maximum possible tensile forces for given conditions at the site and of the allowable tensile forces with a tie which has been built into the ground.

c. In the case of piling anchors, no matter whether for an open tie or for a tie built into the ground, one must resort to empirical values with regard to the tensile strength of such anchors.

Further advantages of installing the tie into the ground are:

a. Limitation, for the duration of the construction process, of the danger of subsequent sliding of the slope when the latter has been excavated for the foundations; this sliding can occur in particularly exposed terrain zones as a consequence of continuous successive placement of individual prefabricated structures;

b. A reduction in the danger of sagging of the tie support owing to reduced water infiltration;

c. An increase in the lateral stiffness of the snow rake;

d. Absence of the necessity for terrace maintenance.

In addition to the tension forces, the uphill rake foundation must also be designed to resist the ground compression forces in accordance with the Guidelines. Where the admissible soil compression of loose rock is too low, in order to strengthen the tie support, support timbers should be rammed into the undisturbed soil (compare Figure 5) as deeply as possible beneath the tie in the direction of the support grid plane.

In the interest of completeness, we shall also list here the process of anchoring the ties in the adjacent rock by means of steel anchors, as is also shown in Figure 5. It is also possible to use cable anchors in place of steel anchors to simplify the drilling operation.

The downhill main framework of the snow rake consists of a stringer running in the direction of the contour and two supports. The stringer lies -- in the shape of a double cantilever -- directly on top of the supports. In order to obtain minimal stringer cross-sections as required for the purpose of wood protection, the stringer design is carried out, as in the case of the grid beams, on the principle of equilibrated bending moments. Likewise in the case of the supports, the minimum required diameter should be derived by determining the support length at the structure site and on the basis of buckling calculations in accordance with the Guidelines. The stringer connection at the upper end of the support should be adapted as well as possible to the form and the diameter of the stringer. By careful fitting with a bow-saw and with the aid of a circular segment template corresponding to the particular stringer diameter at the bearing location, this adaptation can be carried out without difficulty at the building site itself. Wedge-shaped stringer bearings are undesirable; they lead to a splitting of the heads of the supports.

For the purpose of stiffening the main framework against lateral loading, two diagonal braces per installation are arranged on the uphill side between the supports and the stringer. Diagonal braces for the purpose of protecting the grid are more effectively positioned and flexurally stronger than the long swivelable slats which previously were employed on the downhill side of the supports. Stiffening slats attached to the uphill side of the grid which magnify the frictional resistance of the grid and hence increase the forces acting on the structure in the event of snow motions are not advisable.

Normally, armored concrete plates serve as support foundations; their base areas should be designed in accordance with the admissible ground compression in the direction of the force. The support stands with its foot directly upon the foundation plate; its position is made secure by means of an iron mandrel placed in the middle of the foundation plate and penetrating the central drill hole in the foot of the support. In order to reduce water infiltration in the ground abutment of the support foundation and in order to increase the lateral stiffness of the rake construction, the support foundation holes can be covered over again with the excavation material. In this case, the lower part of the supports which is embedded in the ground must be specially protected against rot, as in the case of a tie inserted into the ground (compare Section 14); however, in the latter case, the steep cutting of the slope or covering with stone and the maintenance of the support holes is not required.

For the connections of support grid and main framework as well as of the structural elements of the main framework among themselves, nails are employed having a cylindrical shaft and a circular cross-section. Nail fastenings are cheaper than bolt or screw fastenings; usually they can be carried out quickly by any worker at any work location using the simplest tool, without preliminary drilling in dry and in wet wood.

We have requested the Wood Division of the Federal Material Testing and Experimental Institute for Industry, Architecture, and Trade (EMPA), Duebendorf (department head: Prof. H. Kuehne) to carry out loading experiments with nail fastenings in round timbers, as they occur in round-timber snow rakes. On the basis of the results of these experiments [19], H. Straessler makes the following recommendations [20]:

"a) General Remarks: The SIA Standards No. 164 contain no data regarding the nailing of round timbers; according to DIN Standard 1052 the allowable carrying force for the fastening of thick planks, square timber, etc., to round timber should be reduced to two-thirds their value and nail fastenings of two round timbers are not allowable in the case of load-carrying structures. Thus in previously constructed round-timber snow rakes 'unallowed' nail fastenings were employed; nevertheless they have thus far proven satisfactory in practical use.

"b) Allowable Holding Strength: Experiments carried out by the EMPA with nail fastenings [19] (per fastening, two nails 8.5/300 without preliminary drilling and driven in by means of hammer blows) between tie round timbers and grid beam round timbers exhibited substantial displacements for values of tensile force per nail amounting to 400 kg and above. In our view, a factor of safety of at least 1.5 should be maintained against this creep-load. Thus, the allowable load per nail 8.5/300 mm would have to be set at 250 kg. The following table contains the converted holding strength for the nails employed in the construction of round-timber snow rakes.

Table 2. Holding Strength of Nails for Round-Timber Snow Rakes

Nagel-Typ ϕ / Längen [mm] 1	4 zulässige Tragkraft pro Nagel bei Scherbeanspruchung	
	gemäss Formel in den S.I.A.-Normen 164 [keine Abminderung wegen Rundholz-Anschlüssen] 2	geschätzt auf Grund von Belastungsversuchen der EMPA 3
8,5/300, 275	199 kg	250 kg
7,5/260, 245	164 kg	205 kg
7,0/230	147 kg	185 kg
6,5/215, 200, 180	131 kg	165 kg
5,5/160, 150	100 kg	125 kg
5,0/150, 140, 130	85 kg	105 kg

Key: 1. Nail type, outside diameter/length [mm]
2. Allowable holding strength per nail under shear stress
3. In accordance with the formula in the SIA Standard 164 [no reduction because of round timber connections]
4. Estimated on the basis of the loading experiments of the EMPA

"The values underlined in this table are valid only under the assumption that the design instructions contained in Section d with regard to nail spacings, etc., have been maintained.

"c) Possible Ways of Increasing Holding Strength: There are many possible ways of increasing the holding strength of this nail fastening: preliminary drilling of the nail holes, arrangement of three instead of only two nails per connection (difficult for space reasons), flattening the contact surfaces, the use of screw bolts above 200 mm in outside diameter, the use of screw nails, etc. Of these proposals, the most valuable is that of preliminary drilling of the nail holes (drill hole diameter = about 85 percent of the nail diameter), which has the effect of increasing the holding strength about 25 percent and of substantially reducing the risk of splitting. Other proposals are in part considerably more expensive and in part involve additional difficulties. Screw nails [ring shank] possess a high resistance to extraction; the thread end of screw nails is therefore more firmly seated in the wood than is that of the conventional nail having a smooth shaft. Hence, the deformation of the nail fastening is less. However, whether the holding strength can be substantially increased is something which must be clarified by experiments of the EMPA.

"d) Carrying Out the Nailing Operations: Since the nailing of such round-timber snow rakes differs in some respects from nailings in conventional wood construction, in the following instructions are given for carrying out round-timber nailing (see also Figure 7):

"1. Nail length and driving depth: The choice of the nail type should be based not only on the tensile forces to be encountered but also should take into account the required length. According to the SIA Standards, in single shear connections, the nail point should penetrate at least 8d (d = nail diameter) into the second piece of wood. Since this recommendation is somewhat optimistic and since with round-timber nailings the risk is particularly great that in consequence of oblique nailing this limit will not be maintained, we propose, independently of the nail type: s $\geqq$ 10 cm, i.e., the nail length should be at least equal to the diameter of the round timber to be nailed plus 10 cm.

"2. Nail spacings: In order to reduce the danger of splitting, we propose the end distances, intermediate distances, and boundary distances listed in the sketch.

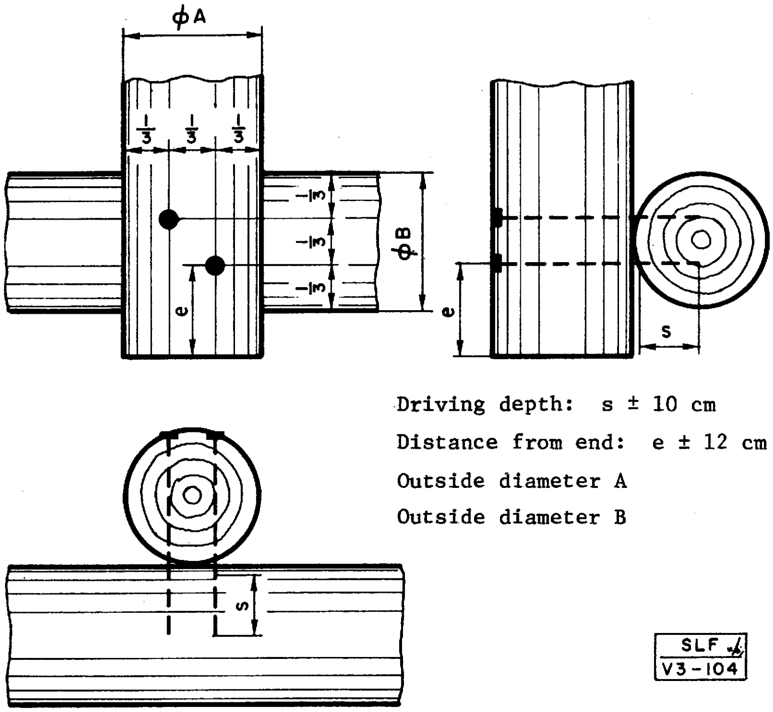


Figure 7. The nailing of round-timber snow rakes (after H. Straessler).

"3. Driving the nails: The nails are to be driven straight, i.e., perpendicular to the plane of the grid. This reduces the danger of splitting (the nails do not travel in a precisely radial direction and avoid any shrinkage cracks which may already be present) and the proposed standard measurements for end spacings, driving depths, are more likely to be guaranteed. The nail heads should not be driven into the wood; drive to the point of contact between the underside of the nail head and the surface of the wood.

"4. Nail surface: Phosphated nails should be employed; in contrast to plain nails the danger of rust is eliminated (or at least significantly reduced) and besides the extraction resistance is significantly higher."

When the nail fastenings between the grid and the main framework no longer suffice to resist the tensile force acting in the plane of the grid, the tie and stringer should be connected by a wire cable in addition to the grid nailing, as shown in the sketch contained in Figure 5. Here it should be noted that the compression stresses in the stringer and in the tie along the cable bearing must not exceed allowable transverse compression stress values, otherwise this situation should be prevented by suitably dimensioned flat steel support.

Stringer and supports are finally connected by a steel strap which is nailed to the supports on both the uphill and downhill sides.

What has been said regarding the checking of permanent supporting structures (compare W. Schwarz, Section 5), applies with appropriate changes also to temporary supporting structures. Here, in addition, it is also necessary to periodically subject the structural wood to a thorough investigation for fungus infestation. Just the external appearance alone of the wood surface -- primarily a brown to gray-black discoloration along shrinkage cracks and at cross-cut ends -- gives the wood specialist valuable indications of possible foci of rot. Often small to fairly large fungus spores can also be found on the surface of the wood and these will lead to further investigations for the presence of wood rot. Especially to be recommended is rapping on the wood with a hammer. Healthy wood gives a characteristic more or less bright sound, while zones attacked by rot are recognizable by their dull sound. In doubtful cases, boring samples provide direct information regarding the local condition of the wood. (Drill holes should be impregnated after removal of the sample and should be closed with a treated wood plug.) Also, the wood which is built into the ground should be included in these investigations at least at intervals of several years, taking samples by laying bare parts of the wood. Only by means of repeated field tests of this sort will one's attention be drawn to the particularly endangered structural portions of supporting structures and will one be in a position either to carry out suitable wood protective treatments before it is too late or to replace wood which has been weakened by rot before the entire structure collapses under the snow burden. Checks and maintenance operations carried out consistently and in a technically correct manner contribute substantially to an increase in the useful life of wood structures; they belong in the list of duties of the responsible agencies.

For data regarding the costs of the round-timber snow rake (type SLF) we can for the present only base our judgment on the Stillberg experimental project which is currently in progress. The type of structure used there, with a tie built into the ground and a structure height of 3.4 m, came to 304 Swiss francs per running meter of completed construction in 1971 (including material, transport, labor, shut-down times [Wegzeiten], building supervision). The material costs were 22 percent, labor costs 78 percent. All construction operations were carried out with in-house workers at a gross pay of 6.8 Swiss francs per hour. The installation costs mentioned also include the expenses of research; they are therefore to be considered relatively high and should not be taken without qualification as a guide for normal practical conditions.

1.6 Height and Arrangement of Temporary Supporting Structures

The height and arrangement of temporary supporting structures must correspond to the principles set down in the Guidelines. Thus, the same principles apply as in the case of permanent supporting structures. This is a logical consequence of the observation that the task and the action of permanent and temporary supporting structures -- with the sole exception of the shorter useful life of temporary installations -- are the same.

As in the case of permanent structures, allowance can be made for the various safety requirements of temporary supporting structures by introducing various spacings which at the same time are in accord with the Guidelines. The sharper limitation of allowable structure height in the case of end structures in wood construction (compare Figure 6 and Table 1) makes it appear advisable to build wood structures having more than 3 m of height in continuous arrangement. In this way, it is possible to reduce the number of end structures to a minimum.

1.7 Further Development of Temporary Supporting Structures

With the development of the round-timber snow rake presented here with its higher holding strength and greater durability, we are only at the beginning of properly engineered temporary supporting structures. It is now necessary to become familiar with the limits of applicability of this construction and this shall be on the one hand by means of comparative calculations assuming variable site conditions and variable wood cross-sections; and on the other hand by field sampling of various types of construction under extreme snow and ground conditions.

Special further development is required for:

a. the wood fastenings;

b. the uphill structural anchors in the required variants and for various types of soil;

c. protection of wood which is introduced into the ground.

The following coordination tasks arise:

a. the properly scheduled planning of temporary supporting structures on the part of the forest service, when necessary in conjunction with the EISLF (consultation, professional recommendations);

b. properly scheduled provision of main framework wood of suitable dimensions and varieties on the part of the forest service;

c. properly scheduled storage of standardized and impregnated main framework wood on the part of the wood protection industry and the forest service.

In order to be able to deal with this program, there is moreover a need for an assured interdisciplinary cooperation on the part of forest engineers, snow mechanicians, wood construction engineers, material testers, wood protection biologist, the wood protection industry, and the forest service. Finally, the results of these efforts in the interest of the technical development of effective and economic temporary supporting structures should be continuously communicated to all interested circles by means of publications, in courses, with consultations, as well as through education in advanced schools and schools of forestry.

2. Protection Against Gliding Snow

2.1 Introduction

Since the winter 1946/47, the EISLF has been occupied in special investigations and field experiments with the problems of snow gliding and of protection against gliding snow. The results of these studies have in part already been published [21, 22]. Therefore, we can limit ourselves here to a summary of the most essential principles governing the production of antiglide structures.

2.2 Snow Gliding and the Effects of Gliding Snow

On a smooth, inclined surface, for example, on long-bladed grass or on smooth flagstones, a snow cover having a wet lower layer can acquire a slow movement. This translation of the entire snow cover on the surface of the ground at rates ranging from millimeters to meters per day is called snow gliding (compare M. de Quervain, Section 3).

This occurs with pronounced frequency in gliding snow locations which are smooth, grassy slopes having an inclination from about 28° to 50° at elevations of about 1,200 m to 2,500 m and having an east by south to western exposure. Extreme snow gliding manifests itself in sickle-shaped glide cracks and in avalanche-like gliding snow fractures [Gleitschneerutschen]. In combatting snow gliding the primary purpose is to prevent these extreme processes. Depending upon whether the ground is frozen or unfrozen during snowfall and in the further course of development of the snow cover, the snow cover glides only on certain days or during the entire winter. Gliding snow zones can be located at slight cost simply by means of a few photographs of typical gliding snow situations -- particularly after snowfall on unfrozen ground.

Among the causes of the motion of gliding snow are:

a. the shear force which results from the weight of the snow cover and which is directed parallel to the slope down the fall-line;

b. the low frictional forces of the wet lower layer of the snow cover on a smooth foundation;

c. failure of the snow cover to bond to the ground.

Uphill of natural and artificial obstacles, snow gliding imposes a marked magnification of the practical blockage range, i.e., that zone in which substantial compressive stresses are evoked by the snow cover. The extension of this blockage range up the slope is thus equivalent to an increase in the snow pressure acting on the obstruction.

The damage caused by gliding snow to structures and vegetation in structural control projects and in afforestations can be considerable if the glide factor has been too optimistically evaluated. In addition to instances of damage to individual structures, it is possible for entire groups of supporting structures to be squeezed out together with the top soil. Forest plantings are either scraped by the friction forces of the snow gliding over them or are partially to completely torn out. The criteria for estimation of the glide factor are contained in the Guidelines [2].

2.3 Protection Against Gliding Snow

Combatting snow glide is based primarily on increasing the roughness of the ground surface and upon bonding the snow cover to the ground and vegetation cover by artificial means. In the Guidelines, it is recommended for zones having high glide factors to weigh whether an increase in roughness of the ground surface is economically preferable to the construction of stronger types of structures. In the case of the creation of temporary supporting structures having a foundation which on the uphill side is not very strong in tension (e.g., an open tie anchored with pilings) this artificial increase in roughness is elevated to the level of a prerequisite (compare Section 1.5). Similar preventive measures for the limitation of snow gliding should be carried out in the case of afforestation on gliding snow slopes.

Depending upon their mode of action, the following are the most appropriate antiglide measures:

a. increasing ground surface roughness: terracing (stepped terraces, dished terraces, planted holes);

b. an increase in ground surface roughness and, at the same time, an anchoring of the snow strata which are near the ground: pilings, antiglide structures (suitable for gliding snow regions having a tendency to wet snow fractures);

c. meshing the snow cover base with the vegetation layer: planting.

In carrying out the various antiglide measures the following important points are to be noted:

2.3.1 General Remarks

With an arrangement of the protective structures which is dense and distributed over an area, care must be taken not to exceed the allowable ground stresses and the allowable shear stresses of the snow.

On smooth slopes, antiglide structures should be constructed for slope inclinations above about 28°.

2.3.2 Stepped Terraces (Figure 8)

Breadth 30-50 cm constructed in excavation;

Stepped terrace ground inclined in the direction of the slope and constructed of sod squares which have been solidly tamped and flattened in the uphill direction, tilted laterally outward onto a rough-hewn step and built into abutments perpendicular to the fall-line;

Depending upon the water drainage conditions, the stepped terrace axes incline against natural drainage channels;

Slope distances:

Slope Inclination	Spacings
28°-35°	140-120 cm
35°-40°	120-100 cm
40°-45°	100- 80 cm

Continuous or broken arrangement with dished terraces (stepped terraces about 50 cm long having an average lateral spacing of 100 cm in a triangular formation);

Avoid recent slides and loose, rough soils;

Construction in the spring (settling, solidification up till the next winter);

Relatively low construction costs;

Reduction of the costs of nursing young vegetation (does away with the need for combatting weeds in the first years).

2.3.3 Wide Terraces (Figure 9)

Breadth 100 cm and more, built in the form of excavation and fill;

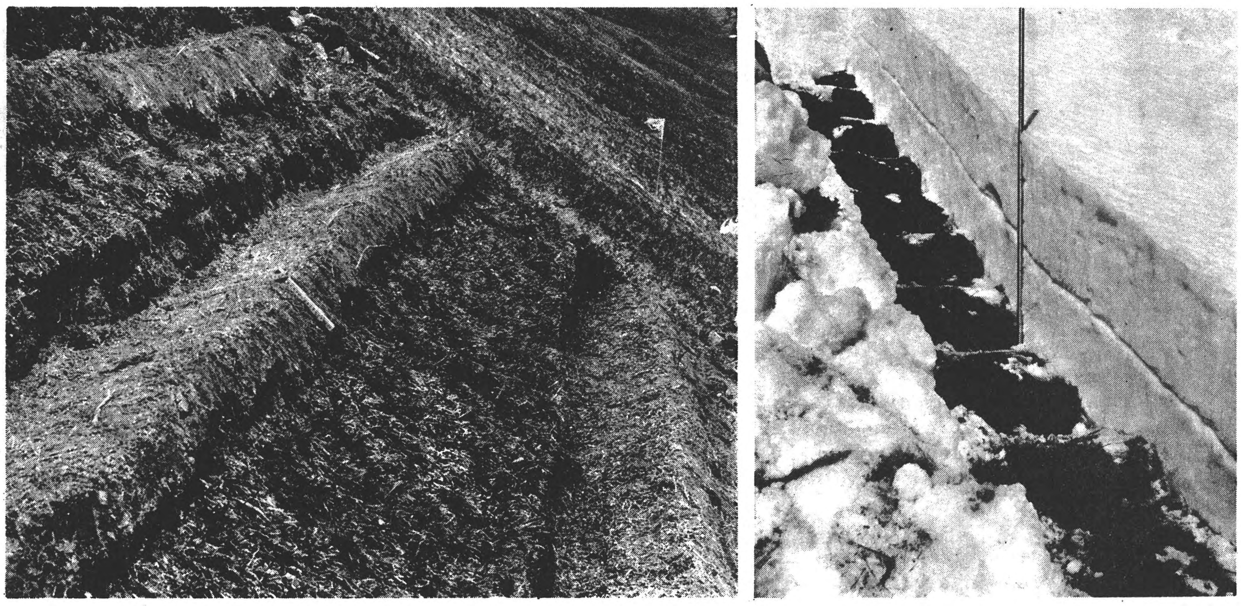


Figure 8. Left: stepped terraces, continuously arranged. Right: increase in ground surface roughness by means of stepped terraces (photos H. in der Gand).

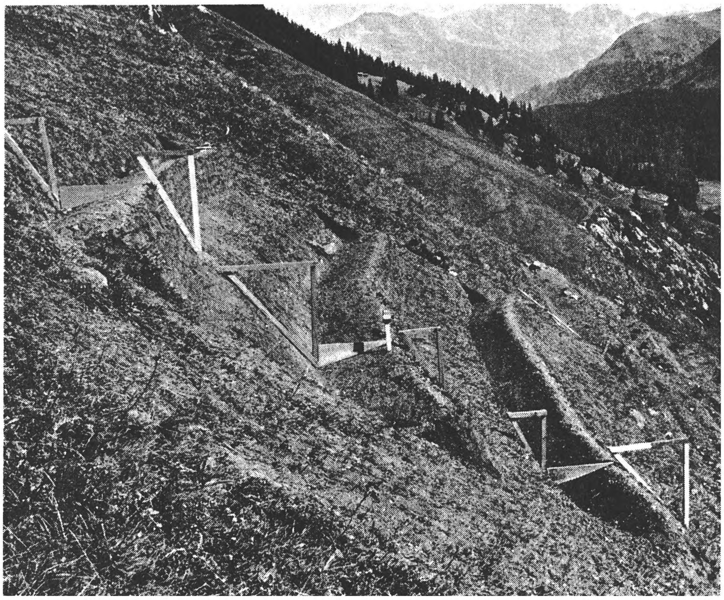
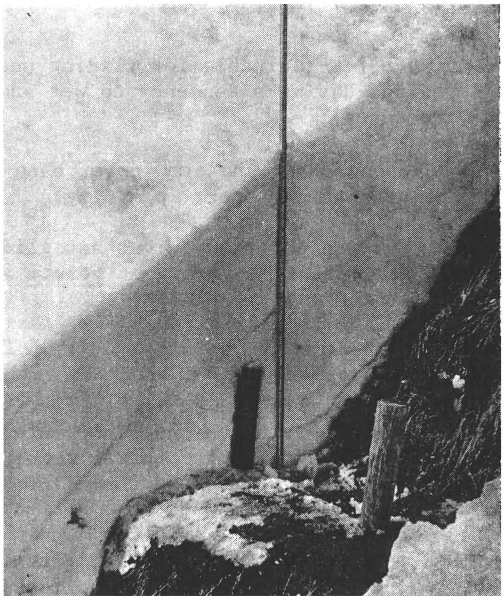
 

Figure 9. Left: wide terraces. Right: wide terrace with piling; deformed old fracture formation in the snow cover at the edge of the terrace (photos H. in der Gand).

Disadvantageous are the steep, long slopes of cut and fill which have the effect that slope distance becomes greater with increasing slope;

Formation of tension zones along the edges of the terraces = zones of potential glide cracks and slab avalanche fractures;

Danger of compression of the terrace embankment by the action of snow pressure;

Unsuitable on steep, snowy slopes;

Relatively high building costs;

Additional antiglide measures are required between the broad terraces.

2.3.4 <u>Pilings</u> (Figure 10)

Piling spacing becomes smaller with increasing slope inclination and snow depth ($\leqq 30^{o}$/HS 150 cm = piling spacing 200 cm, 45-50^{o}/HS 300 cm = 90 cm; for guide values compare [21]);

Arrangement in triangular formation, possibility of plantings between the pilings (increase in ground surface roughness);

Minimum piling diameter: ● 10 cm, ◓ 16 cm, ▲ 20 cm (radius = 10 cm);

Required ratio of depth of burial to piling height above ground = 2:1;

Minimum burial depth (dependent upon snow pressure and ground strength); dense soils -- 60 cm, loose soils -- 80-100 cm;

Figure 10. Pilings (photo H. in der Gand).

Minimum piling height above ground (dependent upon tendency for the formation of wet snow fractures) 30-50 cm and more.

2.3.5 Antiglide Supporting Structures (Figure 11)

Rake and tripod structures of wood (also made of other materials, in the case of permanent structures, e.g., steel, compare W. Schwarz, Section 8);

Are suitable in the case when soil depth is inadequate for structures between the supporting structures and also in regions with a tendency for the formation of wet-snow slides;

Only local action against snow gliding in the immediate neighborhood of the structures;

Snow pressure effects not substantially less than in the case of normal supporting structures;

Perpendicular structure height 1.0-1.5 m;

Structure length not greater than 3.0 m, broken arrangement (do not undercut snow cover over a long length, owing to [possible] formation of zones of tension and zones of shear = zones of potential glide cracks and slab avalanches);

Slope distance not greater than 10 m (slope inclination 37^{o});

Anchor uphill foundations against tensile stresses (e.g., steel pilings).

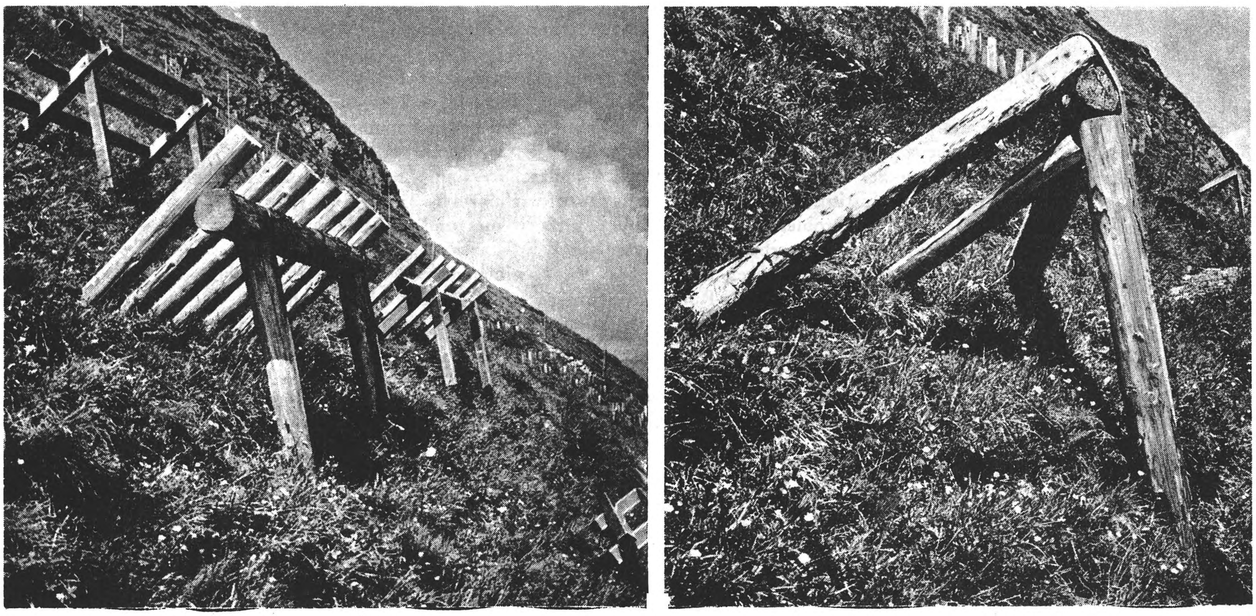


Figure 11. Left: antiglide rake of round timber. Right: antiglide tripod of round timber (photos H. in der Gand).

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English Translation of German Titles

[1] An Analysis of the Avalanche Control Structures in the Bernese Oberland.
[2] Avalanche Control Structures in the Starting Zone, Guidelines of the Federal Forest Inspectorate for Supporting Structures.
[3] Contribution to the Use of Standardized Wood Structural Designs in Avalanche Control Structures.
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[12] Experience and Developments in the Protection of Structural Wood.
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VIII. THE SAFETY OF SUPPORTING STRUCTURES

(Balthasar Rageth, Domat/Ems)

The almost frightening success of science and engineering has caused man to become uncritical in evaluating the limits of technology. He is easily inclined to place blind confidence in technical progress without taking further thought. In broad segments of the population, the view is prevalent that avalanche structures in the starting zone offer absolute protection.

It is the purpose of the following study to review the reliability of supporting structures and to explain the difficulties which beset the goal of absolute avalanche protection.

The task of supporting structures consists of preventing the occurrence of avalanches in the construction region, or at least to arrest or retard snow movements which do arise, so that no damaging effects need be feared (compare B. Salm, Section 4.1). This formulation [1] already contains the observation that absolute protection of starting zones is not attainable. Absolute safety means the exclusion of any possible risk even in situations of extraordinary danger (compare W. Schwarz, Section 2).

Snow is not a homogeneous substance. Its properties change with time and place and its behavior under the influence of external forces is subject to great changes. This is the primary source of the difficulties involved in computationally interpreting the self-willed and complex reactions of a mass of snow and of developing suitable protective measures to prevent damage produced by moving snow (compare B. Salm, Section 2).

The use of articulated supporting structures began in the early 1950's. Since then, almost everywhere preference has been given to this system as opposed to the traditional massive construction (walls, etc.). If now it is a question of evaluating the suitability and the effectiveness of these modern construction methods, then at the outset we can be gratified that the great majority of supporting structures have provided the protection expected. One can hardly imagine the damage and devastation that would have occurred in the alpine area without control structures and which would occur in future. Nevertheless, one may not ignore the fact that, on the one hand, avalanches have also descended into constructed regions and, on the other hand, the resistance of the installations with respect to the effective snow forces has in part been inadequate. Likewise, the reliability tests which have existed up to now may be only conditionally taken as a guarantee of the protective effect of our structures against future catastrophic situations of an unpredictable magnitude.

But it would be completely unrealistic to place in doubt the fitness of supporting structures because of occasionally observed deficiencies in individual projects or parts of projects. There will always be reverses. We should not be disheartened by negative individual occurrences, but should be spurred on to increased efforts to eliminate still-existing inadequacies.

Since the beginning of avalanche construction in the second half of the 19th century, this principle has been steadily adhered to. In the thirties, science had begun to concern itself intensively with research into principles. Since then, an active and gratifying cooperation between research and practice has prevailed. After its first edition in the year 1955, the "Guidelines for Permanent Supporting Structures" [1] was revised in 1956, 1959, and 1961. Each revision brought a sharpening of definitions both with respect to structure design and also with respect to the specifications governing projects The last revision, which in addition also covers temporary supporting structures, is dated 1968. This rapid succession of changes in the Guidelines implies that the initial expectations regarding the effect of supporting structures have not been in all respects satisfied. On the other hand, they testify to the continual efforts to usefully apply the new knowledge and the experience which has been acquired. The sharpening of the Guidelines also indicates that projects carried out in recent years -- assuming the installation arrangements to have been in accordance with the Guidelines -- have attained a higher level of safety than have earlier projects.

Science has achieved significant progress in penetrating the mysteries of snow. Here pioneer work has been accomplished by our

Federal Institute for Snow and Avalanche Research in Weissfluhjoch-Davos. But there still remains much to do. Research is still far from the end of its far-ranging task.

The task of the practical avalanche engineer consists of referring acquired general experience and new knowledge to a specific individual object and there to apply it appropriately. As the subsequent commentary will attempt to show, this is not an easy undertaking.

Natural conditions in winter terrain are extremely manysided. Every site is distinguished by its own special character which manifests itself in conjunction with a number of individual factors and which depends upon elevation, slope inclination, exposure, snow depth, nature of the soil (rock, coarse gravel, earth, smooth or rough surface), topography (sharp crest, broad crest, couloir, ravine, uniform slope, etc.), slope changes above and below the installation site, effect of wind upon snow distribution, ground covering (forest, grass), etc. Should we be surprised that in structural control of avalanches, one must be content with Guidelines, i.e., with instructions which often have wide variability?

The determination of the combined effect of the local factors with regard to processes in the snow cover and the inference from these, by using the Guidelines, of correct conclusions for determining the position and size of installations is the most important and most difficult task of the practitioner. The achievement, in a project, of a level of safety corresponding to requirements is largely identical with the capacity of the planner to recognize avalanche starting zones and to delimit them and to determine the winter conditions prevailing at the site. The determination of avalanche starting zones in winter is not always guaranteed. It is true that after the descent of an avalanche the contours of the fracture lines are still recognizable. But avalanches frequently occur in bad weather. The fractures, especially those of dry, high-altitude avalanches leaving few marked traces in the starting zone, are obliterated by new snowfalls or snow movements so that the course of the fracture lines can be reconstructed at best only in certain places or not at all. This work requires reliable observations, imagination, and a deep knowledge of the processes of winter. The spooky notion of "God sight" which is still occasionally encountered among foresters must finally be banned from avalanche structural control.

One of the critical decisions of the practitioner is the choice of the structure spacings down the fall-line (compare B. Salm, Section 4.2). This determines structure density. With increasing density, the effectiveness of the project increases. The Guidelines leave relatively great latitude in the determination of spacing. The great range of allowable structure spacing permits the planner to design the project to given conditions. The allowed latitude is, however, to be used exclusively for the purpose of fitting structure spacings to the safety requirement of the project. High requirements are imposed for example by the protection of inhabited settlements and hence this calls for structure spacings which are near the lower limit of tolerance. However, this latitude does not mean a concession with respect to construction density for economic reasons. It is not permissible to accept large structure spacings in order to make a control project financially more palatable. Admittedly, larger structure spacings within the framework of the Guidelines provide a theoretical guarantee of the security of the project but produce only a reduction in security against the onset of avalanches. For small projects this requirement -- because it is economically tolerable -- introduces no problems. On the other hand, in the case of large projects, it is often not so easy for the forest engineer, educated as he is to thrift, not to be impressed by high costs. If there is no readiness to subordinate the resources to be employed to the required safety specifications, then the use of supporting structures has failed at the outset.

Especially difficult is the determination of structure heights (compare B. Salm, Section 4.2). Even in the case of extreme snow depths, the support surfaces must reach to the surface of the snow. Snow-covered structures lose their effectiveness and in addition can be overstressed. New snowfalls cannot be sustained by covered structures. It is possible for avalanches to break loose which trigger larger masses of snow below the controlled area. Besides there exists the danger of damaging or even destroying the structures since the latter are not designed for avalanche forces. Meteorology provides a general reference point for determining structure heights which provides us with large-scale area averages of extreme snow depths. However, for the determination of decisive snow depth peaks at the structure site these data are not sufficient. It is also practically never possible to determine from direct measurement at the structure site the highest values of the decisive snow depths -- which on the average occur only once in about 30 years. There remains no other way than the evaluation of extreme snow conditions on the basis of intensive personal observations during several arbitrary winters and on the basis of conclusions drawn with the help of analogy on the basis of the Guidelines [1]. The snow depths are usually measured at representative locations by means of simple snow measuring rods. Zingg [4], using topographic photographs at a scale of 1:2,000, carried out photogrammetrically before and after the snowfall, was able to determine snow depths to an accuracy of 20 cm over an area of 8 hectares. At least for projects having the highest safety requirements and in difficult terrain, this admittedly expensive method of determining the mass distribution of the snow cover in low relief should be given consideration.

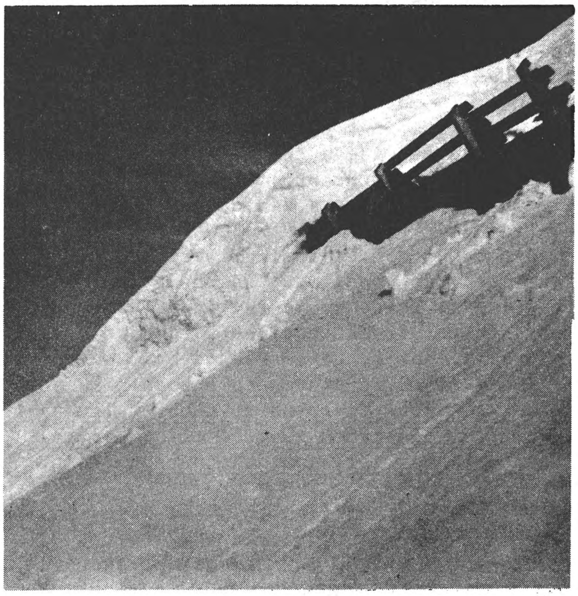

Figure 1. Supporting structure partially covered by wind action (photo H. Fluetsch).

The effect of wind on snow distribution renders the determination of structure heights difficult. It causes considerable modifications in the deposit of snow. Ditches, ravines, flat places, hollows, are often filled in immediately after the first snowfall, while humps, peaks, and ridges often have little or no snow until spring. Therefore, it is essential for the avalanche engineer to know the prevailing winds and their direction and strength.

When in regions acutely threatened by avalanche fractures there appear accumulations of snow which are not penetrated by the largest conventional supporting structures (for snow depths above about 5.5 m), the effectiveness of supporting structures becomes problematical. In appropriate terrain, however, there remains the possibility of smoothing out the snow deposit by artificially controlling wind flow by means of drift structures, thus keeping the snow in less endangered sections of terrain or guiding it into such sections (compare Ed. Campell, Article 9). In the Tanngrindel/Brienz project, W. Schwarz [3], using wind guidance techniques, was able to relieve the uppermost part of the starting zone of 10,000 m^3 of drifted snow, thus meeting the prerequisites for supporting structures. By increased use of wind barriers as a supplement to supporting structures, the protective effect of the latter can in many cases be increased at slight expense.

Slopes having a range of inclination between 30° and 50° are considered to be suitable for structural control (compare B. Salm, Section 4.2). Slopes below 30° are normally not controlled by structures. Similarly, one usually avoids structures on unusually steep slopes (above 45° to 50°), because during snowfalls the latter continually unload in small, undamaging quantities having the shape of a small snow slide. The problem arises at the foot of such readily unloaded terrain rises where suitably large structures are necessary to take up the additional snow sliding down from [such steep slopes]. Continuous slope discharges can cause a premature back-filling of structures and perceptibly interfere with their operation. The snow volume of long, excessively steep slopes can soon reach dimensions which can no longer be sustained by structures at the foot of the slope and which also fill in the back of lower-lying structures with loose snow slides. The quantitative evaluation of these processes is difficult. Wrong judgments with respect to the effectiveness of entire projects can give rise to fatal effects. The difficulties are increased further when the danger of rock impact exists or when steep slopes contain strips possessing the capacity to restrain the snow, producing snow masses which once in motion constitute hardly soluble problems.

Wherever possible, supporting structures should be laid out in closed terrain chambers having natural boundaries. When the lateral boundary lines have open flanks, it is possible for ground avalanches or surface avalanches to invade the controlled zones by lateral extension. Besides we must bear in mind that the avalanche paths can deviate from the fall-line. Also, without special risk to the project boundaries through influences from outside, as a consequence of creep and gliding of the snow cover substantial boundary forces occur which make it desirable to strengthen the boundary structures (compare W. Schwarz, Section 7).

In addition to the design of the structural elements in accordance with the Guidelines, ground anchoring conditions are also of decisive importance in guaranteeing the rigidity of the structures. The uphill beam foundations and the downhill support foundations must in design and magnitude be adapted to the resistance offered by the ground. No difficulties are created by compact easily anchored rocky soil. Soils which are formed by permeable rock fragments are relatively free of problems, for example, deposits of rock originating from rock falls or glacial sediments. Poor foundation prospects are offered by rocks which absorb considerable quantities of water without releasing them, such as clayey rock or lime-containing rock, weathered shale, etc. In the case of soils having low carrying capacity, the upper and lower block foundations must be tightly bound together by a compression bar which has good bending rigidity so that foundation and superstructure form a closed framework. Under unfavorable conditions, the foundation cost can attain as much as 50 percent of the [total] cost of the structure. Standardized compression tests [1], carried out in conjunction with ramming probes, give aid in determining the allowable soil compression and thus assist in designing the foundations. Hitherto too little use has been made of this in practice. In the first years after the avalanche winter of 1951, inadmissible attempts were made in many cases to effect savings in designing the foundations. Individually, these weakly designed foundations were not able to withstand extreme snow pressures (gliding snow, larger snow slides, breaks in snow drifts).

Here attention must be given to another difficult problem. As a rule, only the uppermost starting zones of avalanches are visible. If structural control is applied here, then more low-lying, previously unrecognized, secondary starting zones can appear. When such conditions exist, protection of the visible starting zones by means of structures probably reduces the frequency of avalanche descents, shortens the avalanche path, and reduces the quantity of snow in motion (compare B. Salm, Section 3). But there still remains a danger which at best has been merely diminished. These circumstances, often difficult to recognize, must be dealt with by determining the lower boundary of the control area (compare B. Salm, Section 4.2).

In all larger projects, particularly in those which are technically difficult, one encounters construction sites which are good and some which are not so good. As a rule, possible weak portions can be recognized, after completion of the project, by continuous observation and can be eliminated. In this way it is possible to still achieve, by the use of supplementary measures, a degree of safety

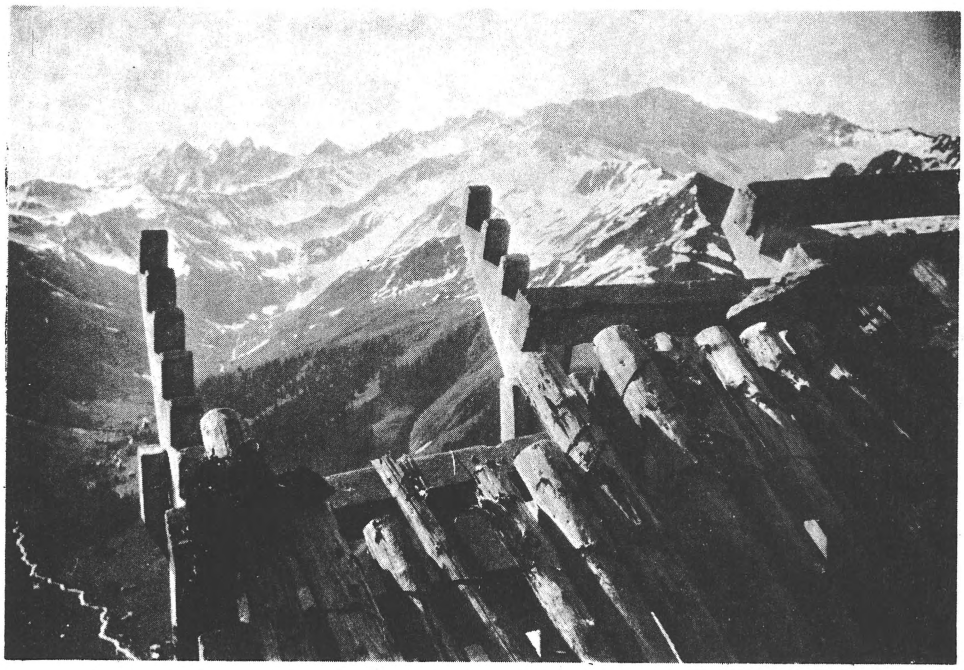

Figure 2. Structure damaged by a snow slide including rock impact; good effect of the wooden protective grid is discernible (photo A. Graemiger).

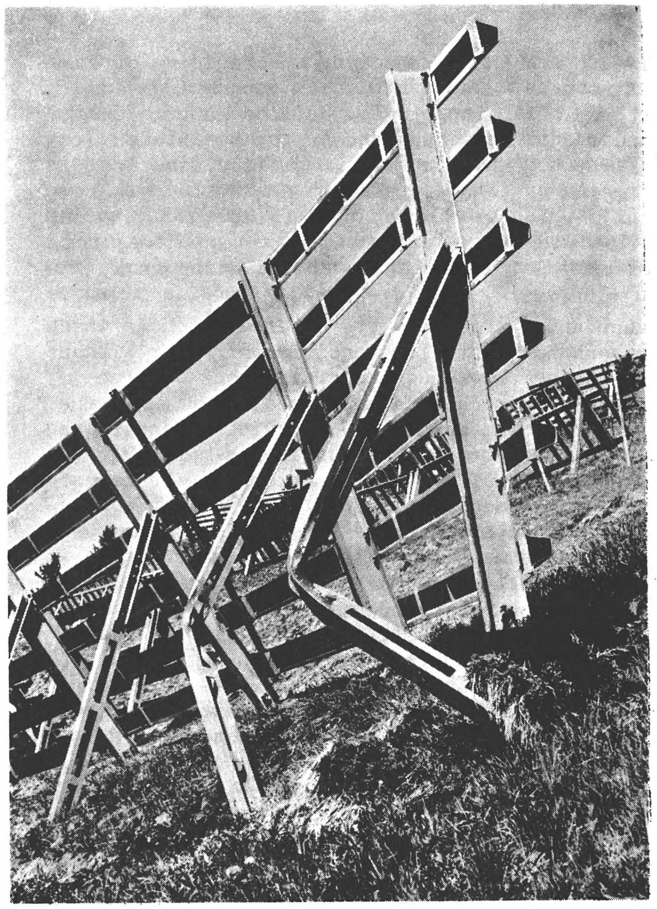

Figure 3. Buckled supports of an end [boundary] structure following marked gliding of the snow cover (photo H. Frutiger).

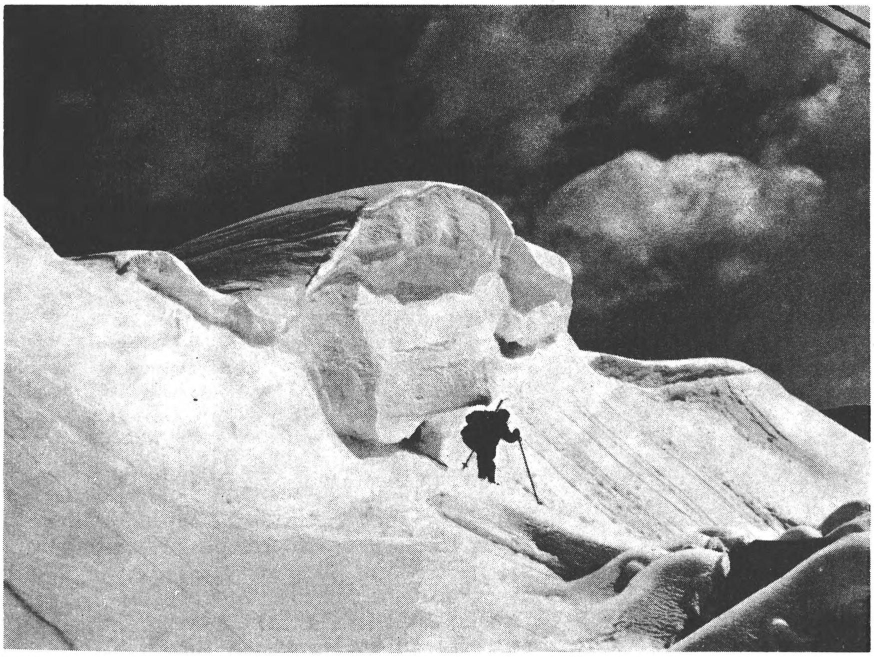

Figure 4. Cornice formation on a ridge crest (photo R. Gerber).

which had been sought at the outset but not attained on the first attempt. The necessity of supplementary credits is frequently to be attributed to this circumstance.

Finally, as reliable an evaluation as possible of the site is to be sought for reasons of cost. On a uniform slope of 45° and 1 hectare in extent one will require, depending upon the circumstances, 600 to 800 m of supporting structures. On the average for the full control of 1 hectare of average difficulty from 500,000 to 600,000 francs must be spent. Hence we have every reason to employ wisely and thriftily the means placed at our disposal so abundantly by the public. Thrift means the best possible determination of the local conditions, the most appropriate delimitation of the control region, and the correct choice of structures and of structure sites. Thrift means, further, good organization, cost comparisons of equivalent structure types, appropriate subcontracting, good raw material purchasing, and expert construction supervision. But thrift never means skimpy design, poor quality, or making concessions with regard to what we know to be the correct structure density. Previous experience has made abundantly clear that when dealing with avalanche construction, this type of saving is not appropriate.

The safety achieved by the project must remain for many decades or even forever. A continuous check of the state of the project is therefore indispensable. Damaged locations must be immediately corrected and any detected deficiencies removed. Negligences in maintenance produce losses of safety which must lead to unpleasant consequences. Hence permanent maintenance of the structures is a prerequisite for guaranteeing undiminished project effectiveness. A damaged control area is more dangerous than an unconstructed slope because the threatened population is lulled by a false sense of security. Maintenance and repair operations, when damage occurs, require considerable expense. We shall find that as the project ages, these expenses will increase. The districts will not be in a position to make the necessary funds available. One day a point will be reached at which both the Federal Government and the cantons will also make contributions to the maintenance of structures. These repair problems, which emerge only later on, and are not to be underestimated, must be thought about even in the planning stage. The better the problems of material transport can be dealt with, the easier and more economical maintenance will be. Hence, it is probable that, looking ahead, in avalanche construction projects of some extent, the installation of construction roads may be preferable to the use of temporary cable cars or helicopter transport, as long as the road-building costs lie in an acceptable range.

From the preceding remarks it should not be difficult to see that the remaining residual risk of supporting structures cannot be expressed in numbers and percentages. In winters having normal snow conditions, the protective effect may be described as safe. But we build primarily for extraordinary catastrophic situations and for this case -- as mentioned at the outset -- absolute protection is not fully guaranteed. Practically, this reservation means

a. that people below structurally controlled regions in times of danger should adapt themselves, by suitable behavior, to the existing residual risk (e.g., temporary avoidance of travel in the town, occupancy of suitable rooms such as cellars, and evacuations when necessary) and

b. that when supporting structures are installed, the avalanche endangered regions lying below it (red zones) can as a rule be converted at best into regions of reduced avalanche danger (blue zone) but not into avalanche-safe regions (white zones).

Nevertheless, supporting structures attack the problem at its root and in comparison with all other measures of structural avalanche control, it offers advantages which make it appear to be the best solution in most cases. But whenever the nature of the terrain in the starting zone presents excessive technical difficulties and the possibility of a technically satisfactory supporting structure in accordance with the Guidelines is doubtful, or whenever projects using supporting structures gives rise to unwarranted costs in proportion to the significance of the object to be protected, the idea of supporting structures is then out of the question. As a rule, a way out can be found by means of other construction alternatives.

Many will find it a disappointing admission to concede that supporting structures do not provide absolute safety. Steep winter slopes cannot be compressed into mathematically exact formulas. One may double or otherwise multiply the expense, but the fact still remains that a residual risk remains. This is a fact which we must learn to live with.

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English Translation of German Titles

[1] Avalanche Control Structures in the Starting Zone, Guidelines of the Federal Forest Inspectorate for Supporting Structures.

[2] Avalanche Control Structures in the Starting Zone, Commentary on the February 1961 Guidelines for Permanent Supporting Structures.

[3] The Limits of Modern Avalanche Control Structures in the Starting Zone.

[4] The Determination of Snow Depth Distribution Photogrammetrically.

IX. SNOWDRIFT STRUCTURES (Eduard Campell, Bever)

1. Foreword

Experienced avalanche engineers who are active today in preventing avalanches would be in a distinctly better position to write this article than I am. Indeed, no one would wish to expose himself to the criticism which such an empirically founded type of construction must expect. The following discussion is based upon data in the literature, reports of forestry officials who supervised control projects, and upon my own observations.

While gliding snow protection and supporting structures on an avalanche slope attempt to prevent just about any sort of motion of the snow cover, it is the aim of snowdrift structures to influence snow masses which are put in motion by the wind.

2. Effect of the Wind Upon the Snow Cover

When wind is completely absent, snowflakes fall as light structures made up of a variety of snow crystals which adhere to one another and which, at low temperatures, form a loose snow layer. In a protracted snowfall, such deposits can lead to outbreaks of wild snow. In the higher elevations above timberline, this phenomenon is a great rarety. At that elevation the wind is more the rule than the exception. The wind quickly tosses the snow crystals into the air, deforms them, and combines them into dense flakes. All snow is more or less blown about either while falling or subsequently on the ground, much like blown sand in the desert (Figure 1). We call the wind-blown snow drifted snow (Figure 2). The nonuniform distribution of the snow cover is a typical phenomenon of irregular terrain in the mountain landscape. In the very first snowfall, ravines, hollows, and flat parts are covered over while crests, elevated peaks, and ridges are swept clear. The terrain profile is progressively leveled off by the snow.

In order for the wind to attain sufficient shear force, a minimum wind velocity is required which, depending upon the climate and the nature of the snow, varies between 3 and 7 m/s [15]. In dry climates and on slopes, snow drifting can start even at a reduced wind velocity. Freshly fallen dry snow is naturally more easily blown than wet snow and old snow.

Snow particles deformed by the wind are hurled together and densely deposited without intermediate spaces. Thus there arises a layer of compressed snow which becomes deeper. If the foundation of this new consolidated snow cover consists of old snow which either has been or is being loosened by frost and metamorphism, this gives rise to the so-called slab. The latter usually has only slight bonding to its foundation. A slight overload or shock can cause the foundation to slump and the snow slab situated on a slope to begin sliding.

Over crests and gradient breaks the wind sweeps the snow away. An eddy arises and individual snow particles are plastered in the form of compressed snow against the edge of the gradient break and this in time produces a cornice while the remainder of the drifted snow is deposited in the form of loose snow on the lower lying lee slope.

3. Wind-Control Structures Along Traffic Arteries

On the relatively flat terrain of valley floors and on mountain-pass roads, drifting impedes traffic. Railway facilities have been protected from drifts by means of galleries, jet walls, snow walls, etc. Along highways, depending upon the region and snow conditions, fences, lattices, nets, etc., have been set up in various designs and tested. In our area, we use the Graubuenden type snowfence which can be repositioned when necessary. The investigations of Croce [4] and T. R. Schneider [15] have led to the following conclusions: continuous fence installations having a density of 50 percent and a fence-to-ground gap of at most 15-20 cm have proven best. These installations should wherever possible be set up perpendicular to the main wind direction. A maximum deviation of 20° is allowable. Wide boards reduce the effectiveness of the fences. For a 50 percent density, a slat width of 5 cm should not be exceeded. For the distance of the fence from the road which is to be protected from drifts, a standard of 15 times the fence height is assumed. When a second fence is put up in the rear, this is placed at a distance which is 10 times the fence height. In level terrain, Croce set up the following formula for the

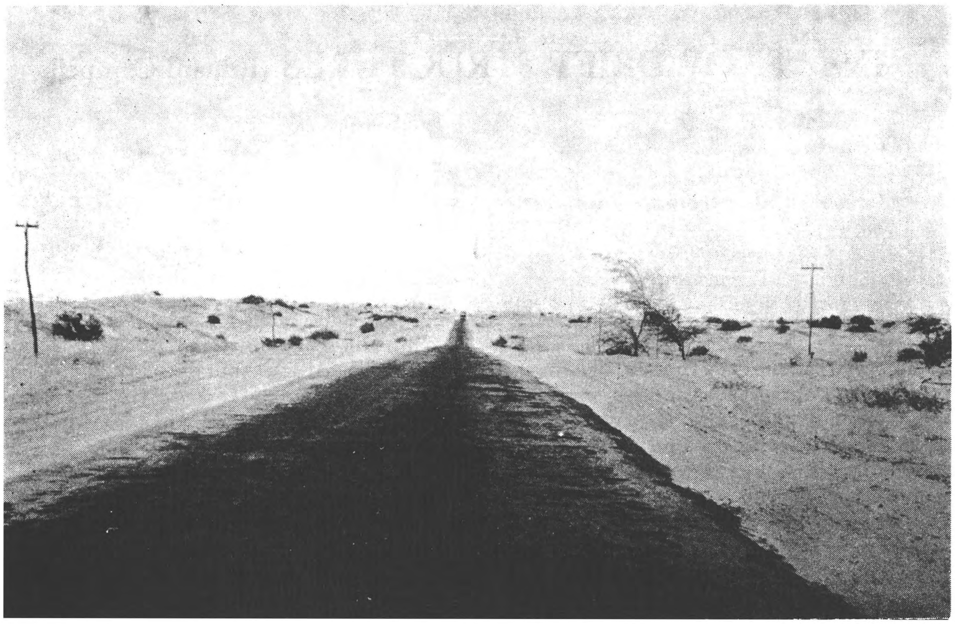


Figure 1. Blown sand desert along the Peruvian "Pan-American Highway" near Piura, 5° latitude South, 12 May 1966 (photo Ed. Campell).

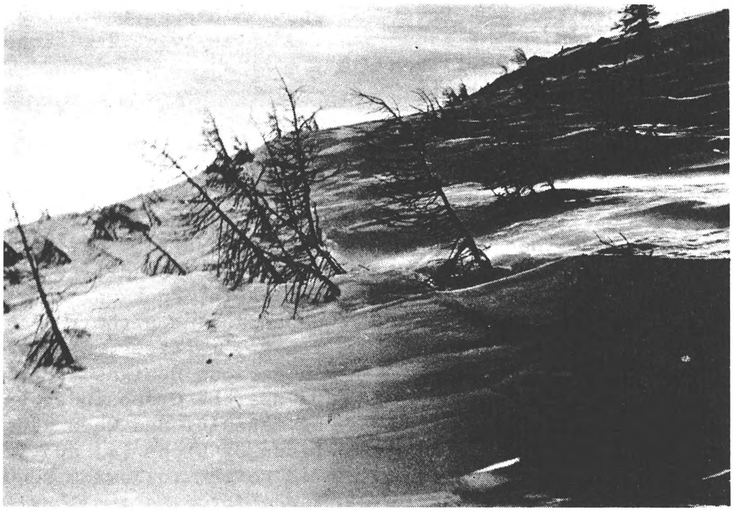


Figure 2. Drifted snow on the "Pru dal Vent" at Alp Gruem, 15 March 1934 (photo Ed. Campell).

distance from the wind barrier to the object to be protected

$$A = \frac{11 \cdot 5h}{k} \div 5$$

where A is the distance and h is the height of the barrier and k is a factor which varies between 0.8 and 1.35 depending upon fence density, which is assumed to be between 35 percent and 75 percent.

4. Snowdrift Structures in the Structural Control of Avalanches

Even in the oldest avalanche control projects, the action of the wind has been utilized, perhaps unintentionally. The construction of short, staggered, dry walls indicates a recognition of this principle. The more sharp wall-corners there are, the more snow deposition is disturbed. As far back as the thirties, in the Schafberg project at Pontresina at an elevation of over 2,600 m, we achieved good results by erecting angular, elevated wall-wings and high individual elements in place of rounded wall-flanks. In old avalanche projects, we often encounter in the slope direction or above the starting zone in predominantly flat parts of the terrain so-called cornice walls. Because of the unsuitable nature of the stone, the installations could usually not be built high enough so they became prematurely drifted-in and ineffectual. In order to deal with these disadvantages, compact wooden walls and wooden rakes have been set up but these did not produce the success which had been hoped for (Figure 7, profile 4). E. Eugster [5] in the thirties was the first in Switzerland to investigate and describe various types of wind barriers in the upper Valais. Here he established that snowdrift structures as a means of restraining snow, in addition to preventing cornices, merited close attention, especially in unobstructed terrain and above timberline, as a supplement to supporting structures.

When after the avalanche winter of 1951 there began a new period of avalanche defense construction and articulated supporting structures came into general use, the practitioner also became increasingly interested in snowdrift structures. In a certain respect, the articulated type of structure itself exerted significant influence on the drifted snow and hence unintentionally stimulated the development of snowdrift structures.

But it became continually more evident that as a result of snow drifting certain upper limits are set to the design of supporting structures in the starting zone [17]. Supporting structures are often overloaded and the costs of stronger and higher structures exceed an acceptable size. Also the underlying soil is often no longer adapted to carrying heavy loads [11]. This circumstance has contributed to putting a brake on the real culprit, the wind, or to the utilization of its forces in snowdrift structures.

Depending upon the purpose and the mode of action, the following two types of snowdrift facilities may be distinguished. Different types of barriers have developed for each:

a. Structures which hinder the transport of drifted snow, slow the wind, and produce a deposition of the transported snow before the latter is deposited excessively in the starting zones of avalanches. These include snowfences with horizontal slats [Treibschneehag], and snowfences with perpendicular slats [Treibschneezaun].

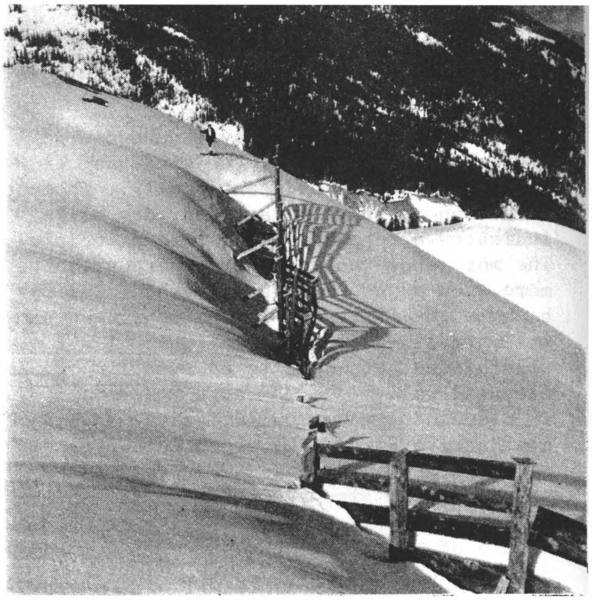
b. Structures which promote the transport of drifted snow, which deflect the wind in such a way that the drifted snow is continually swept away from certain avalanche starting zones or in such a way that the wind turbulence disturbs the normal build-up of the snow cover. These structures include the jet roofs, drift-snow ramp [Pupitre or Pultdach], and Kolktafeln [eddy panel].

4.1 Structures Which Weaken the Shear Force of the Wind

The design of these structures is based on the principle of the porous wall. Instead of filling them out completely, gaps are left between the boards or planks. The drifted snow is blown through the gaps. Wind velocity is reduced and thereby its carrying capacity is weakened. The greater the density of the obstruction, the more quickly will the drifted snow fall out. On the other hand, the density must be so selected that the snow masses deposited on the leeward side of the barrier are deposited at the desired location without, influencing the function of the barrier. The height of the latter is determined by the quantity of drifted snow which must be held back at the site. By increasing the height of the structure the duration of its effectiveness can be prolonged into late winter [17]. Fences staggered one behind the other considerably increase the amount of drift snow caught.

The simplest design for a snowfence with horizontal slats has been used (Figure 3) by A. Graemiger on Hubel-Tschatschuggen on the Kueenihorn in St. Antoenien (Figure 3). The boards are fastened horizontally to the lee side of 3-4-m-high posts, with a density ranging from 50 to 60 percent. For safety, the posts are braced on the lee side with supports. The amazing effectiveness on the lee side of the ridge of this simple fence is apparent in Figure 4. Over the entire length of the windward side of the fence cornices have almost been completely eliminated. Here only a slight steepening is visible in place of a cornice. On the left side of the picture one can see exactly where the effect of the fence ceases and a large cornice has been able to develop which in fact led to the fall of the cornice.

Figure 3. Effect of the horizontal board snowfence on the windward side of the "Hubel Ridge" on the Kueenihorn above St. Antoenien, 15 May 1970. The middle of the snowfence was drifted over in the winter of 1969/70. According to A. Graemiger fence height should have been increased there (photo A. Graemiger).



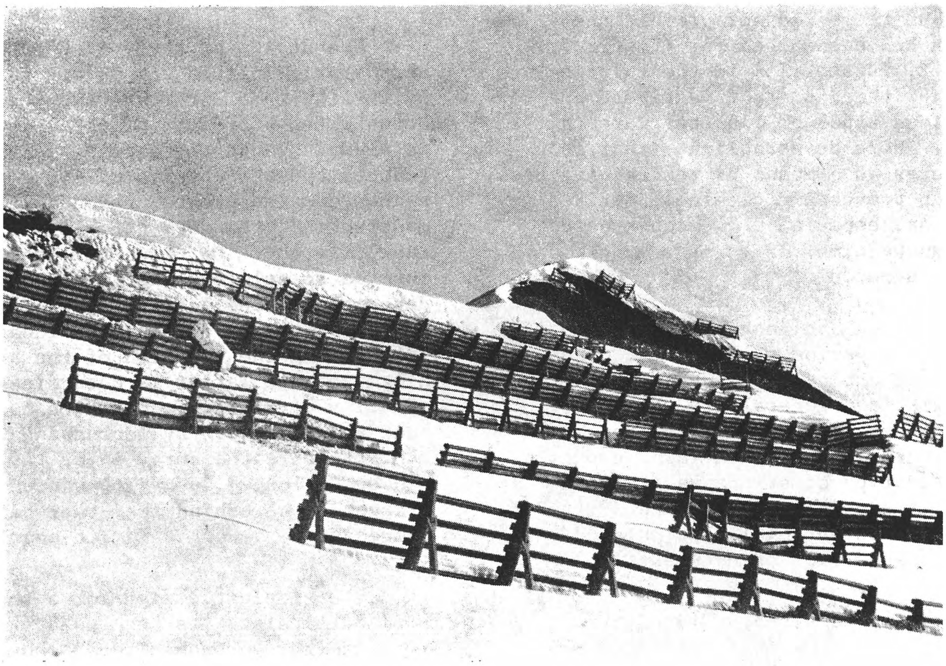


Figure 4. The effect of the horizontal board snowfence (Figure 3) on the lee slope is clearly apparent in the middle of the picture. Instead of a cornice only a short steepening has formed here (photo A. Graemiger).

Here our Tessin colleague Solari would probably say: "By all means don't build up too much snow in starting zones."

At high elevations in the dry zones of our country where there are strong winds on the slopes, good results have been obtained (Figure 5) with both types of snowfences when the slats are attached to alternate sides of the posts. Wind turbulence is amplified by this arrangement of the boards. This system was developed by J. Hopf and J. Bernard [8] in

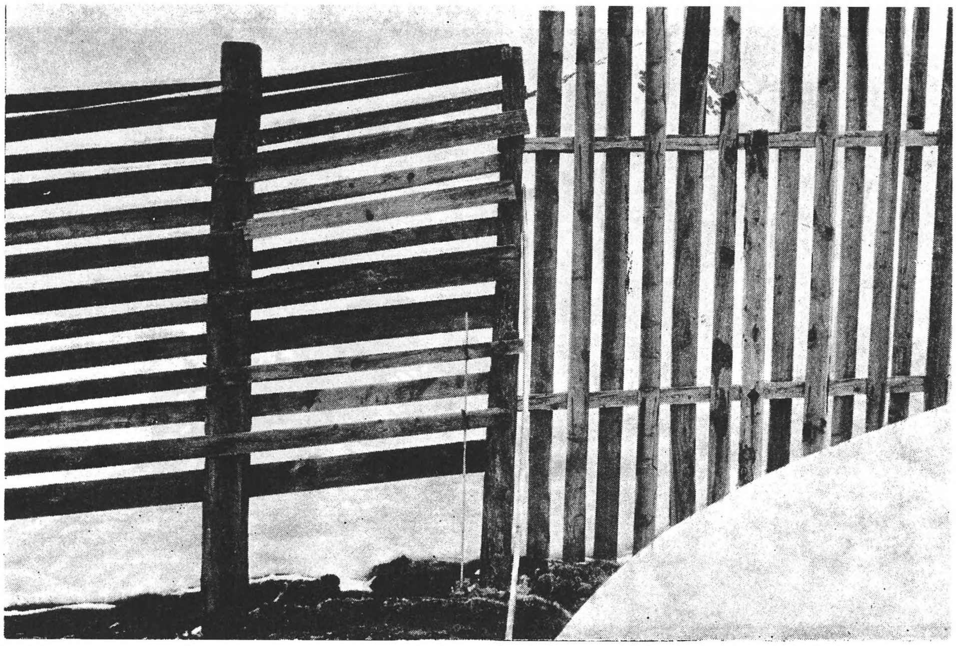


Figure 5. Construction of a horizontal board snowfence (left) and of a vertical board fence (right) in "Pluetschessa," Ftan, with boards on alternate sides of the posts (photo H. Frutiger).

the avalanche control project at Paida in Sellraintal. N. Luzzi [11] was the first to employ this type of barrier in an extensive snowfence project on the Greala High Plateau (2,500 m above sea level), above the supporting structures of the wet-soil Pluetschessa slope of Ftan (Figure 6). Fence heights were 4 m and there was a total of 1,034 m of structures. The posts have a spacing of 2 m, and are buried 1 m in the ground. The boards of the wind screen are 25 mm thick and are on the average 16 cm wide. The density averages 67 percent. For snowfences with horizontal boards, the fence-to-ground gap is 80 cm. For the fences with vertical boards, the boards extend to the ground. The latter type is more effective and is easier to maintain because it doesn't suffer from snow creep. At a slope gradient of 10 percent, it was possible to obtain a mean maximum deposition length of 40 m. The holding capability per running meter of fence [normally] varies from 90 to 170 m^3, but can reach 220 m^3 (Figure 7, profile 3). When we consider that these snow masses before installation of the wind baffles were swept entirely into the steep slope, we can get an idea of the enormous load relief which has been achieved for the supporting structures built on wet ground. N. Luzzi is firmly convinced that the Pluetschessa avalanche project would have been purposeless without wind baffles. The horizontal board snowfences of the avalanche control project in Munt Baselgia, Zernez, and Munt da Lue are carried out in the same design. In the "Val Guestina" avalanche control project above Sent (2,700 m above sea level) this system is combined with Kolktafeln in an arrangement similar to that used for up-slope wind on the Kueenihorn, and has achieved the best results.

Snowfences made of steel elements of the OeAM and aluminum fences of the AIAG have been successfully erected in various avalanche control projects in the Bernese highlands [17] and in the Valais. The aerial photograph of the snow restraining installations above Adelboden (Figure 8) and profile 1 in Figure 7 from the Tanngrindel avalanche control project in Brienz, together with Figures 9 and 10 and the profile from the Valais (Figure 7, profile 2) will allow us to dispense with further descriptions.

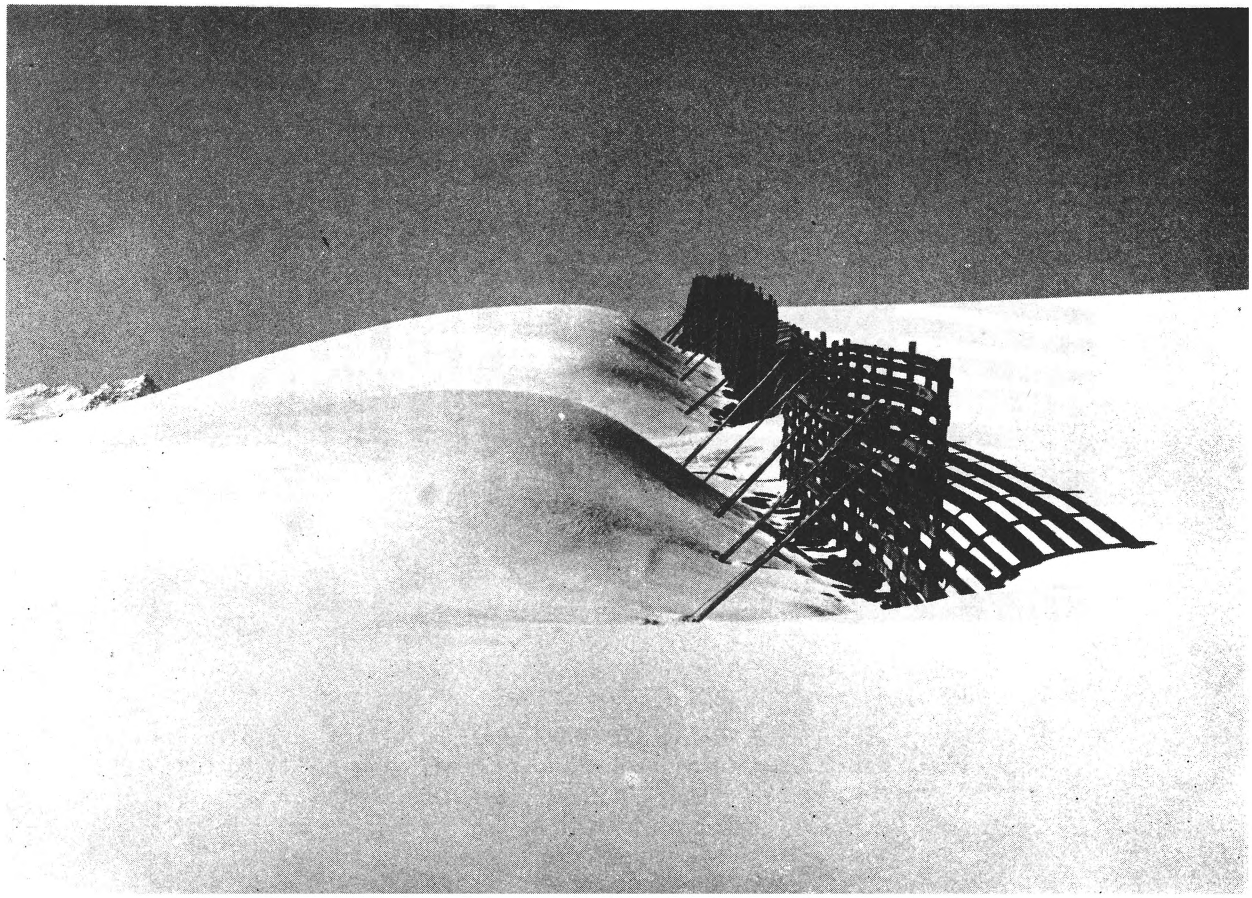


Figure 6. Snow-drift structures on the Greala Plateau (2,500 m), above the Pluetschessa supporting structures, 8 April 1960 (photo H. Frutiger).

Also, W. Schwarz is of the opinion that long fences are more advantageous than short staggered arrangements. He closed any gaps which occurred by using snow bridges made of OeAM elements having a high density. Generally, wind structures supplement supporting structures, but in this case, it is the other way around.

A principal feature of definitive snowdrift barriers is constituted by the stability of the structures against extreme wind stresses. Transverse anchoring of the individual posts using wire cable has turned out badly because the cables are so heavily stressed by snow creep that the fences are damaged or torn down. Instead of transverse anchoring, the posts can also be secured by continuous cables stressed in the longitudinal direction. For this purpose the posts, instead of being in straight line, should be placed along the outline of a flat hyperbola. In this way, each post is uniformly stressed in tension on the lee side support or brace. The installation is also secured against storm winds from the opposite direction. Such a 50-m-long, 5-m-high, woven-wire fence has been standing for 36 years undamaged and without any maintenance on the storm-swept south ridge of the Crasta Mora above Bever. In setting up lasting installations, one must also reckon with permafrost. In the Engadine, this is encountered on the south slope at 2,600 m; on the shady north slope, it can be encountered below 2,200 m.

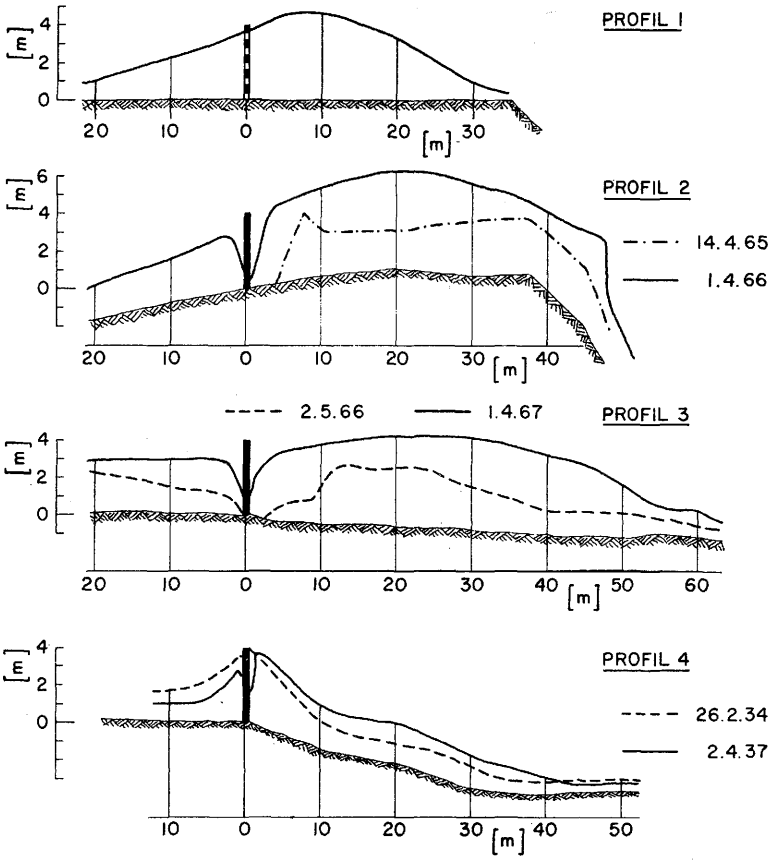


Figure 7. Cross-sections through drift snow trapping structures.

Profile 1: mean trapping capacity of a horizontal element snowfence made of steel elements in the Tanngrindel, 14 April 1964 (field data and drawing by W. Schwarz, Interlaken).

Profile 2: maximum and minimum catch of a vertical-element, aluminum snowfence in Wasen-Heiterich, observations of 1960-1970 (field data and drawing by M. Peter, Brig).

Profile 3: maximum and minimum catch of a horizontal-element wooden snowfence in Pluetschessa, Ftan, observations of 1961-1967 (field data and drawing by H. Frutiger).

Profile 4: snow caught by a compact wall on "Pru dal Vent" above Alp Gruem; the wall produces a wave crest; as soon as the latter [wall] is covered over, snow erosion begins in the wave trough (field data by Ed. Campell).

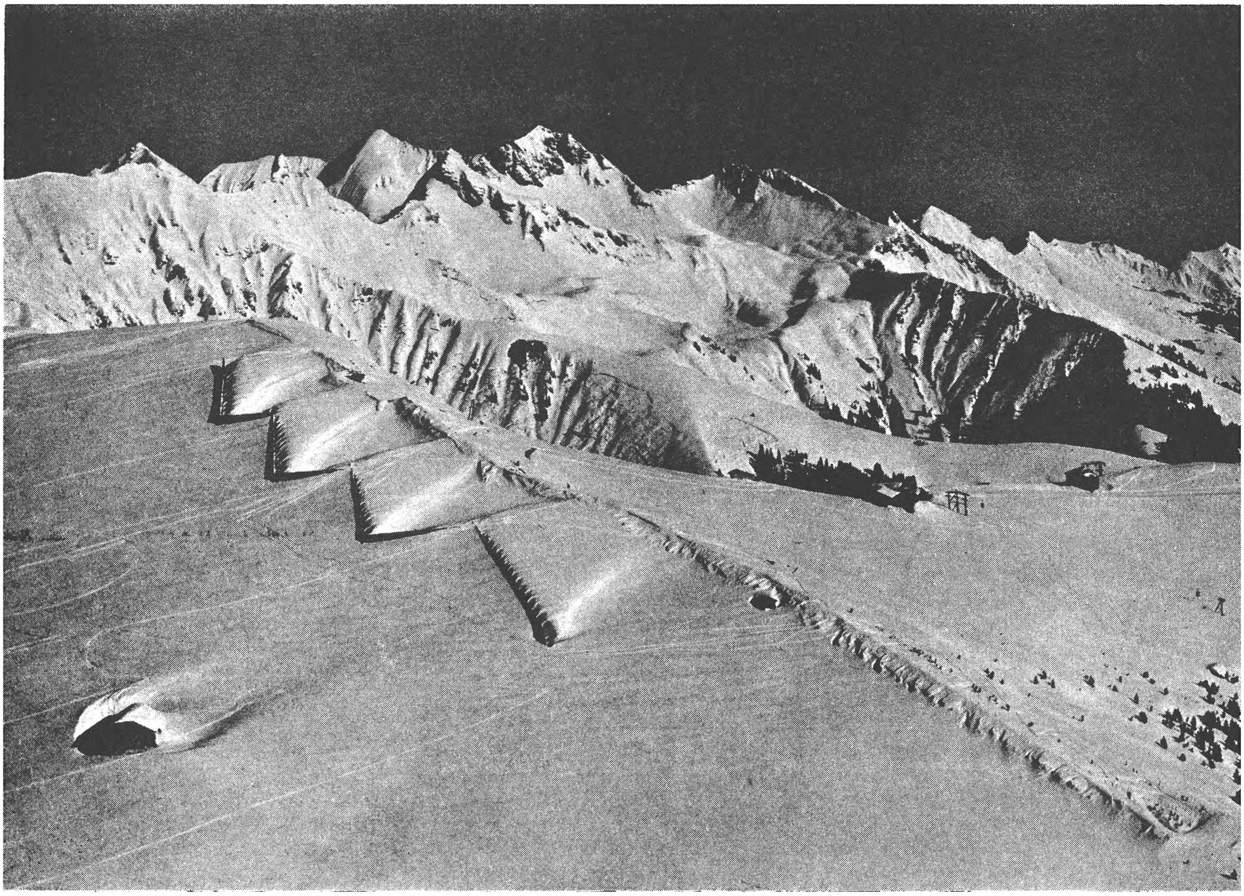


Figure 8. Snow catching structures (snowfences) above Adelboden with eight horizontal-element snowfences and snow bridges made of steel elements from the OeAM, 10 March 1970 (aerial photograph E. Wengi).

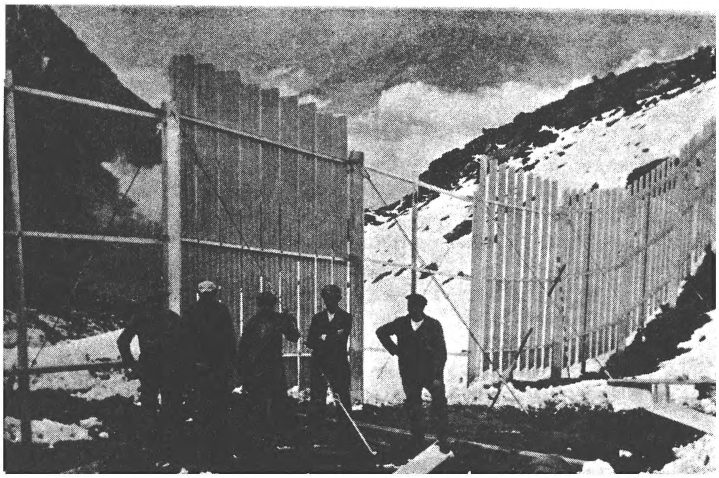


Figure 9. Assembly of a vertical-element snowfence of aluminum with two densities: left 90 percent, right 75 percent, Wasen-Heiterich project (Simplon). No difference in the effectiveness of the two designs could be observed (photo M. Peter).

4.2 Structures for the Promotion of Local Wind Transport

The most effective and most radical wind structures for hindering the formation of cornices and for limiting snow accumulation in the starting zone of the lee slope are jet roofs. An impressive example of a technically correct installation of this type has been built [12] by our colleague J. Manni (whose death was all too early) in the starting zone of the "Am Horn" avalanche project in Vals Precinct. The structure is built astride the ridge and has a hot galvanized steel framework. The roof of the structure has an inclination of 60 percent and produces a deflection of the wind flow into the lee slope where the snow is swept away. In various projects we find small wooden jet roofs introduced. Figure 11 shows a structure in the starting zone of "Ils Pals ob Ardez." This structure prevents the formation of cornices in a concave terrain depression where a Kolktafeln would not have been sufficiently effective.

The drift-snow ramp which has been installed at the recommendation of the Federal Institute for Snow and Avalanche Research behind the Weissfluhjoch station, produced a roof-shaped elongation of the windward slope which extended over the lee side. When drifting snow was blown over the drift-snow ramp, it was impossible for the snow to stick to the sharp ramp edge so that there was no formation of a cornice.

The snowdrift wall or Kolktafeln may be considered to be the simplest, most natural, and the most debated but cheapest form of wind baffle. The idea originates with the Austrian engineer Handl. In the course of time, numerous designs of these individual elements have been tested. The simple, light, trapezoidal board-wall having a height of 3-4 m and a width of 2-3 m is nailed to two posts which are buried about 1 m deep in the ground; it represents the only model which has been repeatedly employed in our country and in the neighboring Italian valleys (Figure 13). Gaps between the structure and the ground are avoided in this design in order for the wind scour to break through the snow cover down to the ground [2], (Figure 12). The trapezoidal form is actually an imitation of nature. Under free-standing groves and upright mountain firs whose bulky branches extend upward, we often find deep scours, while with deep-branched spruce trees, which display a more conical form, this phenomenon is missing. M. Zehnder [18] has established with careful measurements in St. Antoenien that trapezoidal walls cause a scour which is about one-third greater than that produced by rectangular walls of the same surface area set up in the same region. While

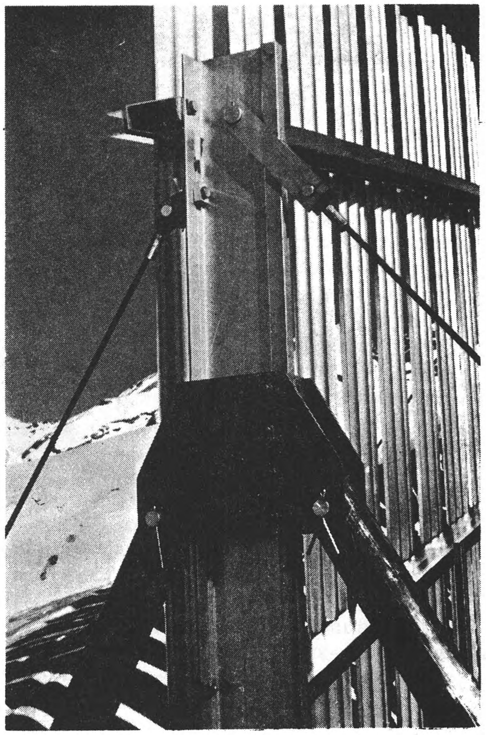


Figure 10. The light aluminum fences of the Schweifingen project above Zermatt had to be strengthened by tubular supports because they were not standing up to the wind load (photo 4. Bachmann)

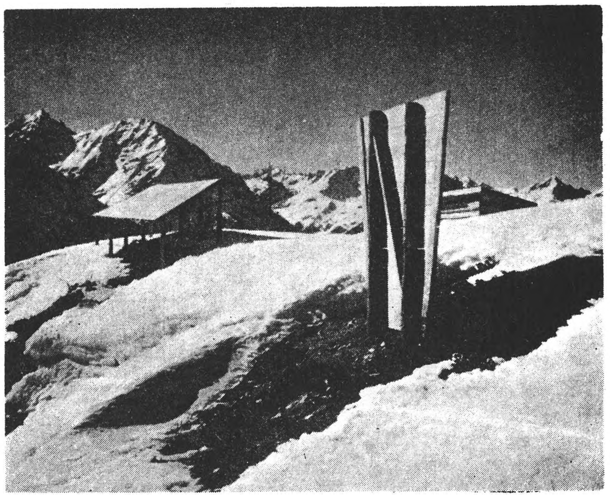


Figure 11. Wooden jet roofs (Left), combined with Kolktafeln in the starting zone of the "Ils Pals" project, Ardez, 19 February 1959 (photo Ed. Campell).

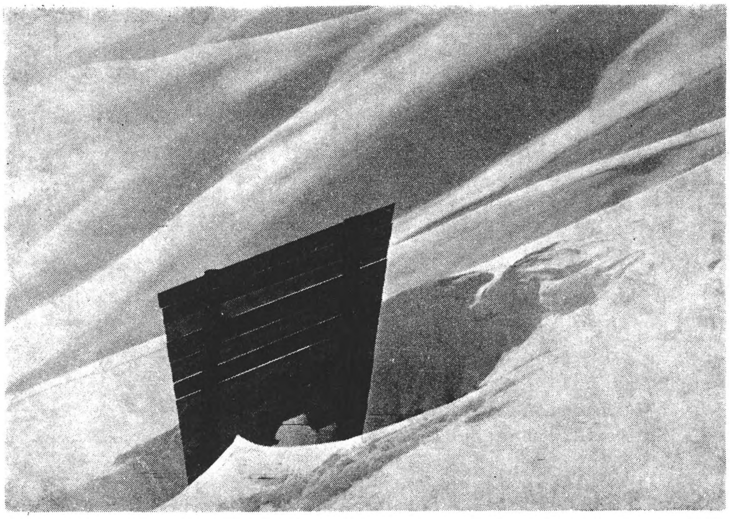


Figure 12. Effect of a trapezoidal Kolktafeln at the boundary of the "Albanas" avalanche control project near Zuoz, at a snow depth of 1.80 m, 26 February 1955. The upper edge of the structure is supposed to follow the inclination of the slope (photo E. Campell).

Figure 13. Protective structures along the Foscagno Pass road (between Livigno and Bormio) (2,290 m). On the left the Kolktofeln protect the supporting structures against drifts, on the right, small snow slabs are stablized by Kolktafeln, 25 March 1963 (photo Forest Inspectorate, Sondrio).

the former displayed an open scour-bottom, rectangular tables were already drifted-in on the lee side in January. Further, in May 1957, M. Zehnder demonstrated at the Kueenihorn that a single, normal Kolktafeln of 7.5 m^2 produced a scour-funnel of 103 m^3 [19].

On the slope, the Kolktafeln must be set up in the direction of the slope gradient to avoid damage by snow creep. On gliding snow slopes and in locations with frequent slushy snow, Kolktafeln should not be installed. On dry soils with relatively small water capacity, these phenomena are rarely encountered. A prerequisite is suitable terrain and possibility of making a fully effective reliable structure. This possibility of setting up the Kolktafel is established empirically. It is an advantage of these structures that they can be easily moved at little cost.

The Kolktafel is suitable for limited local effect. It serves as a stopgap, an emergency device, or to supplement other installations, for example, for relieving heavily drift-burdened supporting structures (Figure 13) or to prevent the formation of snowdrifts which have either not been controlled or only inadequately controlled by fences. The spacing of the individual structures is here decisive. In the "Las Vals" avalanche control project above Tschierv, after experiments over many years, using a distance between Kolktafeln of 7-8 m, we have succeeded in almost entirely preventing the formation of a cornice about 150 m long (Figure 14, situations 1 and 2). The conformation of the scour of the individual Kolktafeln was always the same.

For the purpose of separating avalanche controlled areas from uncontrolled areas, on both sides of the project in Albanas in Zuoz good results have been achieved using one row of Kolktafeln each (Figure 15). Since 1956, I myself have observed seven avalanches starting in the uncontrolled, bordering Val Buera and Val Urezza which broke out close to the row of Kolktafeln without penetrating into the controlled area. Subsequently, for safety, a long, horizontal-element snowfence 2 m high was erected partly inside the row of Kolktafeln, but this was covered over by snowdrifts. Snowdrift structures which are too low will later take revenge for any momentary parsimony.

In uninhabited zones, where the costs can be sustained since there exist no massive projects, snowdrift projects along the upper tree line will avoid many avalanches. There one must take note of the boundary lines between different vegetative communities, because they often reveal the location of avalanche paths. The vegetation serves in addition generally as the best indicator of the various snow sites [1]. Kolktafeln cannot replace other structures but they can effectively supplement them; they also perform good service in protecting afforestations and pioneer plantings for restocking [10].

A rationally designed snowdrift project has a permanent effect, in all kinds of weather, from the first snowfall to the opening up of the snow cover. A prerequisite is a certain amount of wind, which never stops for as much as a day in the upper subalpine zone and above.

Installations which are intended to remove snow from this starting zone have the disadvantage, that they guide the snow masses in the direction of the lower controlled slopes. This circumstance should be noted but excessive significance should not be attached to it. It is best for individual wind structures to be built of durable material in order that they can be effectively worked into the permanent control project.

It is the object of this discussion to confirm the fundamental rule that in avalanche control projects, depending upon the local conditions, the most rational types of structures must be combined with one another to give the most effective protection against avalanches. Any serious effort at avalanche structural control, but especially snowdrift structures, requires the builders to carry out several years of steady, thorough, winter patrols and winter observations; for the effect of this type of structure cannot be calculated in advance. A prerequisite is a knowledge of the principal wind direction in the construction region, which includes both down-slope and valley winds. Up-slope winds need to be considered only on moderately inclined slopes and on windward ridges. However, since the local wind direction is often influenced by the terrain, the introduction of an anemometer, combined with a wind vane [14], can permit a better prognosis. The construction superintendent must be a good observer who lives in the vicinity of the project, for these installations must in the beginning -- at least in part -- be provisionally erected and permanently constructed only after confirmation of their effectiveness. Nor should one neglect, after installing the facility, continuous checking, maintenance, and necessary supplementation of the installation. For here, too, the proverb of Wilhelm Busch is true:

"Oh, how much is still concealed
that is still beyond our ken!"

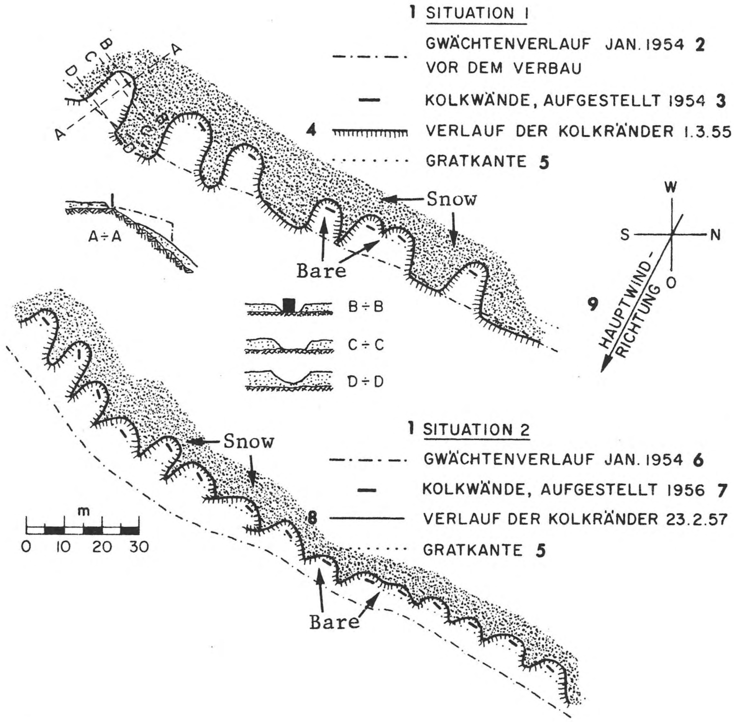


Figure 14. Wind structures "Alp da Munt," near Tschierv, 2,220 m above sea level (field data and evaluation, Ed. Campell).

Key:

1. Plan view
2. Edge of the cornices, January 1954, before the structures were built
3. Kolktafeln, set up 1954
4. Edge of snow, 1 March 1955
5. Ridge crest
6. Edge of cornices, January 1954
7. Kolktafeln, set up 1956
8. Edge of snow, 23 February 1957
9. Main wind direction

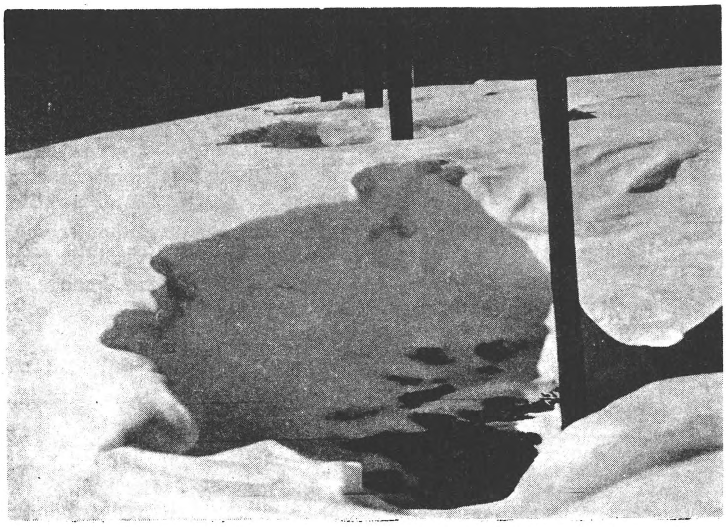


Figure 15. Row of Kolktafeln separating the "Albanas" supporting structures from the uncontrolled avalanche starting zone of Val Buera. The scour hollow reaching the ground interrupt the snow layers and also the hardened scour-walls contribute to snow stabilization, 26 February 1955 (photo E. Campell).

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English Translation of German Titles

[1] Principles and Application of the Provisional Wind-Snow Ecogram.
[2] Contribution to the Theoretical Foundations of Avalanche Defense Construction.
[3] Snow-Drift Walls and Their Application in Avalanche Control Structures.
[4] Experimental Measurements With Snow Fences in the Winters 1940/41 and 1941/42.
[5] Snow Studies in the Upper Valais and Their Application to Avalanche Control Structures.
[6] Snow-Drift Control Structures in Pluetschessa, Ftan.
[7] Recent Developmental Tendencies and Problems of Avalanche Control Structures in the Starting Zone.
[8] On the Significance, Nature, and Distribution of Wind-Dependent Structures in Avalanche Defense Construction and Avalanche Prevention.
[9] The Vegetation on the Stillberg.
[10] Wind-Walls for the Protection of Afforestations.
[11] Avalanche Control Structures and Afforestation in Cluenas-Pluetschessa of the Community of Ftan.
[12] Note on Snow-Drift Control Structures.
[13] Wind as a Site Factor in Afforestations of the Subalpine Zone (Stillberg Alp in Dischmatal, Graubuenden Canton).
[14] Snow-Drift Control Structures.
[15] Problem Formulation for the Snow-Drift Testing Field in Sils-Maria, Engadine.
[16] Jet Roofs, Snow-Drift Ramps, and Snow-Drift Walls.
[17] The Limits of Modern Avalanche Control Structures in the Starting Zone.
[18] The Effect of a Kolktafel.
[19] Observations of Snow-Drift Control Structures in St. Antoenien in the Winter 1956/57.
[20] Snow and Avalanches in the Swiss Alps.

X. DEFLECTING STRUCTURES (Eugen Sommerhalder, Weissfluhjoch/Davos)

1. Introduction

Structural protective measures against avalanches are determined by the nature of the objects to be protected (settlements, alpine roads and railways, as well as individual objects).

Supporting structures in the starting zone serve principally for dealing with avalanche problems in settled areas and only occasionally along communications arteries. In most cases, these protective measures are financially unacceptable for transportation routes or they are technically impossible and unnecessary for individual structures. Hence, in such cases, the avalanche problems are resolved by measures taken in the track and runout zone, by guiding the moving snow masses, deflecting them, slowing them, or stopping them. The technical and financial resources at our disposal permit us to consider various possible protective procedures such as galleries, guide dikes, deflecting dikes, avalanche wedges, retarding structures, and arresting dikes. In the following discussion, we shall examine these types of construction -- particularly galleries -- in some detail.

2. Questions of Safety

2.1 Safeguarding a Highway Against Avalanches

In a potential forest zone at lower elevations, when avalanche protective measures are required, supporting structures with simultaneous afforestation are preferred whenever possible.

If the upper boundary of the avalanche path lies above timberline so that avalanches in gorges, gullies, or straight clearings break through the forest, then, depending upon the size of the region invaded, financial and engineering factors will determine the type of structures required.

Let us suppose, for example, that a stretch of highway 100 m long is to be protected against avalanches. The relatively small avalanche path has a construction area of 5 hectares. The cost of supporting structures runs to about 0.5 million francs per hectare, those of a gallery to about 10,000 francs per running meter. The financial outlay for the supporting structures amounts to 2.5 million, that for the gallery to 1 million francs.

At high elevations where the dense forest disappears and in its place there are only individual groups of trees and then with increasing elevation open slopes and rocky terrain, the gallery clearly offers the highest level of safety. Its protective effect relates not only to avalanches but also to other external agencies acting on the highway, such as the results of summer storms (rock falls, landslides). In addition, the cost of snow removal to keep the highway open in winter is entirely eliminated or held within tolerable limits. Galleries are also built on stretches where snow drifting is so severe it is impossible to handle it even by continuous operation of conventional snow removal equipment.

The choice of the alternatives "supporting structures or gallery" is not decided just by the question of cost, but also with regard to the degree of winter safety to be sought for the highway concerned. With the gallery, one obtains an absolute safety and with supporting structures a limited safety associated with some residual risk which under some circumstances, or important main arteries, is not acceptable. Also, if the road is exposed only to small avalanches which can start just below or within the structures then these apparently insignificant events suffice to bury persons and vehicles or knock them off the roadway.

2.2 Winter Safety on Highways

In regions where, during the winter, alpine routes serve only local traffic and for the most part are used by natives or people familiar with the area who know the danger sites and also can evaluate the avalanche risk in conjunction with weather conditions, avalanche accidents can be largely avoided. The mountain dweller, familiar with the conditions, in earlier days also accepted the inconvenience of having individual settlements occasionally cut off from one another and the necessity of reestablishing communications with laborious snow removal operations. In many localities, galleries were built only in the paths of especially large avalanches primarily in order to deal with the massive avalanche deposits and to facilitate the clean-up. This engagingly "primitive" but risk-taking attitude is unthinkable today. Many mountain dwellers, particularly the younger generation, are employed outside the valley. Small schools in remote settlements are being closed down and combined at central locations in the valley. The subsequent education, whether it be learning a trade or a profession, takes place outside the valley. Hence, the residents in the locality are increasingly dependent upon having a thoroughly winter-safe system of communication; it can become an issue of existence itself.

On the other hand, the progressive and large-scale elaboration of pass highways and main highways as well as the promotion of tourism in the alpine region leads to a situation in which the means of communication are used to an increasing degree by travelers unfamiliar with the mountains and having no idea of winter conditions. Therefore, increased attention must be given to avalanche conditions and a degree of winter safety must be sought which is either complete or as great as possible.

By <u>complete winter safety</u> we mean the continuous accessibility of a highway without avalanche risk. In certain cases, severe snow drifting is also included, which can endanger and interfere with traffic.

The concept of <u>limited winter safety</u> is relatively new. It asserts that the road concerned is to be considered as not winter safe but it requires temporary closure only in extraordinary avalanche situations. The stretches frequently crossed by avalanches are protected by structural measures (galleries). Translated into practice, a road possessing limited winter safety is one which has 1 to 3 days of traffic interruption annually as a result of road closures as preventative measures against anticipated avalanches.

2.3 Clarification of the Avalanche Conditions

2.3.1 Avalanche Cadastral Survey

The observation and recording of all avalanche descents into settled valleys and their listing in so-called <u>avalanche cadastral plans</u> provide rather reliable documentation for evaluating avalanche conditions affecting a highway. They permit conclusions with regard to the localities in which one must reckon with avalanches, with regard to the types of avalanches (flowing avalanches, powder avalanches, or mixed types) and they tell us with what frequency and in what magnitude they can occur.

In unsettled regions or in newly located alpine transportation routes, the observations are lacking or are only scanty and deficient. With regard to the avalanche cadastral survey, it must be clearly understood that this is merely an inventory of previously observed avalanches which, as a rule, extends only over a relatively short period of time amounting to one to two generations, in which rare avalanche events normally cannot be included.

2.3.2 Avalanche Danger Map

The avalanche danger map is created on the basis of a detailed terrain evaluation, an avalanche cadastral survey (to the extent that it is available) and with the aid of avalanche engineering calculations which take into account local climatic conditions. The danger map represents the endangered zones and road stretches in plan form and describes the avalanche frequencies to be expected in the individual <u>zones</u> (avalanche paths) as well as describing the degree of winter safety on the <u>routes</u> (highway) as follows:

<u>Danger Zones</u>

Starting Zone, Paths & Tracks	Frequency of Occurrence of Avalanches
Red	Mean recurrence interval of 30 years or less.
Blue	Mean recurrence interval between 30 and 60 years.

<u>Dangerous Routes</u>

Highway	Winter Safety
Red	Not winter-safe. Routes with acute avalanche danger. (Depending upon the safety requirement which has been set, the blue danger zone may also be included.)
Blue	Limited winter safety. Route is only rarely endangered by avalanches, in extraordinary to extreme situations.
Yellow	Limited winter safety. Only dust avalanche activity.
Orange	Not winter-safe. Routes with very severe snow drifting.
Green	Winter safe. Routes where avalanche danger is absent or improbable.

3. Galleries

3.1 Task and Mode of Action of the Gallery

As avalanche protection for a highway, which runs through the terrain like a narrow band, normally only a roofing-over in the form of galleries can be considered at acceptable financial outlay. The avalanches are either conducted over the gallery or they are partially deposited on the roof in their run-out region without disturbing the traffic on the highway. Figure 1 is an example of a gallery which leads through interconnected avalanche paths lying on steep slopes.

3.2 Avalanche Forces and Stresses on the Gallery

In planning avalanche galleries, it is necessary to know the nature and magnitude of the forces to which the protective installations are exposed in the most unfavorable case. The gallery does not constitute an actual obstacle which noticeably affects avalanche motion. The force effect consists essentially of the deflection force and the friction which the stationary and the moving snow loads apply to the gallery roof. The gallery design must be dimensioned in terms of these forces.

3.2.1 Experimental Derivation of the Forces Acting on a Gallery

In order to get a clear idea of the magnitude of the forces, in the year 1962, mechanical measuring devices were specially designed for this purpose and installed on gallery roofs (Lukmanier, Schoellenen, and Vintzay VS) [1]. Every winter the maximum values of normal and shear force produced by avalanches and avalanche deposits are measured. In order to be able to draw generally valid conclusions from this, the measurements must extend over a series of years.

These force measurements refer throughout to flowing avalanches. The powder avalanches sweep over the gallery and generate only insignificant frictional forces. Suction forces can occur on small galleries completely inundated by powder avalanches. According to observations and computations up to now, values of $-p < 100$ kg/m^2 occur. The previously

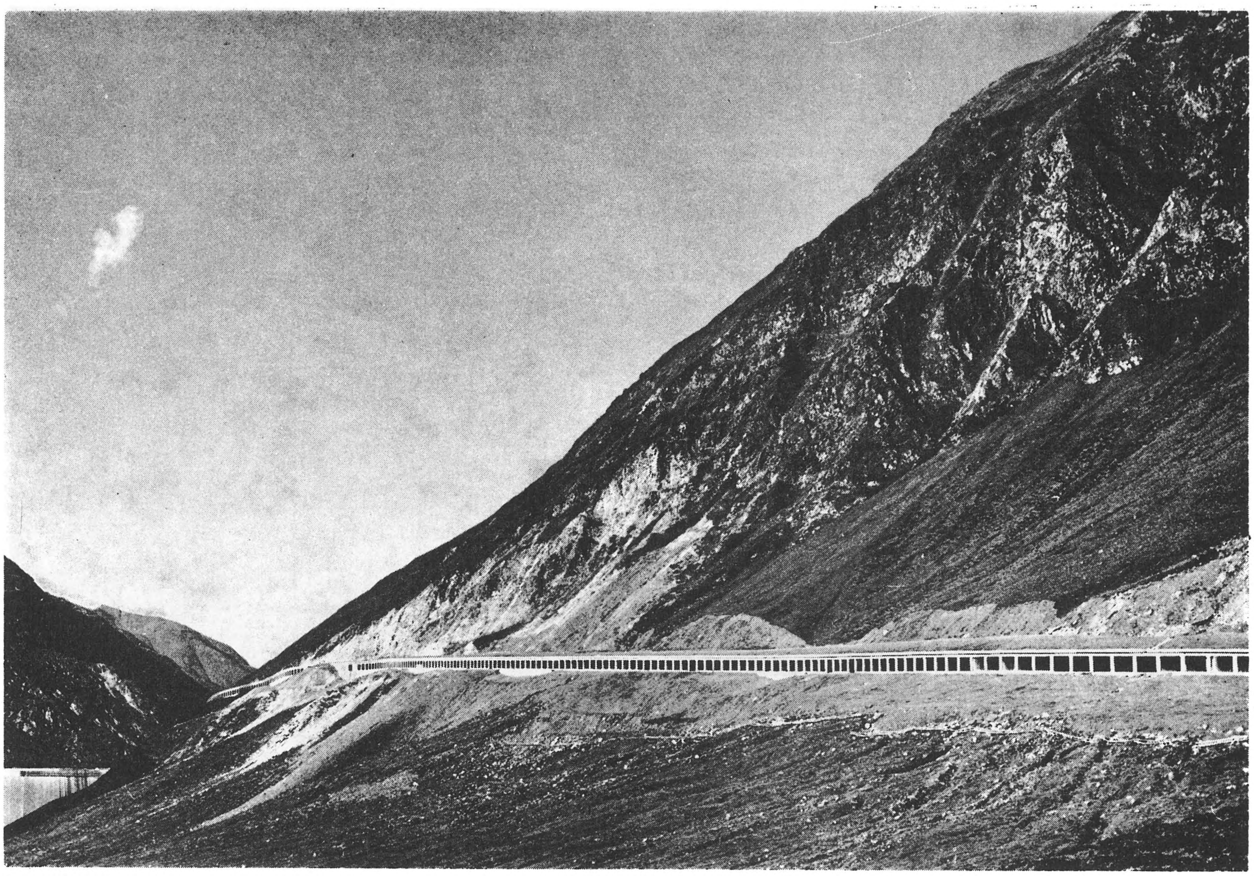
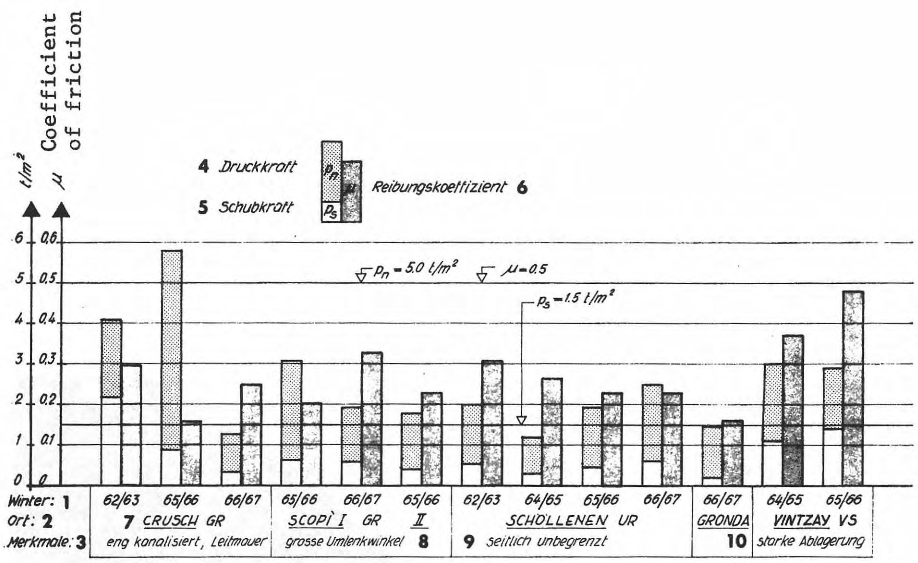


Figure 1. Gallery on the Lukmanier highway, along the Sa. Maria impounded lake (photo E. Wengi).

mentioned measuring devices serve particularly for the investigation of frictional forces. In order to be able to compute these quantities for each special case it is necessary to derive a coefficient μ which arises as the measured quotient of shear and normal force. As a supplement to the field measuring devices, analogous but more precise experiments are being carried out [2] with electrical measuring methods on the snow slide path near the Federal Institute for Snow and Avalanche Research on Weissfluhjoch. The provisional measurement results [3] are contained in Figures 2 and 3. In Figure 2, the measured compression and shear forces as well as the coefficients of friction derived therefrom may be seen. In Figure 3 is shown the profile of the average of the coefficient μ evaluated from 14 measurements over the breadth of the gallery. The highest average value is μ = 0.32, the average over



Key:
1. Winter
2. Place
3. Characteristics
4. Compression force
5. Shear force
6. Coefficient of friction
7. Narrowly canalized, guiding wall
8. Large deflection angle
9. Laterally unbounded
10. Heavy deposit

Figure 2. Measurements on gallery roofs: normal force, shear force, and calculated coefficients of friction.

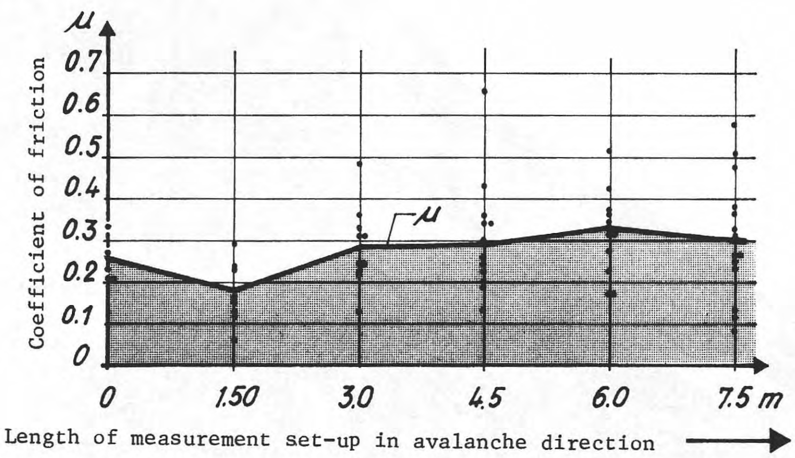


Figure 3. Coefficient of friction, average of 14 measurements.

the breadth of the gallery (7.50 m) is μ = 0.27. For calculations, a coefficient of friction $\mu \geq 0.40$ is assumed. In Figure 4, there is shown an individual gallery with a measuring device installed.

3.2.2 Computational Derivation of the Forces Acting on a Gallery [1], [4], [5]

An assumed extraordinary avalanche situation serves as the initial condition for all avalanche engineering discussions.

The stresses produced by snow are composed in general of the following components:

a. Weight of the snow deposit present on a gallery before or during the descent of an avalanche, in special cases it includes creep compression also.

Conventional assumptions for average conditions:

Density of the snow cover γ_a = 400 kg/m^3
Magnitude of the snow cover on the roof during descent of the avalanche
d_a = 1.50-2.00 m

Calculation: normal force

$$p_{na} = \gamma_a \, d_a \cos\beta \quad (kg/m^2)$$

where β denotes the angle of the roof inclination

b. Weight of the avalanche flowing over the gallery.

Conventional assumption:

Density of the flow avalanche

$$\gamma_t = 300 \text{ kg/m}^3$$

Calculation:

Flow height d_t

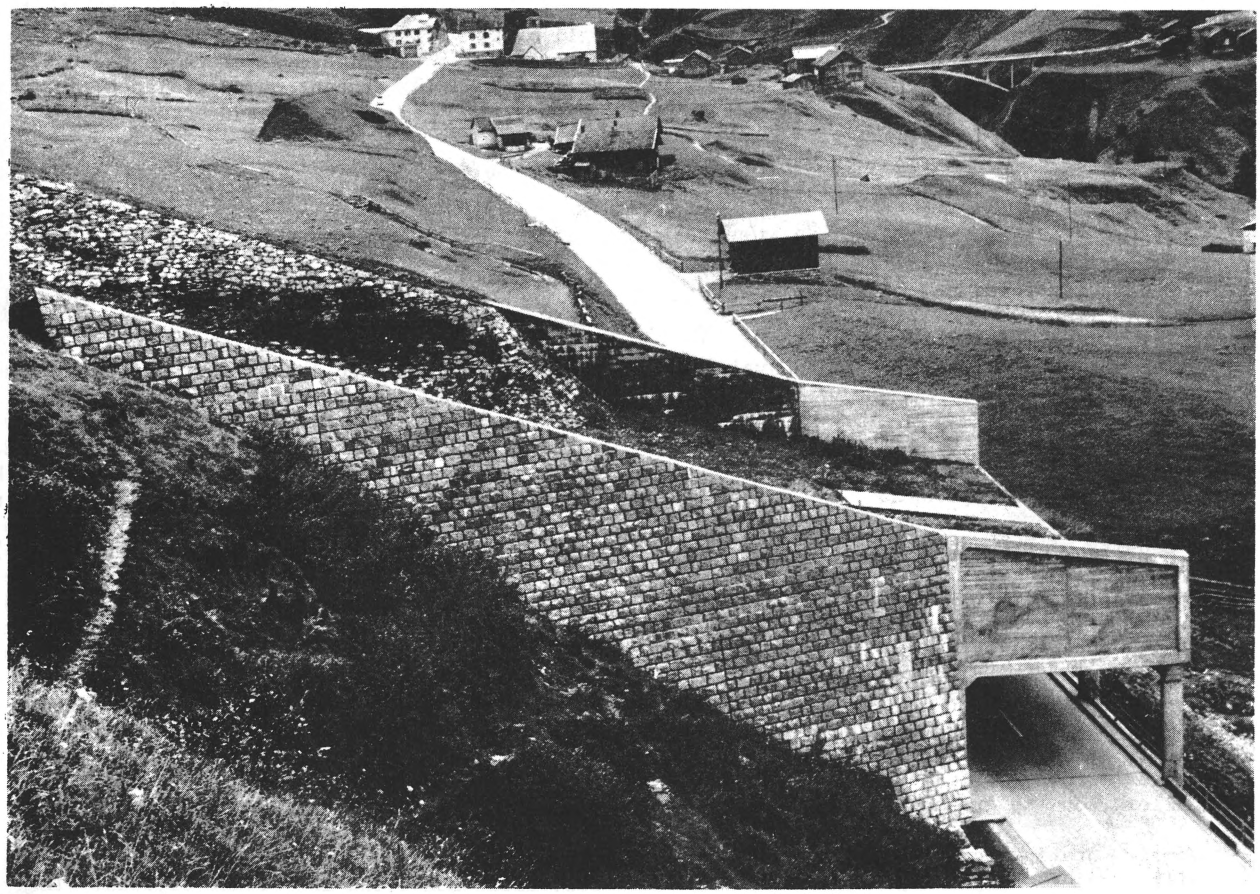


Figure 4. Avalanche gallery with built-in measuring device: in the foreground are guide walls and dikes, in the middle and in the background of the picture deflecting dikes are visible (photo E. Wengi).

Normal force $p_{nt} = \gamma_t \, d_t \cos\beta$ (kg/m²)

c. Deflection force resulting from a change in the flow direction of the avalanche constrained by the gallery roof, through a deflection angle α.

Calculation:

Flow velocity of the avalanche v_t
Normal force $p_{nd} = \frac{d_t}{L} \frac{\gamma_t}{g} v^2 \sin\alpha$ (kg/m²)

(for the remaining symbols see Figure 5, loading cases)

The gallery and its covering should preferably be so arranged that the gradient break (deflection angle) occurs at as great a distance as possible uphill of the gallery.

d. Total of the normal forces which act upon the gallery in an avalanche descent. $p_n = p_{na} + p_{nt} + p_{nd}$ (kg/m²)

e. Friction forces.

Conventional assumption:

Coefficient of friction $\mu = 0{,}4$

Calculation: components consisting of

Stationary load $p_{sa} = \gamma_a \, d_a \sin\beta$ (kg/m²)
Moving avalanche load $p_{st} = \mu \, p_{nt}$ (kg/m²)
Deflecting force $p_{sd} = \mu \, p_{nd}$ (kg/m²)

f. Total of the friction forces which act upon the gallery in an avalanche descent. $p_s = p_{sa} + p_{st} + p_{sd}$ (kg/m²)

g. Weight of the avalanche deposit.

Conventional assumption:

Density of the deposit

Calculation: $\gamma_a' = 500$ kg/m³

Mean deposit depth d_a'
Normal force $p_{na}' = \gamma_a' \, d_a$ (kg/m²)

h. Additional earth pressure on the uphill gallery wall caused by the friction forces or deposit forces acting, above the gallery, on the ground.

i. Static snow pressure on the downhill side of the gallery front when the gallery is completely surrounded and covered by the avalanche deposit.

k. Forces caused by avalanches which do not flow from the mountain side over the gallery roof but flow toward the structure from the valley side opposite the gallery.

But naturally the forces which have been mentioned will never all occur simultaneously, at least not in their maximum magnitude. The calculation of the avalanche velocities, of the depths of flow and deposit as well as of runout distances are not treated in this article in any more detail; these should be determined by trained avalanche specialists.

For designing a gallery, the possible loading cases shown in Figure 5 need to be considered: a) static and dynamic load (avalanche descent), b) only static load (avalanche deposit). In each case, the most unfavorable loading of each type is to be considered. Figures 6 and 7 serve as an illustrative example in which the loadings acting upon an avalanche gallery are schematically represented in cross-section. Figure 6 shows the forces on the gallery roof and on the back wall of the gallery, resulting from the stationary load. Figure 7 refers to the case of stress during descent of an avalanche in which static and dynamic loads occur.

4. Guidance Dikes

Wherever gully-shaped avalanche tracks discharge onto fan-shaped cones of deposit in the flatter valley floor and there is a possibility of marked lateral extensions of the avalanche and changes in its direction, the avalanche path can be limited in its breadth by means of guidance dikes, i.e., can be canalized. In this way, it is possible to reduce the length of the relatively expensive gallery to a certain size. These dikes or walls should as a rule be carried up to the roof of the gallery (Figure 4) to positively prevent a lateral outbreak of the avalanche over the entrances to the gallery and onto the road. It is a mistake to constrict an avalanche track funnel-wise with guidance dikes toward the gallery in order to achieve higher savings in gallery lengths. The constriction makes the outflow of the avalanche difficult. Pile-ups occur on the roof which lead to an excessive loading of the structure. The snow masses flowing behind the avalanche front fall to left and right of the gallery ends onto the highway. Guidance dikes are also used to protect settlements and individual objects. The determination of the position, the height, and the length of a guidance dike is carried out on the basis of a careful study of the character of the ground and on the basis of avalanche computations.

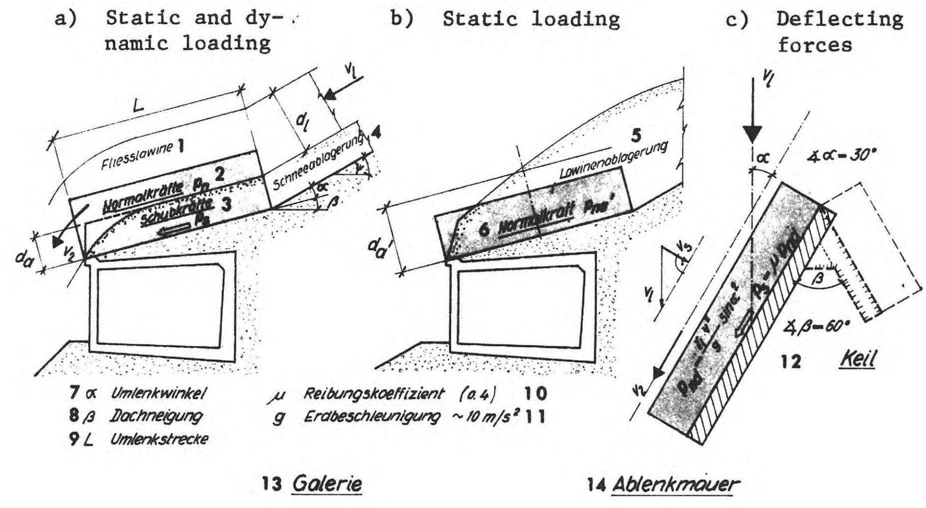
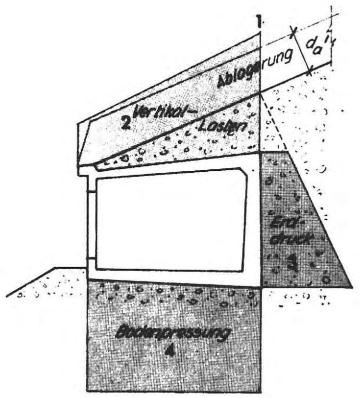


Figure 5a, b, c. Various loading cases.

Key to Figure 5a, b. c:

1. Flow avalanche
2. Normal forces
3. Shear forces
4. Snow deposit
5. Avalanche deposit
6. Normal force
7. Deflection angle
8. Roof inclination
9. Deflection interval
10. Coefficient of friction
11. Gravitational acceleration
12. Wedge
13. Gallery
14. Deflecting wall



Key to Figures 6 and 7:

1. Deposit
2. Vertical loads
3. Earth pressure
4. Compression of the ground
5. Horizontal load
6. Flow avalanche

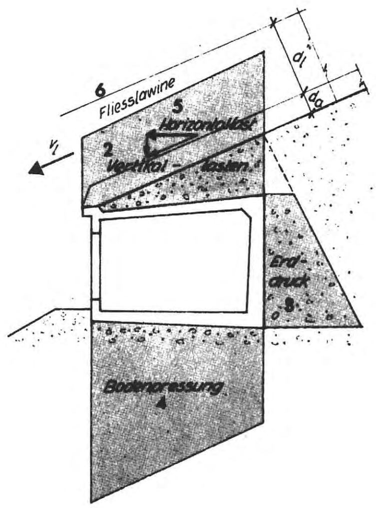


Figure 6. Stress on the gallery resulting from static loads. Schematic loading plan.

Figure 7. Stress on the gallery. Schematic loading plan for static and dynamic loading cases.

4.1 Computational Derivation of the Height of Guidance Dikes

In avalanche tracks where as a consequence of the gradient no very large avalanche deposits can form, one must take into account the naturally deposited snow cover and one must determine the flow height of the avalanche.

Assumption:

Magnitude of the snow cover $d_a \geqq 1.50$ m

Computation:

Magnitude of the flowing avalanche d_t
Dike height above the floor of the avalanche track $D = d_a + d_t$

It is more difficult to determine the dike height in the avalanche runout region with terrain inclinations below 17°. Depending upon the locality, in the course of a winter several avalanches both small and somewhat larger may run which leave behind corresponding deposits whose magnitude is difficult to evaluate. For subsequent large descents, adequate space will no longer be available -- otherwise the guidance installations would have to be overdimensioned. Flat runout stretches after sharp gradient breaks are especially critical. Here, under some circumstances, the wisdom of employing guidance dikes may be questioned because the required dike heights can hardly be attained with reasonable means. In such situations, the original avalanche track width may be constricted only very slightly or not at all.

Assumption:

Magnitude of the deposit in front of the extraordinary avalanche descent (estimate or computation) d_a

Computation:

Magnitude of the flowing avalanche d_t
Velocity of the avalanche v_t
Mean deposit depth $d_a' = \frac{v_t^2}{4g} + d_t$

Dike height above the descent path floor

$$D = d_a + d_a'$$

For guidance walls in the runout zone, one must also take into account the static snow pressure on the inner side of the wall and, in certain cases, one must also allow for a deflecting force.

5. Deflecting Dikes

In contrast to the guidance installations, deflecting dikes are intended to deflect a flowing avalanche into a desired direction or restrain a lateral outbreak after the track changes direction. Deflecting installations have practically no effect upon powder avalanches.

The protective installations are designed in accordance with their mode of action. Their effectiveness does not depend solely upon the height of the installation but also upon the slope of the terrain and the deflection angle. In the all-too-flat avalanche runout region, instead of a deflection they cause a pile-up and a back-filling of the installation. In steep tracks of large avalanche paths, very large dike heights are required (depending upon the choice of deflection angle) which can entail difficult and hardly soluble construction problems. Deflecting dikes or deflecting walls promise success in locations where they contribute to an elevation of the lateral gully boundaries and to a magnification of the channel cross-section, thus hindering the outbreak of avalanches (for example, after the track changes direction with subsequent outflow channels running transverse to the fall-line (Figure 8a)). Successful deflection of the avalanche depends largely upon the size of the deflection angle. If the angle of encounter with the obstacle is too great, the descending flow avalanches leap over the dike and only those snow masses moving sluggishly in the rear are deflected. The deflection angle should not exceed about 30°. The smaller the angle the better the avalanche deflection and the smaller are the forces (deflecting force and friction) acting on the deflection installation.

5.1 Computational Derivation of the Height of Deflection Dikes

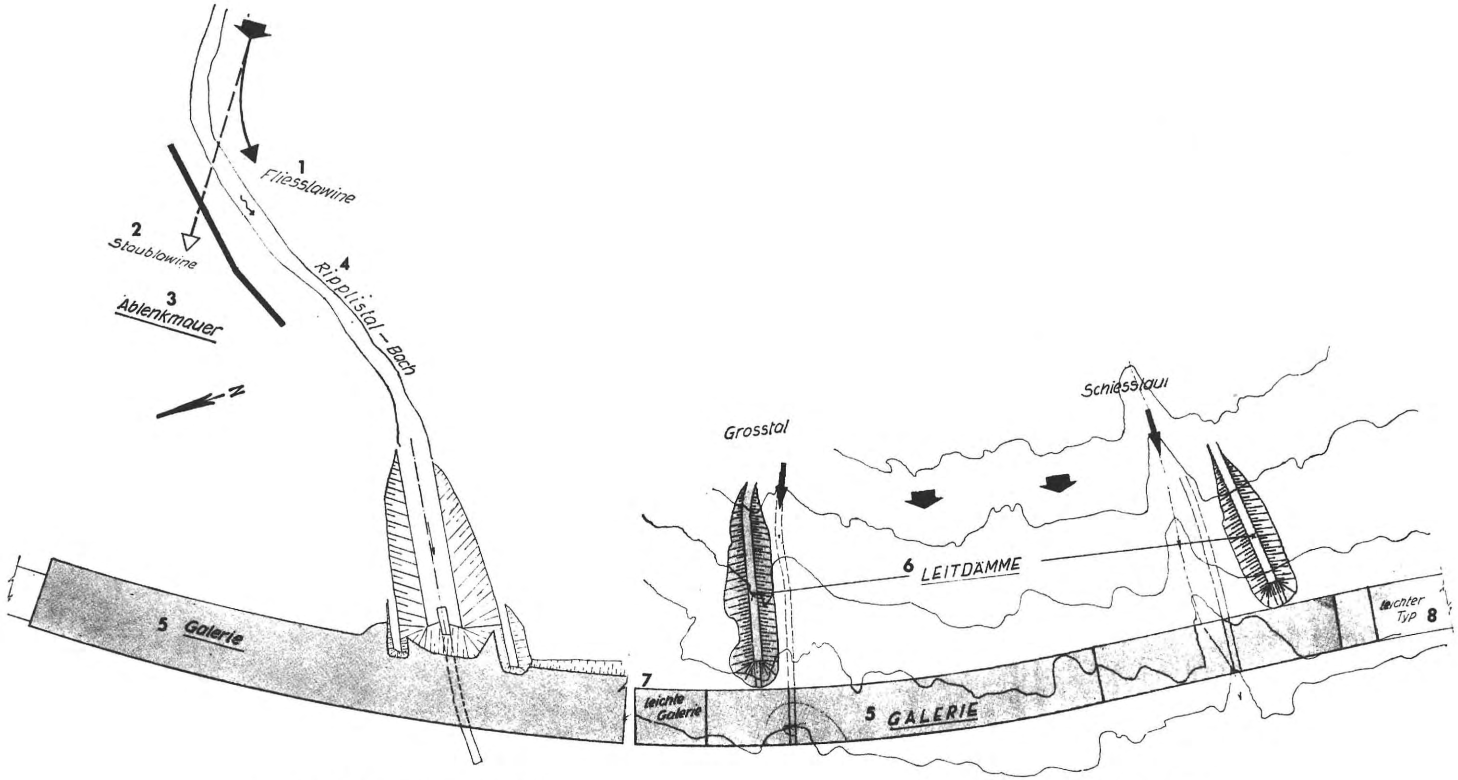
The sketch (Figure 9) shows an example of a deflecting dike on a low spot in the ridge out of which large avalanches emerge and endanger the edge of a village.

From the scientific aspect, the following must be calculated [5]:

The existing discharge quantity (avalanche snow) Q_{vorh}
Magnitude of the flowing avalanche in the track above the protective installation d_t
Velocity of the avalanche v_t

The required height of the protective installation is determined as follows: The following quantities are first established in the given gully cross-section.

Height of the channel boundary measured from the floor D_{geg}



a) Deflecting installation

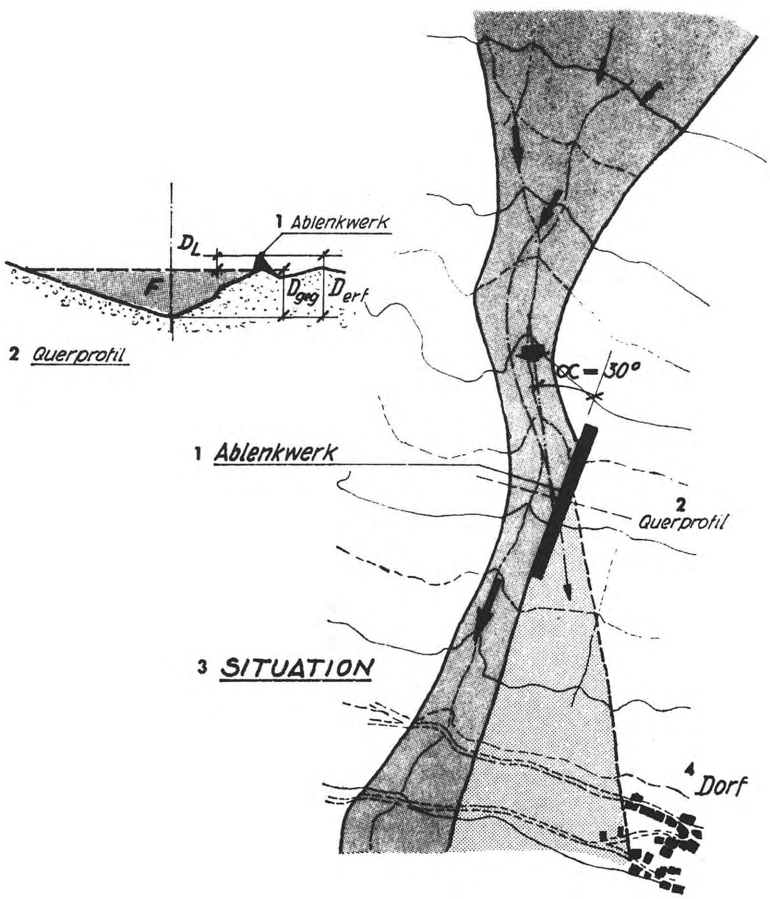
b) Guidance installations

Figure 8a, b. Gallery, guidance, and deflection dikes; example from experience with the National Highway N2; in the Canton of Uri.

Key:

1. Flowing avalanche
2. Powder avalanche
3. Deflecting wall
4. Ripplistal stream
5. Gallery
6. Guidance dikes
7. Light gallery
8. Light type [gallery]

Figure 9. Example of a deflection installation, situation plan.



Key:

1. Deflection installation
2. Transverse profile
3. Plan view
4. Village

Cross-sectional area of the channel F_{geg}
Allowable discharge quantity in the given cross-section Q_{zul}

The allowable and the existing discharge quantities are compared with one another. The following condition must be satisfied (without taking into account the deflection):

$$Q_{zul} > Q_{vorh}$$

What is now sought is the required height D of the deflection installation.

Using the component of the velocity vector v: perpendicular to the deflection wall v_g, the pile-up height d_{max} is calculated. In this way one gets the superelevation d_Δ compared to the flow height d: at the outer side of the descent path curvature.

$$\text{Superelevation } d_\Delta = \frac{v_s^2}{2g}$$

The required elevation of the wall crown and dike crown above the descent path floor is obtained by

$$D_{erf} = d_a + d_: + d_\Delta$$

The effective height of the protective installation D_L is derived from

$$D_L = D_{erf} - D_{geg}$$

Design of the deflection installations to meet the avalanche forces is done on the basis of the loading plan in Figure 5.

6. Avalanche Wedges

The use of the avalanche wedge with its relatively restricted protective capability is to be considered whenever individual objects, such as isolated buildings, high-voltage towers, and cable-car towers stand in an avalanche path. As a rule, the wedge is placed directly at the object or in its immediate neighborhood. In contrast to deflection dikes, the avalanches are separated and the snow masses guided to left and right past the object to be protected. The side of the wedge must have sufficient length in order that the parts of the avalanche flowing behind the wedge will not strike the object.

6.1 Computational Derivation of the Height of Wedges

The flow heights and velocities of the flowing avalanches must be calculated on a theoretical basis.

The height of the wedge walls and the stress produced by avalanche forces must be determined as in the case of deflection dikes under Section 5.1. The angular aperture of the wedge should not exceed 60°.

7. Concluding Remarks

It is the purpose of this study, with regard to the continuing expansion of the alpine highway system, to display the associated avalanche problems and possible protective measures. We do not enter into the subject of theoretical avalanche calculations because this would carry us too far within the limits available. For the practitioner, we have just given a few recipe-type indications.

Deflection construction for the protection of highways increased very much in significance in the last 10 years. Today it has about the same importance as supporting structures in the starting zone, for the protection of settlements and other objects.

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English Translation of German Titles

[1] Stresses Applied to Avalanche Galleries by Snow.

[3] Compression and Shear Measuring Devices on Avalanche Galleries, Description of the Installations, and Results Thus Far.

[4] Principles of Structural Control of Avalanches.

[5] Avalanche Forces and Object Protection.

XI. RETARDING STRUCTURES (Hans Doenni, Brig)

Structures built in avalanche paths with the object of reducing avalanche velocities and of shortening the avalanche path are called retarding structures. It is intended that the avalanche should be split up by obstacles into as many arms as possible, thus losing energy and finally being brought to a halt. It is not arrested suddenly but slowed gradually and the energy dissipation should not take place directly at the obstacles but primarily within the avalanche itself. This method of construction developed from experience with splitting wedges and deflecting dikes. Except that the obstacles are not placed in front of the objects to be protected but in the path of descent of the avalanche. The splitting of the avalanche at the most forward splitting wedges is followed in a field of further obstacles by an additional collision of the split-up avalanche arms with one another and further encounters of these with the next wedges. By the introduction of obstacles into the avalanche path the normal flow process of the snow masses is disturbed, the internal friction of the avalanche as well as friction between snow and the slide path are amplified and thereby energy is dissipated and the flow motion or impact force is reduced.

The ideas underlying retarding structures seem evidently correct and this method of control is promising.

What experience has thus far been acquired in retarding structures and under what assumptions can such experience be applied with a corresponding effect? Austria, the pioneer country in the use of retarding structures, possesses the greatest amount of experience in this connection and hence in what follows we shall discuss some examples of Austrian retarding structures [1].

With the object of protecting Muehlau, after careful weighing and checking all possible modes of construction, the first retarding structures were built in the years 1935 to 1941. The Muehlau retarding installation consists of eight wedges having an average height of 4 m and an earth core, 0.5-m thick concrete walls at the impact locations and mortar walls at the remaining surfaces; in addition, the facility contains four guidance installations of the same material. There are located in a flat stretch of the track having an inclination of 25-30 percent and at an elevation of 1,025-1,050 m above sea level. In addition, 200 m above the retarding structures in the narrow avalanche track, a wedge was installed as a preliminary obstruction. These concrete wedges were supplemented at 940 m above sea level by two arresting basins which are closed by arresting dikes up to 9 m in height and which serve to trap the parts of the avalanche which have been able to break through the retarding structures. This group of retarding structures seems to have been successful. The catastrophic years 1945 and 1951 brought severe avalanches whose principal mass was arrested by the structures. Smaller portions flowed over the obstacles but remained lying at the bottoms of the slopes. The concrete wedges cut the avalanche at an angle of 90°. Depending upon the nature of the snow, the effect was highly variable. In the case of heavy snow, the deflected portions of the avalanche maintained their direction over long stretches and were only deflected by means of new wedges. The looser the snow, the smaller was the deflection, and hence the smaller was the effect.

In laying out retarding structures, this fact should be taken into account. If a retarding structure must be installed at a great elevation above sea level where catastrophic avalanches with loose snow inundate the descent path, one cannot hope for the same success as that obtained at Muehlau where the retarding facility, supplemented by arresting basins lies between 940 and 1,050 m above sea level.

Above the retarding structures in Muehlau it was possible for a hill of loose debris to obstruct the avalanche up to a height of 11.0 m [sic]. Despite the fact that almost every year the avalanche passed over it, the fury of the avalanche was not sufficient to carry it off. It has the same effect as the expensive concrete wedges; in other words, it appears to be possible to replace the latter with significantly cheaper earthen mounds.

These ideas were taken into account as early as 1949-1950 in retarding structures for the Allerheiligenhoefe avalanche at Innsbruck. Fourteen earth mounds 3-4 m high in the form of truncated circular cones and five guidance installations were erected; on the uphill side they were surfaced with the stones derived from the excavation. The cones were placed checkerboard style close together so that there was no open lane in the fall-line. The cost was less than one-tenth that of an equally large concrete installation or mortar-masonry installation. So far as we are aware, these retarding structures have performed well.

In 1951, three large avalanches descended into the retarding structures; all of them remained in the construction area. The upper cones were buried to a height of several meters, the lowest row of cones remained free. Snow mounds formed at the obstructions slowed the following avalanches. About 100,000 m^3 of snow were restrained. In 1953, a powder avalanche descended into the structures and was split up; no damage was observable in the adjacent forest. It appears that in this case, the retarding structures also had a favorable effect upon a powder avalanche. Thus far, the cones have not been damaged, despite various avalanche descents.

The good results in Austria caused avalanche construction engineers in Switzerland to employ these methods under certain conditions.

In 1957, in order to protect part of the barracks area of Andermatt at the foot of the Kirchberg, eight blocks of concrete with earth back-filling were set up. The concrete walls are 4.0 m high and 5.0 m wide. The cost per block was 6,000 francs. Figure 1 gives a survey of the type and arrangement of installations.

In 1958, retarding structures were set up in Alpogli/Wilerhorn, in the Briezwiler Precinct (Bernese highlands) [2]. The avalanche starts on the south slope of the Wilerhorn, 2,004 m above sea level, the inclination amounts to 45^{o}-50^{o}. In Alpogli (1,440 m above sea level), the avalanche encounters a flatter slope with inclination of about 35-40 percent [about 20^{o}] which is closed off by a natural obstruction. In the last 50 years, avalanches on several occasions broke through this natural obstruction, partially destroyed the forest below, and invaded the village of Brienzwiler, 702 m above sea level. After the cutting of wild hay was discontinued (causing a marked increase in the sliding factor as a consequence of the long-bladed grass) the number of dangerous avalanches increased. Protective measures for the security

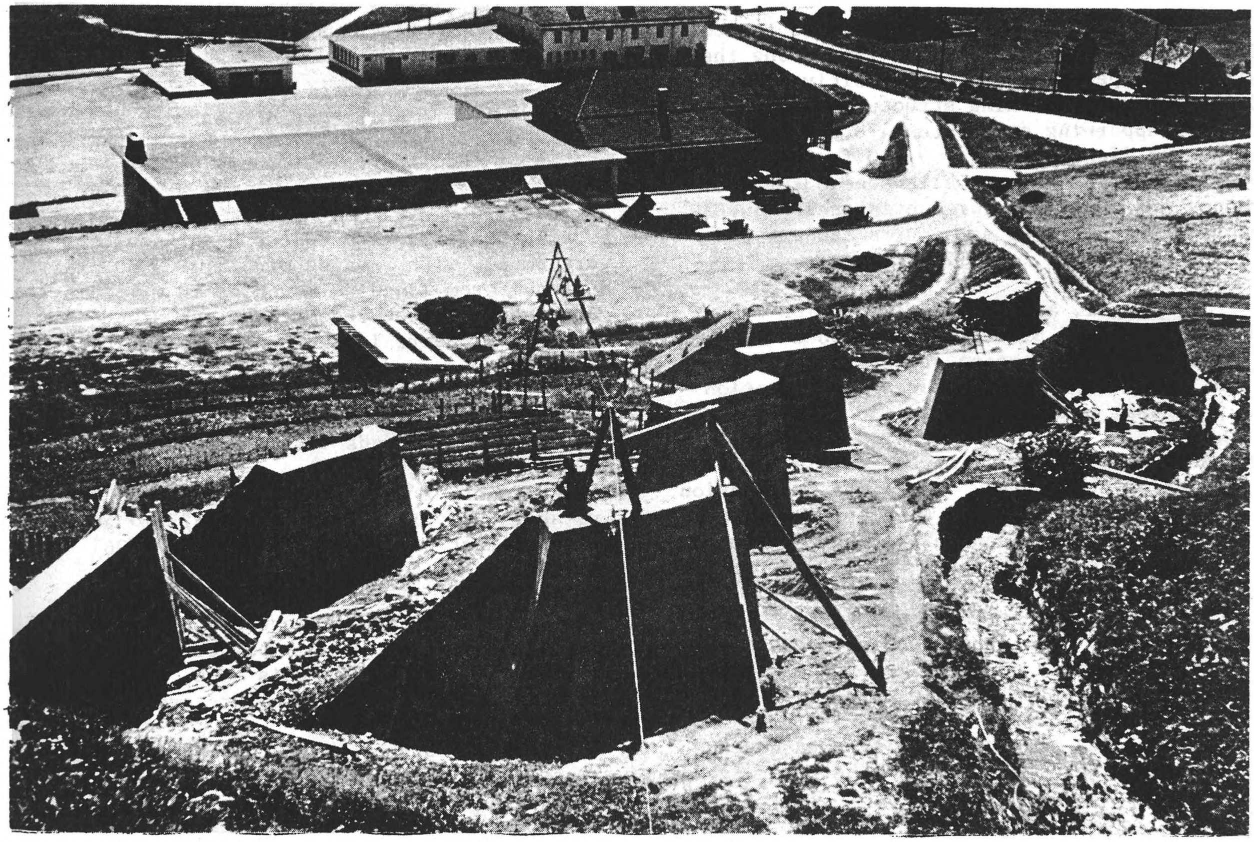


Figure 1. Retarding structures above the Andermatt Barracks (photo K. Oechslin).

of Brienzwiler became urgently necessary. A fully effective set of supporting structures in the starting zone of the type required would occupy an area of about 4.75 hectares. The slopes are sharply peaked and the foundation conditions are unfavorable for supporting structures; the cost of supporting structures is correspondingly very high.

A simple set of retarding structures does not offer reliable protection against the avalanches breaking out of the Wilerhorn, since the existing space is scanty and it is not possible to produce the required staggering in-depth of the retarding structures.

By using a combination of supporting structures and retarding structures, it was possible to take the most economically favorable safety measures. These construction operations are supplemented by reforestation wherever possible in areas totaling 2.2 hectares.

The Alpogli retarding structures with 23 retarding mounds and an arresting dike 170 m in length was installed with the best possible utilization of the terrain (Figure 2).

The cost of this project comes to a total of 790,000 francs. This is divided among the following types of operation: cultivation 50,250 francs, retarding structures 146,400 francs, supporting structures 478,000 francs, enclosures [fencing, etc.] 5,000 francs, access roads 18,200 francs, miscellaneous 33,000 francs, and provision for contingencies 59,150. The use of supporting structures alone would have required over 1 million francs.

In Alpogli, an economical solution for the protection of Brienzwiler was found by a combination of supporting structures, afforestation, and retarding structures -- to mention the principal measures.

As Figure 2 shows, the terrain is suited to retarding structures. The slope inclination at the lowest mounds is 6° to 17°, in the upper row it is 17° to 26° and only at the uppermost three mounds is it 26° to 30°. The uppermost limiting value of slope inclination for effective retarding structures amounts to about 12° to 15°, which corresponds to the minimum coefficient of friction of the flowing snow (compare B. Salm, Section 5.2). This inclination -- with the exception of the forward splitting mounds on Alpogli -- is not substantially exceeded in the cases of the retarding projects listed.

The height of the retarding mound in Alpogli, corresponding to the quantities of snow expected, has been set at 5.0 m and only the three uppermost mounds have a height of 4.0 m. The pressure of the avalanche masses upon retarding elements increases as the square of the velocity of the avalanche.

It is definitely true that the higher the retarding elements, the greater will be their effect. Hence, it would be desirable to install as many overdimensioned mounds as possible. The volume (V) of the conical mound may be computed as follows

$$V = \frac{h\ a\ b}{3}\ \pi$$

h = height of the mound (perpendicular to the slope up to the vertex of the cone),
a = half of the largest diameter of the elliptical base area,
b = half of the smallest diameter of the elliptical base area.

This formula constitutes an argument against overdimensioned heights since the volume increases as the third power of the height (a cone of 5.0 m height has, depending upon the terrain inclination, about the same volume as two cones 4.0 m in height). Excessive heights are therefore uneconomical, nevertheless, the cones must be high enough; the decisive factor is the expected flow heights of the avalanches (compare S. Salm, Section 5.2).

The installations in Alpogli are arranged in a checkerboard pattern with the intermediate spaces of the individual mounds being closed off so that no continuous alleys arise.

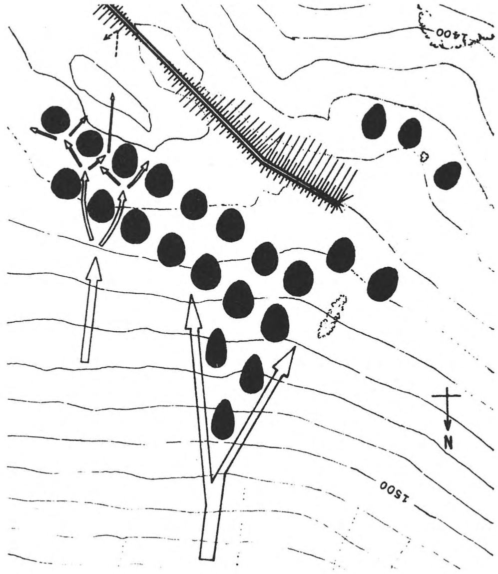
The intermediate spaces have been kept very small, with a value of 5.5 m or an axial distance from mound to mound of 20 m. This corresponds to the recommendations of the Austrian pioneers in the use of retarding structures.

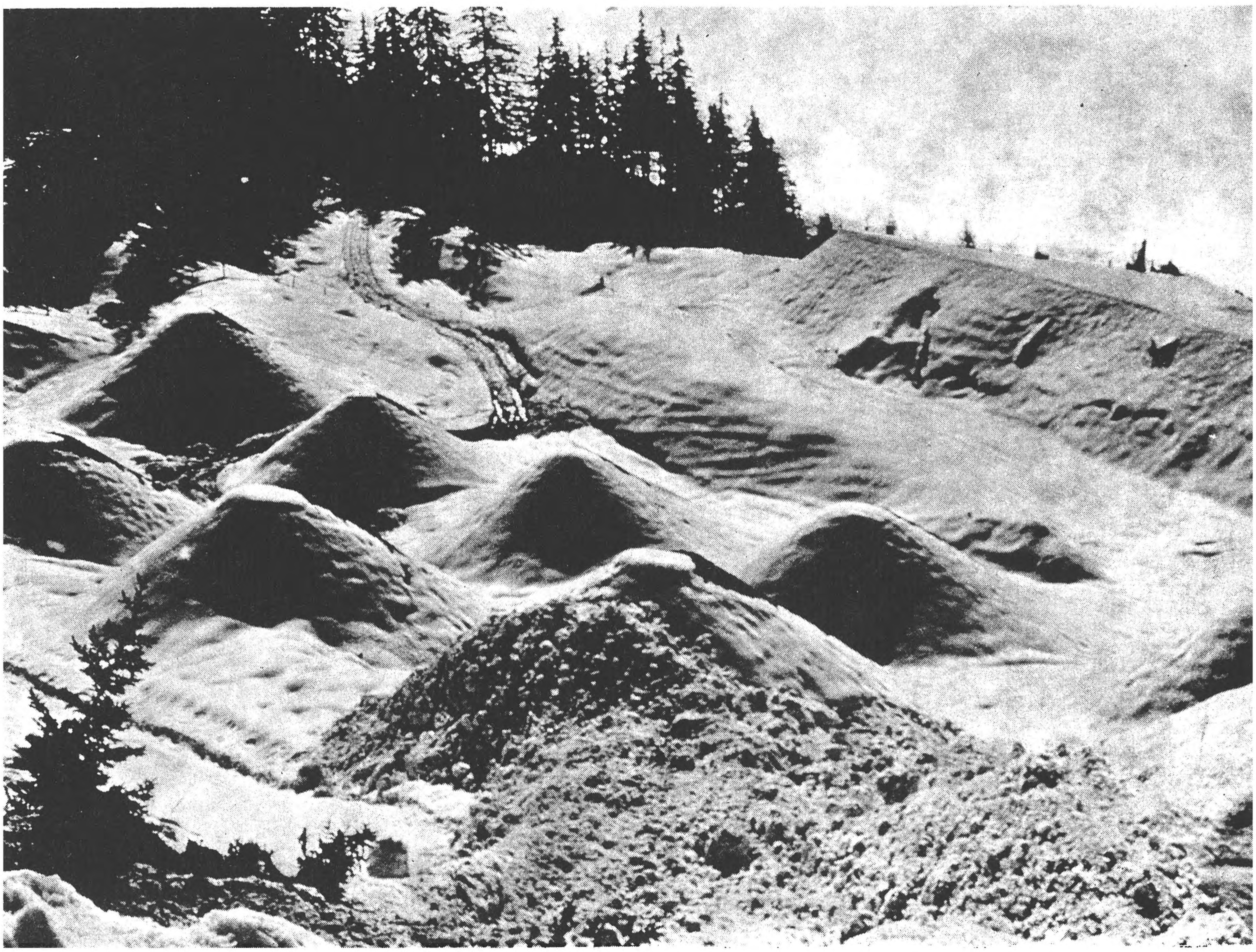
Size and cost: In Alpogli, the sizes of the 5.0-m-high mounds varied from 320 to 580 m^3, and this variation corresponded to the great effect of the slope inclination. On an average, the volume amounted to 427 m^3 and the mean cost per mound amounted to 2,067 francs.

Up to now, this project has proven itself, although on one occasion a powder avalanche traveled through it; in this case, nevertheless, there was a certain amount of retarding effect.

Another form of avalanche control structure is proposed by the VOBAG Company in Adliswil/ZH. The installations are designed for a load of 40 t/m^2 and slow avalanches by lateral deflection combined with a process of squeezing the snow masses between the open beams of the structure. Reinforced concrete is definitely weather resistant, but it is

Figure 2. Retarding structures "Alpogli," Brienzwiler (situation plan and photo W. Schwarz).





sensitive to shock and the stones and timber dragged along by avalanches constitute a great danger for this type of structure.

The effect of retarding structures upon powder avalanches has still been little investigated. In the case of this type of construction, model tests cannot be employed with the same possibilities of success as in the case of supporting structures. Observations of the various retarding structures will provide the best principles for future projects.

It is certainly true that not all possibilities for retarding structures have been exhausted. Depending upon the characteristics of the terrain, the slowing of the avalanche or the total dissipation of the avalanche energy can be transmitted to natural obstacles [sic]. This possibility is indicated by the example of the planned retarding structures in Reckingen; under the same favorable terrain conditions as those in Baechital/Reckingen, this possibility would surely be utilized elsewhere.

On the 24th of February 1970, a tremendous avalanche broke loose on the forward Galmihorn at about 3,300 m above sea level, and on the Hohen Gwaechte at 3,180 m above sea level. This avalanche claimed 30 lives in Reckingen at about 1,330 m above sea level and totally destroyed seven buildings.

For the immediate protection of the village of Reckingen and of the military facilities in Gluringen, there was created, in a first construction stage in 1970/71 a guidance channel about 530 m in length, having a mean height of 12.0 m and a width of 80 m. The calculations for the dimensioning of the guidance channel were provided by the Federal Institute for Snow and Avalanche Research, Weissfluhjoch/Davos. The deposited snow masses of the avalanche amounted to 280,000 m^3. The earth works of the dikes required 50,000 m^3 of earth at an expense of about 3.0 million francs.

In a second stage of construction, a road was built in the Baechital for carrying out the retarding project and in the starting zone of the Baechialp (not included in the retarding project). The length of the road was 12.5 km, the width up to the Baechital was 3.5 m, and from there into the starting zone it was 3.0 m. The cost thus far has amounted to 700,000 francs. In a third stage of construction, to be carried out in 1973/74, retarding structures are to be built in the Baechital against the avalanches from the Vordern and Galmihorn and the Hohen Gwaechte. Because of the high costs, supporting structures are acceptable neither on the Galmihorn, with a construction area of about 20 hectares, nor on the Hohen Gwaechte which has a construction area of 30 hectares. In addition, the soil conditions render an anchoring of the installations impossible (in part glaciers or rock debris and in addition much falling rock).

Planned retarding installations in the Baechital/Reckingen:

The avalanches from the steep slopes of the Vordern Galmihorn and of the Hohen Gwaechte encounter one another on a surface having an inclination of about 33^o and an elevation of about 2,300 m above sea level. Between 2,100 and 2,200 m the mean gradient is 15-17 percent and from there to 1,980 m above sea level it averages 22 percent. Below an elevation of 1,980 m the track again becomes somewhat steeper; the gradient amounts to about 35 percent. The inclination is not uniform; short steep portions are followed by flatter stretches.

From the junction of the avalanches at about 2,300 m above sea level down to the canton highway (residential region), the length of the track is 3.6 km with a mean inclination of 33 percent. The inclination conditions are therefore very favorable for retarding structures, particularly in the flat regions between 1,980 and 2,200 m above sea level. The calculations according to the formula

$$H_D \geqq \frac{v^2}{2g} + H_L + H_S$$

(compare B. Salm, Section 5.2) give a height of 28 m for an individual arresting structure at an elevation of 2,000 m above sea level. The compression force of the avalanches at this location amounts to 15 t/m^2, according to the formula

$$p_n \approx \frac{\gamma}{g} v^2$$

(compare M. de Quervain, Section 5).

The terrain which flattens locally to an inclination of about 15 percent in this region is probably very favorable. But an arresting dike with this computed height, having an uphill slope of 1:1 and a downhill slope of 4:5 requires a width at the foot of the dike (crown width of 2.5 m) of about 70 m. The volume of a single arresting dike with inclined base [Fallboden], would be too great and consequently uneconomical. After close study of the terrain, the retarding facility was planned as follows (preliminary project):

At an elevation of 2,200 m above sea level the flattening of the terrain (slope inclination 15-17 percent) permits the erection of a deflection dike which diverts the avalanche at a sharp angle toward the right flank of the valley. The height of the dike is planned to be from 10 to 12 m. As Figure 3 shows, the cliff rocks are best suited to the dissipation of the energy of the avalanche. This energy dissipation is therefore intended to be accomplished for the most part by natural obstructions -- projecting rocks and sharp notches. Since above these rocky walls no aggregations of snow are possible, no additional masses of snow are released by the diverted avalanches.

Below these rocky projections, at a distance of 350 to 400 m, retarding mounds are provided in the usual shape from 4 to 5 m in height, with giant blocks of rock forming a substantial constituent of the retarding facility. About 200 m below the mounds, at about 2,000 m above sea level, there is planned an arresting installation (inclined ground and arresting dike having an effective height of 12-15 m) in order to trap the portions of the avalanche overrunning the retarding structures. Despite the fact that this project with deflection dike, retarding mounds, and arresting installation requires smaller mass displacements than the facility involving a single arresting installation of 28-m height, its effect will probably suffice to stop avalanches before they reach the canton highway (residential region). The first observations of descending avalanches will show whether these assumptions are correct. The project is still not completely worked out; the probable costs, however, should not exceed 4 million francs.

In order to achieve an approximately equivalent protective effect for Reckingen as that provided for the planned retarding facility, supporting structures on the Hohen Gwaechte and on the Vordern Galmihorn, at a total area of 50 hectares, would require an expenditure of at least 25 million francs (50 hectares x 500,000 francs/hectare). In addition the protective effect of the supporting struc-

Figure 3. Planned retarding structures in Reckingen; deflection dike in the foreground right, left retarding mounds (photo J. P. Graf).

tures would be very dubious since even the greatest installations hitherto constructed would very probably be buried in snow, so that the danger for Reckingen and for the military facilities in Gluringen could not be satisfactorily reduced.

In the case of Reckingen, a retarding facility is distinctly safer and at the same time essentially more economical. With increasing mechanization and with the sharp increase in the cost of manual labor like that required for supporting structures, the price difference between this type of construction and retarding installations gets ever larger. In addition, personnel are becoming ever more difficult to obtain, especially for remote and climatically unfavorable regions. The reasons for this are generally familiar.

Hence, for new construction projects, all possible methods of protection against avalanches should be thoroughly examined and one should not only look for a solution -- although tried and true -- by means of a modern avalanche structure in the starting zone.

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XII. EVOLUTION OF AN AVALANCHE STRUCTURAL CONTROL AND AFFORESTATION PROJECT

(Alexi Sialm, Disentis)

1. Retrospect

After the devastating avalanche winter of 1951 which cost the lives of 96 people and caused damage to forest and fields, to buildings, and traffic arteries running into the millions, officials and forestry people turned with a will to the planning and realization of avalanche protective measures. A large number of completed projects testifies to the extraordinary efforts of the last decades. The struggle with the forces of nature is, however, a permanent struggle. Therefore, it is also not remarkable that today there are still numerous structural control projects awaiting realization. In this connection, it should be emphasized that modern man manifests an increased need for safety in all departments of life. The consistent expansion of all forms of social insurance and the demand for public pension systems are testimony of this. In mountain communities, this need expresses itself further in the desire for increased security in the home, on the road, and by rail. But protection against the forces of nature also corresponds to a modern conception of economic development which aims at regionalization and centralization.

2. The First Steps

The first steps toward clarification of an avalanche structural control project are normally undertaken by community officials together with forestry organizations. Frequently a common reconnaissance takes place in which general technical, legal, and economic aspects of the prospective undertaking are discussed. As a result of these joint conversations, a general preliminary project is submitted by the district forestry office to the cantonal forestry office and the Federal Forest Inspectorate (OFI). On the basis of this general preliminary project, which contains only summary data regarding the purpose of the project, the installation to be provided, the anticipated operations schematically diagrammed in plan view, and the approximate prospective costs, there is then a review on the part of the federal and cantonal forestry organizations in conjunction with the representatives of the Board of Works. The most important result of this review is the decision as to whether the proposed project can be undertaken by the Federal Government and the canton or not. Further, it is determined on the basis of this reconnaissance whether the building project should be immediately planned as an urgent program and subsequently carried out or whether it should be postponed for some weighty reasons. Naturally, there is also a discussion of technical questions with regard to the building project and the building performance. In many cases, also as a result of this review, the Federal Institute for Snow and Avalanche Research, Davos/Weissfluhjoch (EISLF) is commissioned to provide a professional opinion. On the basis of all these discussions as well as of any possible professional opinion from the EISLF, a final project is worked out in accordance with the "Specifications of the Federal Department of the Interior for Forest Projects and Their Support by the Federal Government." For avalanche structural control and afforestation projects of great magnitude whose performance extends over a long period of time, it suffices at this point to work out a general overall project. In such cases, detailed projects must be set up within the framework of the overall project; these detailed projects must be approved by the OFI before the beginning of construction. The final project (for the formulation of which various further discussions with the cantonal forestry office and with the OFI with regard to financial and technical detailed questions may still be necessary depending upon the importance and the financial and architectural extent of the project) is submitted, after its final review, to the cantonal and federal subsidizing officials for approval and assurance of subsidies.

3. Technical and Economic Prerequisites

A prerequisite for the planning of any type of structural control is danger to a locality, a road, a railroad line, or the restoration of endangered protective forests. With regard to the various possible methods of structural avalanche control, we refer the reader to the article by Hans Oppliger on avalanche protective measures in this same publication.

Theoretically, it is possible to deal with almost any danger by means of some measure or combination of measures. Various types of construction, depending upon the topography and situation of the objects to be protected, are, however, associated with different costs. An economic weighing is therefore of decisive importance. Nevertheless, the economic point of view ought not be the only decisive factor. At the center of all considerations is man, his security, his endangered environment. Thus, economic considerations should only play a role in the evaluation of measures which are of equal value but different in cost. In this connection, it is worthy of mention that resettlements in the sense of dislocations of entire villages or parts of villages have, up to now, never been carried out. The residential uprooting associated with such resettlement can hardly be sponsored today with public resources. But the situation is somewhat different in the case of a resettlement of individual houses within the same settlement area.

In any project, attention must be given to the following considerations: deflecting structures and galleries represent direct methods of protecting an object. But such measures often lack total-economic and total-planning aspects. As a rule, they only protect individual objects. With structures in the starting zone of the avalanches in combination with afforestations, one usually achieves an integral improvement, in contrast to measures that directly protect objects. The former measures guarantee desirable avalanche protection, contribute to the growth of forests, to improved yields and to the acquisition of recreation space while at the same time often meeting the needs of landscape protection. Some projects and professional opinions in recent years have demonstrated that in various places supporting structures together with afforestations are able to sustain a cost comparison with galleries and deflection constructions. But from the total economic point of view, the former are also interesting because the starting zones and afforestation areas are in general made accessible by means of a road network which as a rule leads from settlements in the valley far up into the control area. Thus, frequently both agriculturally important and forest regions are made accessible and more easily reached by the general public.

Undoubtedly, construction and afforestation projects, in addition to their primary tasks of protection and safety, also result in secondary accomplishments such as opening up and creating additional recreation regions. In the Swiss midlands, the communities often encounter great difficulties in the procurement of land for public purposes. Therefore, whenever in mountain cantons new land areas can be acquired thanks to avalanche control and afforestation projects, this can only be an advantage. The flat country and the mountain cantons today more than ever form a common working, free-time, and recreation unit. In this sense it should not be too difficult to promote avalanche construction projects and afforestation projects also from the aspect of space planning.

4. Legal Principles

The legal prerequisites to financial support of structural avalanche protection measures on the part of the Federal Government are described in essence in articles 37, 37bis [second part of article 37], and 42 of the "Federal Law Respecting the Federal Supervision of Forest Police." It may be asserted that this federal law in great measure promotes avalanche safety measures and thereby to a remarkable degree contributes to the total economic benefit of our mountain communities. In addition, we refer the reader to the discussion, by W. Bauer, of federal subsidizing procedures in this same number.

5. Various Phases of Planning and Their Time Requirements

It may be of interest to laymen to get some idea of the course of an avalanche construction project and afforestation project from the time of the first reconnaissance until the first spadeful of earth [is turned]. The complexity of avalanche construction projects excludes simple schemes and cheap household recipes. It should also be evident that a small and simple project can be set up in a relatively short time and normally will not require more than about 1 year while, on the other hand, a larger more complicated project requires more time expenditure for planning and execution.

In the planning, one distinguishes the following phases:

a. the general preliminary project -- preliminary examination;

b. final project -- first spadeful of earth.

5.1 General Preliminary Project -- Preliminary Examination

As has already been mentioned at the outset, each construction project must be announced to the OFI in the form of a general preliminary project. This very concise preliminary project, for which no detailed field operations are yet necessary, forms a first foundation for the review which must be carried out. Since avalanche construction projects by their nature are usually very urgent, the preliminary examination as a rule also takes place very soon after submission of the general preliminary project. To the extent that it is not only forest interests which are involved, which is very often the case, representatives of other professional services of the Federal Government and of the canton who might be interested in the project are invited to the preliminary examination if this invitation seems necessary. The review in the terrain itself serves for a preliminary clarification of the entire project and provides the foundation for further detailed project work.

5.2 Final Project -- First Spadeful of Earth

On the basis of the discussions occasioned by the previously mentioned review, work now begins on the final project. This will in itself be a detailed project when the building project is of small extent and of short duration. When the building operations are of great extent and of long duration in performance, this can be a general project which will be followed, after its approval, by the corresponding partial detailed projects. But even the general project must concern itself very particularly with details regarding the nature and manner of the construction, of the types of structure to be provided, the extent of the structural installations, of the nature of the access provided, and of the construction transport to be employed, etc. Here the thorough and comprehensive processing of the project in the field and in the office begins.

Since the planning of supporting structures in the starting zone on the one hand requires operations in the field, on the drawing board, and at the computer and, on the other hand, presupposes an observation of the avalanche slope over a number of years, the working out of a project is accompanied by certain difficulties. In this connection, it should be mentioned that many district and regional forest officers since the avalanche winter of 1951 have collected very valuable documentary material which contributes substantially to the solution of avalanche engineering problems in a reasonable length of time.

The procurement of cartographic documentation is rather time consuming. In our mountain communities, we must often be happy when a survey plan is available to a scale 1:10,000. This permits a rough preliminary clarification but no more. To the extent that no better documentation is available from other sources, one is compelled to set up plane-table surveys of the construction region or, when recent aerial photographs exist, to have these cartographically evaluated to the desired scale. Recently, the orthophoto plan [aerial photos with the scale corrected for slope] has offered us a very valuable aid for the layout.

For each construction project, snow observations are an indispensable foundation. Unfortunately they are often not available, so that one must get along with assumptions, which perhaps it may be possible to supplement somewhat with observations of neighboring regions. Therefore, it is indispensable, from the moment of commitment to avalanche construction, to carry out observations in the construction region. In most cases, one thereby obtains, prior to the beginning of the actual construction operations, some documentation which is valuable for the detailed design. Naturally these observations must continue to be carried out during the entire construction time and also later. To the extent that it appears necessary, a professional opinion of the specialists of the EISLF can be obtained. In the case of large projects, this professional opinion is as a rule requested by the OFI.

A point which can entail unpleasant delays is the acquisition of land. To the extent that the construction region involves public ground, this is a simple matter. It becomes more difficult and time-consuming whenever private land must be obtained, especially in the case when a satisfactory agreement is not reached and steps must be taken toward expropriation.

In many cases, the design of the final project is distributed among the cantonal forestry offices and the OFI for comment in order that possible suggestions and criticisms may be taken into account. After cleaning up all still open questions, the project can be submitted to the Federal Government and the canton for subsidizing and this as a rule does not require too long a wait, and thereafter work can begin on the construction. In very urgent cases it is even possible, prior to the approval of the subsidizing authorities, to obtain a preliminary construction permit in order that the project operations can be commenced without delay.

From the preceding, it is not difficult to see that it is hardly possible to provide binding data regarding the time consumption of an avalanche structural control and afforestation project from the moment of the preliminary examination to the first spadeful of earth. In the most favorable case, this may be 1 to 2 years, but under more difficult circumstances, it can be many times that.

6. Project Documentation

In accordance with the "Specifications for Forestry Projects and Their Support on the Part of the Federal Government" dated 1 September 1961, for each project at least the following documentation must be supplied:

a. A technical report,

b. A preliminary cost estimate,

c. Plans, profiles, standards,

d. Aerial photographs, photo documentation,

e. Construction statement.

The aggregate of all project documents serve not only to produce subsidy assurances on the part of the Federal Government and the canton, but rather they represent for the project planner, the forest engineer supervising the construction, and in particular, the community officials a comprehensive presentation of all questions relating to the project. They represent a well-thought-out basic conception which is designed to eliminate incorrect investments and incorrect planning. The following table of contents of the technical report of an avalanche and afforestation project gives an insight into such a documentation.

"Crap-Stagias" Avalanche Structural Control and Afforestation Project

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11. Project Execution and Building Supervision
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Graphics

Average Precipitation 1936-45
T [temperature] Monthly Average 1864-1900
Scheduling Plan and Financial Requirements, 1971-1982-1995
Form A (Technical Data)
Form B (Cost Estimate)

In many construction projects millions of francs are involved. Even when large contributions have been provided by the Federal Government and by the canton, the annual allotments of what are often hundreds of thousands of francs represent no small financial burden for the Board of Works. Therefore, it is necessary to work out with each project a so-called scheduling and financial requirement plan (Table 1). This is intended to facilitate the overall financial planning of the community. It is also desirable, especially when one is operating under a master plan, to set up appropriate network plans. These constitute a great organizational aid.

We refer the reader to the discussion by F. Pfister of operations engineering aspects of avalanche construction, in this publication.

From what has been mentioned above, it is evident that the project papers which have been described constitute a comprehensive documentation and source of information which, together with the financial requirement plan, scheduling plan, and possibly also with the network plan permit the subsidizing authorities, the construction supervising forest engineer, and in particular also our precinct officials to have a complete insight into the entire complex of questions relating to the construction project.

7. Project Execution and Project Duration

The specifications, already mentioned, for forest projects and their support by the Federal Government prescribe that the construction supervising forest engineer shall annually submit a construction program to the OFI. The partial detailed projects which follow up the general construction project are a constituent of this construction program. To the extent that the Board of Works does not encounter any special circumstances such as a labor shortage, financial difficulties, and so on, the annual construction program is in substantial agreement with the long-term scheduling and financing plan.

An avalanche construction project and afforestation project usually include a great number of operations such as control structures, afforestations, drainage operations, construction of access roads, protection of the afforestation from grazing and wild animals, etc. It is only rarely possible to carry out all these operations simultaneously, more commonly the work scheduling requires, as shown clearly in the attached scheduling plan (Table 1), that the timing be staggered. In addition, owing to the weather conditions at these high elevations there is a short annual work period of scarcely more than 100 days in summer. The relatively small volume of work possible under these circumstances, particularly in the case of large projects, compels one to accept a long overall project time. Particularly with afforestation, one must reckon with very long periods of time. It is well known that afforestations in the region of the upper tree line are associated with very great difficulties.

In view of all these difficulties in the construction process, for the practical execution of an avalanche construction project and afforestation project one must count on long time intervals. In the best case such a project, if it is of small extent, can be realized in about 8 to 10 years. But large, difficult construction and afforestation projects can require decades.

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Table 1. "Crap-Stagias" Avalanche Structural Control and Afforestation Project, Scheduling and Financial Requirement Plan 1971-1982-1995 [In 1,000's of Swiss Francs]

Designation of Operations	Total Amount	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983-1995	Contingency
Forest Plantings	280	1	5	5	10	20	20	20	20	20	20	20	20	99	
Avalanche Structures:															
Permanent	3072					400	450	500	550	600	572				
Temporary	1107	70	40	10				100	50	50	50	200	250	287	
Access:															
Roads	1065	250	280	280	255										
Patrol Paths	45	5	5		10	10	15								
Grazing Protection	19.5		5	1	1	1	.5	.5	.5	.5	.5	.5	.5	8	
Land Purchase	10		10												
Miscellaneous (Hut = H)	434.2	90	44.2	15	H80	20	20	20	20	20	20	15	15	55	
Contingency	467.3														467.3
Annual Financial Requirement		416	389.2	311	356	451	505.5	640.5	640.5	690.5	662.5	235.5	285.5	449	467.3
Total Financial Requirement	6500														

XIII. MANAGEMENT ASPECTS OF AVALANCHE CONSTRUCTION PROJECTS

(F. Pfister, Brigels)

1. Managerial Development

It may be generally asserted that the treatment of managerial problems lagged behind the technical development which has been described. To be sure, in various articles, attention has been drawn to the unavoidable necessity of taking economic principles into account in solving technical problems. Under the impression that avalanche construction projects must necessarily be erected at the cost of great financial sacrifices, nevertheless an attempt was made in this area of the construction process to keep techniques of organization and rationalization in the background.

Nevertheless, it should also be noted that the theory of construction management has only recently been accorded the significance it merits. It is precisely in the building trade that utilization of managerial knowledge is especially important. Both of these statements are based upon the special characteristics of the building trade as they have been described by Soeser [7]. Special features, such as single part production, contractual production, and building site production, more closely described by Beste [1], must be given special attention in avalanche construction. But it is a mistake to oppose managerial studies out of a fear of the effects which have been mentioned. In recent years, the consequences of these negligences have begun to show themselves. Because of the special situation in the building market, there has often been no relation between the offers and the primary costs. There were extreme differences between the bids. In the absence of the necessary documentation, the building administrators could evaluate the price development only with increasing uncertainty.

Hence, it becomes urgently necessary to deal with the following man-problems, listed in a concise form:

a. effective cost surveillance by means of a practical auditing system;

b. the effect of construction features, weather, operational structure, and other factors influencing cost;

c. effect of the timing and planning configuration of a project upon its cost;

d. efforts to introduce efficiency into the engineering process.

Under the guidance of Prof. Dr. H. Tromp and the vigorous cooperation of the "Working Group for Avalanche Construction" I had an opportunity to investigate some of these problems [5]. This experience has given rise to proposals for the improvement of planning, performance, and surveillance of avalanche construction projects, which will be briefly described and supported in what follows.

2. Critical Consideration of the Existing Auditing Procedure

The principles of cost accounting are outlined by Fein [4] as follows: "Cost accounting has the task of determining costs correctly and completely and of distributing them. Only in this way can the two tasks of uncovering sources of loss and of correctly pricing individual products be accomplished." From this there arises the possibility of estimating, in the preliminary cost accounting, the prospective costs for a particular product and of checking and correcting this estimate in the later cost accounting. In the management of avalanche construction projects, it will be possible to take into account all the conditions which have been mentioned only when the building operations are conducted under in-house control and -- with limitations -- when they are conducted under the control of an entrepreneur. The performance of the project is usually let out under contract so that the accounting can be carried out only with respect to amounts of performance and prices bid. But if one desires to know not only which expenditures have vouchers to cover them but also to have information regarding the economics of the activity, then in addition there must be an operating cost statement.

The auditing procedure desired by the Federal Government does not provide any systematic division into types of cost and departmental costs. The auditing specifications prescribe a division in terms of the varieties of work (Form B), but these are inadequately described and unequally applied. Since, therefore, it is scarcely possible to distribute the costs, according to the cost-origin principle, precisely over the performances of the operation, preliminary cost accounting and later cost accounting become unrealistic. This finally led to the uncertainty in evaluating offers mentioned at the outset, while at the same time it was no longer possible to check the justification associated with demands for particular performance achievements.

From the preceding consideration, it follows that it is a central problem of cost studies to work out an effective auditing method. In addition, the operating cost statement, built upon the three levels of cost type auditing, departmental cost auditing, and cost carrier auditing, must be designed while taking into consideration various types of performance, modes of construction, work systems, etc.

But in order to be able to assign as many direct and indirect costs as possible to parts of the operation which are delimitable organizationally, operationally, and cost-wise, the operations of an avalanche construction project were contracted out for 3 years to the control of an entrepreneur. It was possible to supplement and solidify the evaluations of these latter operations, in the mentioned investigation, by means of additional data collected in six other projects in the cantons of Uri, Bern, Graubuenden, and Tessin.

In order to determine the various cost types according to cost department, it was necessary to construct a well functioning reporting system. Corresponding to the significance which is attributed to the determination of costs and performances, in the following section there will be an account of the problems connected with this process and of the routes which have been taken toward solving these problems.

3. Reporting System for Determining Costs and Performance

The reporting system is intended to make it possible to survey the building process, to carry out control checks, and to make necessary decisions. In addition, most of the data serve the purpose of auditing with respect to all personnel and levels of authority participating in the construction. For the solution of these problems, the reporting system must supply the necessary information regarding initiation of operations, consumption of operating resources and of raw materials as well as the job progress. If one is not to have merely a few randomly jotted pieces of data, but if instead all statistics are to be true, meaningful, and unambiguous, then it is specially important to limit the scope of the questions while outlining the questions exactly. In constructing a report procedure which can satisfy the enumerated requirements, special attention should be given to the aid called "Construction Operations Key" (abbreviated in the following as BAS).

The BAS is nothing but a list of all existing construction operations. Up until the present, construction operations have been predominantly subdivided from the point of view of performance. The various performance lists concern themselves with individual contracts and products which are subdivided by positions in program execution segments. The subdivision is thereby adapted to the requirements of the contract consignor so that the same operations appear under different position numbers and ordinal designations.

Instead, the BAS bills on the basis of a subdivision of operations. This gives rise to a constant system of subdivision for the purpose of the operating cost statement, cost accounting, and especially for planning and organization. This can be adapted to the various conditions and types of contract in other projects without thereby abandoning the possibility of inter-operational comparisons. If descriptive documentation and performance measurement are also arranged in accordance with the BAS, then a system is created which will give the construction supervisors all necessary documentation for carrying out their managerial tasks.

Every type of operation in the BAS receives a number which is constructed in accordance with a decimal classification system. In the appendix to my dissertation [5], the BAS, set up for the studies which have been mentioned, is reproduced together with precise description and delimitation of the individual components. The sequential order and grouping have been adapted to the development of the auditing procedure and the requirements of network planning technology.

4. Operating Cost Statement

The operating cost statement is carried out tabularly on operating cost statement sheets for which, in general, the abbreviation BAB is employed.

Its principal purpose is to derive the differentiated additional payment and additional charge figures for cost accounting. Here it must be assumed that, by means of this cost accounting, a double object is pursued: On the one hand it is intended that by means of the cost carrier auditing (under the condition of a correct and complete cost determination and cost assessment) there should be a cost accounting of the costs per performance unit for erecting the installations, separated with respect to systems. On the other hand, the departmental costs should be delimited in such a way that for checking and evaluating the bids it will be possible to compare subsequently cost accounted cost values corresponding to the unit prices.

4.1 Cost Type Auditing

In cost type auditing, all costs of the operation are collected. In contrast to subsidy accounting, the costs for preliminary operations in completed or subsequent building programs are to be included and excluded respectively. The corrected costs to be charged are charged immediately to the cost carriers as direct costs or included as indirect costs in the auxiliary cost and principal cost locations which in turn are passed on to the cost carrier, if possible without keying (which guarantees only an approximately correct distribution). This principle can be extensively followed with the aid of the BAS and the rule that all overhead cost vouchers should be immediately accounted with the originating cost department.

In the previously mentioned investigation, the cost types have been grouped under the following generally valid concepts: material costs, equipment costs, rent costs, personnel costs, foreign costs, write-offs, repair and maintenance costs, and other expenses. For a discussion of the individual cost types and their evaluation in special auditings, the reader is referred to the literature [5].

4.2 Cost Department Auditing

A subdivision of the operation into components which represent only locally or functionally delimited areas does not satisfy the requirements of cost department auditing. These requirements consist, among others, of acquiring documentation for the evaluation of bids. In order to be able to compute the unit costs for performances of similar type, the costs should be combined together in operationally significant areas from the point of view of accounting technique.

The auxiliary cost has been separated from the principal costs which have been subdivided into the two production stages: installation substructure and installation superstructure. This is because the auxiliary costs contribute only indirectly to formation of the cost carriers.

The question of the distinction of cost types and the possibility of their being distributed over cost departments played an important role in setting up the cost departments. We have already referred to the decisive function of the BAS in this connection. Despite the close relationship between BAS and the cost department list, these two concepts are, however, not to be equated. The BAS goes further in the direction of subdivision on the basis of additionally required data for cost accounting, operations studies, organization planning, and interpretation of results than does the cost department list which primarily divides the total performance into subperformances. Different positions of the BAS have therefore been combined for the cost department auditing. In contrast to the BAS which creates only a distribution basis for operation-referred costs, the cost departments include all cost types.

4.3 Cost Carrier Auditing

The overall accounting of the performances accomplished in a period, divided according to cost carrier groups, is accomplished in cost carrier auditing. By means of it, it is possible to calculate the costs per unit, i.e., carry out the cost accounting. Additional charge, assessment, and additional auditing of the cost departments are connected with the cost accounting. Here all the procedures are used which will be briefly described in the following:

Division cost accounting is applied in the case when a uniform type of performance is set up. Although in an avalanche construction project many different types of installations are erected, it was not possible to take these differences into account in the first investigations. The cost sets for the cost carriers were obtained by division of the sum -- formed from the direct costs and all additional charges -- by the corresponding summed installation lengths. By the same method, all unit costs were calculated for those component performances which were delimited in terms of cost departments. The division cost accounting is preceded by the assessment of the cost departments. This takes place predominantly in the form of an additional charge upon the direct costs, in other words from the point of view of additional charge cost accounting.

The assessment of the cost departments can, however, in individual cases also be carried out by means of key quantities and follow the principles of equivalence-figure cost accounting.

5. The Results of Collecting Cost Statistics

The accounting carried out according to the preceding principles during the several years of investigation in various construction projects produced the following highly compressed results:

Among the cost type groups, personnel costs constitute by far the greatest portion, with over half the total cost sum. Avalanche construction projects are still very work-intensive in comparison with other construction operations. The portion of the cost sum consisting of material costs still clearly lies below that of the personnel costs despite repeated use of prefabricated elements.

With respect to cost departments, almost half of all costs must be assigned to the substructure, where in particular excavation and concrete pouring of the foundations were of decisive significance.

The cost accounting of the unit costs for the suboperations included in the cost departments forms the basis of auditing the price offerings made by the entrepreneurs and for bid evaluation on the part of the construction administrators. The basis of this cost accounting consists of the measurable units of performance which are accomplished in the individual departments. The costs calculated for these units in the BAB are composed on the one hand of the cost types which are included in the cost departments, and on the other hand of the assessed costs of various auxiliary departments.

The assessment must be regulated in accordance with the construction site organization and is to be adapted to the account documentation. By means of the investigation, it was possible to derive the empirical figures for the additional charges to the department costs associated with the various component operations.

The results are based only upon cost statistics in individual projects. Nevertheless, it was possible to establish that the relative shares of cost types and of auxiliary cost department additional charges are only slightly influenced by the various conditions and project circumstances.

The situation is different for the absolute values of the unit costs, whose dependence upon the building market, upon the state of employment, upon the size of the operation, and upon the building program must be taken into account.

As an essential result of cost statistics gathering, the significance of personnel costs has been emphasized. In comparison to the significance of operation-referred productivity, the effect of the uncertainty factors which have been enumerated is slight. Therefore, by means of an additional determination of work times in six other constructions, there has been derived the documentation for inter-operational comparisons of work-referred productivity. This also provided data regarding the effect of the most important operational conditions upon the cost configuration. These conditions may be subdivided by combining effects in the domain of operational quantities (for example, of factor quality, of factor prices, et al), the domain of the peculiar characteristics of the object constructed (local transport and building site transport, degree of difficulty, structural features, etc.), and into the domain of production sequencing. Out of this multiplicity of influences the peculiarities of the building sites which are significant for the cost configuration are selected and in particular the cost functional-dependencies of various building features are analyzed.

With these general indications of the important relationships existing between working time expenditures and construction features, it was necessary to close the investigations of cost effects. It is true that still further effects are influential in determining the construction price and the construction costs. But they are of variable significance in the different building sites and must be investigated from case to case by means of further analyses. With the restrictions which have been mentioned, the effects of the most important operational conditions upon the cost configuration of a project can be inferred from the cost statistics which have been gathered. The additional time measurements in the domain of work-referred production furnish guiding values for adapting and transferring the results to other construction objects, while taking into account the special peculiarities of the building sites. These then are the principles of a minimal cost auditing which can in practice be carried out without great additional expense.

6. Cost Functions

Attention has been drawn to the problems associated with the cost accounting and the legally prescribed cost surveillance of avalanche construction projects. By means of detailed investigations of several building programs in one project and of additional installations in other projects, possibilities have been uncovered for improving the cost accounting. The developed cost accounting system can be introduced not only in a particular project but by adaptation to conditions of various sorts can also be introduced into other projects. In the event that the system is interpolated into the bookkeeping of construction enterprises this should give rise to no problems. But for lack of time and assistant personnel the construction administrators will usually find it impossible to carry out completely comprehensive analyses, in the manner shown, for the individual building programs.

If ever the cost influences of the specific circumstances of an avalanche construction project are investigated in their details, it will subsequently suffice for the construction administrators to know, for the purpose of cost surveillance, the most important cost functions and hence the order of magnitude of the building prices with reference to the principle of reasonableness [or "principle of suitability"]. The development of the cost functions and their significance for cost surveillance is described in what follows by means of an example and thereby simultaneously a proposal for a minimal cost accounting is described.

Cost accounting, account documentation, performance determination, and accounting are constructed in accordance with the operation divisions of the BAS. Thereby the auditing documentation is at the same time subdivided from the point of view of cost department divisions and cost carrier divisions. In order to set up the preliminary cost estimate and to evaluate submitted offers, therefore the cost department unit costs are calculated in a first step. As follows from the results, in this connection, of the investigations which have been mentioned, the unit costs are composed for the most part of the principal costs collected from the cost types and of an additional charge to the assessed auxiliary costs. The general observations implied by the results may be summarized as follows:

a. The share of the total department costs which consist of personnel costs is extraordinarily high and amounts on the average to about 50 percent.

b. Taking into account effects of various construction features, the ratio between the share consisting of personnel costs and the shares of the remaining types of cost to the department costs for all building programs and building segments displays a clear constancy.

c. If one evaluates the ratio of the auxiliary costs department additional charges to the department costs then these ratios are found to deviate little from one another in the 3 years of the investigation.

Taking these facts as a basis, cost functions can be constructed for the purpose of calculating cost department unit costs. Here the personnel costs form the reference magnitude for which one must make use of the work coefficients which are determinative in the calculation of such personnel costs. In the ratio to the personnel costs, the remaining cost types are added and in this way the direct department costs are obtained. In order to derive the total departmental unit costs, finally the auxiliary department costs are added to fixed percentages.

The minimal cost accounting described may now be explained by means of the example of the foundation excavation operations and assembly operations (price base 1965/66).

a. Foundation excavation

On the basis of preliminary investigations a rock quota of 70 percent is assumed for the calculation.

The investigation gives for the excavation work coefficients of 2.8-4.3 hours/m^3 (earth excavation and rock excavation). If one takes the ratio of these values to the rock quota, then a guiding value of 4.2 hours/m^3 may be derived from the results. Under the assumption of a factor price of 9.0 Fr/hr one gets from this personnel costs of 37.80 Fr/m^3. For the component performance considered, the personnel costs amount to about 75 percent of the total departmental costs. In order to obtain the latter, therefore, 20 percent equipment costs (i.e., 26.6 percent of the personnel costs = 10.05 Fr/m^3) and 5 percent material costs (i.e., 6.7 percent of the personnel costs = 2.55 Fr/m^3) must be added on. To the calculated direct department costs of 50.40 Fr/m^3 there are added, on the basis of empirical values 3 percent for the personnel staffing and 7 percent for the general building site equipment -- in other words, a total of 10 percent of the department costs. The unit costs for the foundation excavation thus amounts to 55.45 Fr/m^3 (earth excavation and rock excavation).

b. Assembly installations system A, B, and C

Similarly to the auditing process described under a, in the following table there are collected the cost functions employed for the calculation of the unit costs for these component operations:

Table for Calculating the Assembly Unit Costs From Cost Functions

Installation System	A	B	C
Work coefficient (AK) assembly	1.90	5.60	2.30
AK hand transport (mean distance 70 m)	1.90	2.20	1.10
Total AK (hr/m')	3.00	7.80	3.40
Rate (Fr/hr)	10.00	10.20	10.10
Personnel Costs (Fr)	30.00	79.60	34.35

Personnel costs in percent of the department costs (according to experience obtained in the investigations)	96.00%	89.00%	98.00%
Equipment costs corresponding to the preceding	4.00%	11.00%	2.00%
Department costs 100%=	31.25	89.45	35.15
Additional charges in accordance with the investigation results			
Personnel quota in percent of the department costs	3.00%	3.00%	3.00%
General building site equipment in percent of department costs	10.00%	10.00%	10.00%
Cable transport (main funicular 280 m, auxiliary funicular 150 m)	25.00%	10.00%	24.00%
Total additional charges in percent of the department costs	38.00%	23.00%	37.00%
In Fr/m'	11.90	20.60	13.00
Unit costs for assembly in Fr/m'	43.15	110.05	48.15

If, in analogy to the two examples, the unit costs are derived for all cost departments, then building upon this and adding the direct costs one can calculate the cost carrier unit costs. Needless to say, the values obtained by means of drastically simplifying assumptions only produce assertions about the order of magnitude of the unit costs to be expected and the minimal cost auditing merely constitutes an accessible route for the preliminary cost accounting. Even if the work coefficients can be rather accurately estimated by the construction administrators, still the assumptions with regard to factor prices, which are based upon average administrative salary rates, contain errors. They will deviate from the prices set by the entrepreneurs, depending upon the situation on the construction market, the composition of the labor force and various operational quantities.

Despite these reservations, the guide values derived by means of minimal cost accounting will be sufficient to allow the construction administrators to solve the problems of cost surveillance. At least it limits the uncertainty in judging the bids of entrepreneurs.

If gaps appear in the empirical values during calculation of the unit costs, then these gaps must also be filled by means of estimates, at the same time taking special conditions into account. To the extent that the same system of subdivisions from the BAS is employed for cost accounting the different construction operations, the missing data can be found by detailed investigations in suitable projects, combined with interoperational comparisons.

This also brings out the possibility of continuously checking all values relevant to the cost functions and the possibility of completing them and thereby taking into account technical development, in the course of carrying out construction operations.

7. Methods for Improving Efficiency

7.1 Work Studies

Cost statistics and cost analyses, supplemented by additional time measurements, produce important information with regard to possible methods of improving efficiency. Empirical results are obtained which suggest the areas in which improvements are to be sought. In addition, it is possible to estimate the effect of efforts to improve efficiency upon a general reduction of cost and from this to infer degrees of urgency for the measures to be taken. Since the problems in individual operations are quite different from one another, the emphasis will be placed upon explaining the methods of investigation. It must be left to the practitioner to determine, in analogy to the examples described, the best sequencing of work processes of another type.

7.2 Transportation Study

The principles governing work sequencing and time studies may be followed by some remarks regarding the informational value of work studies bearing upon considerations of economy and of procedure comparisons based upon a transportation study. The transportation of elements, building materials, and auxiliary building materials can be subdivided into transportation up to the project area and transportation within the building site. The building sites are divided into zones for the transportation studies. The problem is to find the most favorable combination of the various means of transportation for delivery to the building site and transportation within the building site within these transportation zones when the zones have been formed on the basis of building program delimitations, terrain configuration, and the computed cost rates. With the aid of computation formulas developed for this purpose, cost comparisons of various variants are carried out. Thus for example, the results can indicate those points up to which access by means of roads becomes optimal.

7.3 Machine Use

In searching for substitutable production devices (compare Burkhardt [3]) for the purpose of improving the efficiency of the construction operations by the use of machines, one must primarily give consideration to the production locations which are work intensive and which give rise to high costs. Among these must be counted the excavation of terraces, excavation of foundations, concrete pouring, and assembly work, since in these cost departments altogether 47 to 56 percent of the total cost is contained. This cost consists predominantly of personnel costs.

In connection with efforts to replace concrete foundations with ready-made foundations (where it must be borne in mind that for the prefabricated anchoring elements larger foundation holes must be excavated) there arises, first of all, the necessity of using a construction excavator [dredger]. An excavator, in accordance with the general requirements set for all construction devices, must be universally usable and hence capable of loosening and displacing rock and stone material just as easily as gravel or sand. Simultaneously, however, it should also allow a more efficient introduction of fresh concrete and of the building elements. In addition to these principles, the excavator must satisfy additional requirements which result from the special conditions surrounding avalanche construction building sites. Here we refer to the conditions which require moving up on narrow project access roads, which require mobility over the terrain and good stability on steep slopes. During the 1968 investigations, it was possible in two avalanche projects to employ an excavator which, with few exceptions, met the mentioned requirements.

The employment of an excavator results in a clear organizational structure in the work performance in addition to the proven cost savings. This makes it possible to employ the workers in accord with their capabilities and to shape the sequence of operations according to a logical plan. The advantages associated with this lead to further cost savings which, however, cannot be separately evaluated. The success of excavator use in two building sites, which previously had exhibited difficult building conditions, permits us to assert finally that there exist possibilities for improving efficiency by increased use of machines also in other projects which do not include especially rocky building ground.

8. Project Organization

In the book Project Organization With Network Planning Technique in Building Above Ground and Below Ground, Brandenberger and Ruosch [2] assert that in the field of construction in recent years great efforts have been made to improve the efficiency of engineering operations and to create aids for a comprehensive project organization. The authors see possibilities of obtaining further improvements in a project organization system with the aid of network planning technique. Here the principal task is to create an integrated system, building upon this technique, by the use of already existing subsystems (accounting methods with certain coded account numbers, survey programs, and accounting programs for the creation of submitted bid documentation and comparison of offers, et al.).

Also in avalanche construction projects the cost of planning and surveillance have increased markedly in significance. The ever more complicated processes of an economic and technical nature which must be exactly understood in a reliably conducted operation demand a suitable planning method. This method must meet the demands for a greater flexibility and an increased informational value in planning without at the same time overburdening the surveillance apparatus. This presupposes among other measures, the possibility of employing electronic computers in the evaluation. Moreover, attention should be given to the fact that to an ever greater degree a faster performance of the project is demanded and the public purse requires better and more abundant information regarding project performance.

Although planning has been done prior to this and projects have been satisfactorily prepared and carried out, for the reasons mentioned the efforts are usually still too small and they are certainly too little coordinated. In order to show how disadvantages or deficiencies often exist which prevent the attainment of a better system of project organization, some essential points will be briefly outlined in the following paragraphs:

Attention has already been drawn to the difficulties and deficiencies in cost accounting according to procedures practiced up to the present. Detailed cost analyses on the one hand bring out the necessity for increased planning and, on the other hand, create the foundations of a minimal cost accounting, realizable in practice without great expense, which can be built into a project organization system.

The phase before the beginning of construction is frequently too unrigorously formulated, planned, and adapted to project performance. To the extent that bar diagrams have been set up at all for the organization of the actual construction process, they are too coarse and do not show with sufficient clarity important functional relationships determining the course of the project. If the traditional planning devices are applied in more detail, this is associated with great expense so that adaptations to reality are wanting and many unfollowed-up planning operations lose their informational value. Disturbances of the course of operations, among which weather conditions are of special importance, have the consequence that it is often necessary to improvise boldly. In this connection, it should be noted that on the building site a construction supervisor or construction foreman who is a good improvisator is always of great value, since no planning or organization at reasonable expense can give information about small-scale changes. Still, even this organizational domain of daily activity is becoming more and more limited with the increased use of prefabricated elements.

Finally, in planning increased attention should be paid to the full utilization of the capacity of work forces and production facilities; this exerts substantial influence upon the size of the building program and the fixed costs.

The use of network planning technique offers one possibility for improving an existing planning system which has been criticized because of various deficiencies. The theoretical principles of this method have been explained, inter alia, in the "Buendnerwald" [6]. Their merits manifest themselves in the structure of a comprehensive project organization system which yields the principles governing time-referred studies of cost accounting and cost control and also governing capacity planning and the planning of work sequencing.

In the various domains of this planning method there are also contained many possibilities which are not fully exploited today. By means of planning which is thought of as a first step leading to the project organization system mentioned at the outset, in avalanche projects the following may be asserted by way of summary:

In network planning technique we have a method of planning which is suitable for the organization of avalanche projects and which substantially takes account of conditions produced by weather influences, complicated transportation systems, conditions surrounding engineering operations (falling rock, long approach routes, and transportation routes), limited storage and space facilities. At the same time it becomes possible to cope with the limited short construction time available by means of investigations which lead to an optimum utilization of workers and machines. The listed special conditions affecting avalanche projects hitherto resulted in uncertainties which led to hesitancy on the part of entrepreneurs when considering such an enterprise. By using the network plan, these problems are substantially solved and the construction operations are presented in the correct light, namely as familiar building operations being carried out under difficult conditions. Moreover, net planning technique also allows the construction supervisors to plan the manifold and often tedious project preliminary operations (land acquisition, forest-pasture designation, access, etc.) more purposefully and rigorously; also, it permits them, thanks to computer techniques of evaluation, to better prepare and supervise project performance, despite limited auxiliary personnel. Compelled by larger complex projects, in future many boards of works and their executing agencies will be obliged to employ an integrated system for project organization. When the broadest circles of contract consignors and contractors give thought to such possible overall conceptions, then it will be possible to develop an overall system which is satisfactory to the greatest number.

9. Summary

The technical problems of avalanche control construction have been substantially solved in recent decades. On the other hand, the treatment of managerial questions has lagged far behind the development of the structures. In consequence the entrepreneurs, building superintendents, and boards of works frequently lack documentation for cost accounting, cost surveillance, construction planning and financial planning in avalanche control projects.

Therefore, an investigation has been carried out having for its goal the clarification, based upon cost analysis, of the problems of the most favorable subdivision into cost departments for producing a practically useful cost accounting system. Out of the resulting insights, the procedures and aids for a comprehensive project organization have been developed. For this purpose, it was necessary to create, prior to the operations accounting and cost accounting, a construction operations key which was also regulated by the requirements of planning and organization, and which thereby represents a continuously constant structuring system.

The cost types are distributed into cost departments in the operations accounting sheets developed for avalanche construction operations. They are formulated in categories delimited in conformity with the operations in accordance with accounting theoretic points of view so that unit prices can be costed both for operations of the same type and also for the actual cost carriers.

The results of cost statistics indicate that avalanche construction operations are very work intensive. The cost share indirectly charged to the cost departments amounts on the average to two-thirds of the cost sum and it is composed of the costs assigned to the auxiliary cost departments and the main cost departments in equal amounts. The cost carrier unit costs are composed, during the construction program investigated, in part of various fractions of the indirect costs charged to the cost departments. The conditions responsible for these costs are investigated by an analysis of the individual cost department unit costs.

In order to be able to draw inferences, from the calculated cost, regarding the cost of construction, additional effects must be taken into account such as the character of the building market, parameters of production costs, etc. The effect of the resulting uncertainty factors, because of the decisive importance of the personnel cost component, plays a subordinate role in comparison to that of work-referred productivity. In order to obtain documentation for interoperational comparisons and data about the effect of the most important operational conditions upon cost structuring, additional work time derivations were carried out. The results, together with the values derived from the cost statistics, are compared as work coefficients for the various subperformances. This makes it possible to bring attention to functional dependencies upon various characteristics of the construction and from these to infer the order of magnitude of the corresponding ratios. In the sense of a minimal cost accounting, there is constructed, on the basis of cost functions, an accounting system which can operate in practice without great expense. In this way, there is given the connection between the construction work key, the operations accounting sheets, the results of the collection of cost statistics and time measurements together with their use in setting up cost functions and also in this way there are created the principles for a project organization system. The cost statistics and analyses, supplemented by additional time measurements, yield important information with regard to attempts at improving efficiency and the realization of these attempts is accomplished by means of work studies presented in the form of examples. The success of mechanization in producing improved efficiency in the cost-reducing sense is evaluated by taking as an example the use of an excavator for excavation and assembly operations.

From the results of the cost statistics collection and the work-referred productivity investigations, the great significance of planning can be inferred. Thanks to its comprehensive character, network planning technique in the building trade has in general proven itself in the solution of problems arising in this connection. Hence, on the basis of a building program, an investigation has been carried out of the suitability of this method for the planning and surveillance of avalanche projects. Experience in the project management of a construction program by means of network planning technique has shown that the procedure is excellently suited to the solution of most managerial problems in avalanche control construction. By using it as a basis and by using the described subsystems, it is possible to create an integrated project organization system which leads to the goals established at the outset.

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[1] Dictionary of Management

[2] Project Organization With Network Planning Technique in Building Above and Below Ground.

[3] Cost Problems of Construction Production.

[4] Correct Cost Accounting.

[5] Managerial Investigations in Structural Control of Avalanches.

[6] Network Planning Technique, Its Application in Forestry.

[7] General Theory of Construction Management.

XIV. THE SWISS FEDERAL GOVERNMENT'S SUBSIDIZING PROCEDURE (Walter Bauer, Bern)

Clearing and overcutting of forests together with forest grazing and generally poor management have in the course of centuries led to a sharp reduction in forest area, to a dropping of the tree line in the mountain regions, and to a thinning of forests. As a consequence, there have come inundations, mud slides, landslides, and not least of all, numerous avalanches. At ever shorter intervals the forests were devastated, individual farms, barns, and entire communities were endangered and transportation routes interrupted. The mountain population had little prospect of any effective material assistance. The communities and the educated classes were poor. Each individual was more or less forced to rely on himself and the assistance of his immediate neighbors.

With the Federal Constitution of 1848, there emerged for the first time a possibility of doing something in a common effort, i.e., on the federal plane, for the mountain population. But the time was not yet right for this, there was not yet any confidence in the disinterested altruism of the central power. Further natural catastrophes were required to awaken an understanding of the inescapable necessity for intervention on the part of the central government.

1. The First Federal Forest Law of 1876

In the year 1874, the Federal Government through Article 24 of the Revised Federal Constitution obtained the right to supervise the forest police in the high mountain areas. Then on 10 August 1876, there went into effect the first federal forest law as outlined by Prof. E. Landolt. Amongst other things it was intended to segregate protective forests from damaging influences of all sorts and in particular against avalanches. The law provided federal contributions for new forest parks and afforestations in protective forests to the extent that these were of great significance as protection against terrain dangers or to the extent that they were related to control constructions or to the extent that great difficulties were involved in the creation of such forest preserves.

The contributions were set at 30-70 percent of the cost of new forest parks, and 20-50 percent for afforestations in protected forests. We find here already a realization of the idea which was made clearer in later legislation that in particular existing thinned-out protective forests should be reestablished in order for them to be able to accomplish their purpose. The legislator was conscious of the fact that the mountain regions urgently required the helping hand of the Federal Government. Although at this time the Federal Government was low in resources, nevertheless, it had access to financial sources not available to the financially weak mountain cantons. Nevertheless, the magnitude of the contributions is surprising. The focus of the measures to be adopted was quite clearly in afforestations. The formulation of the text in the law and in the implementation ordinance leaves no doubt about this. The first installations supported by the Federal Government were purely afforestation projects.

A certain warm-up time was required before use was made of the contributing capabilities of the Federal Government. This may be related to the fact that the Federal Government also expected an appropriate contribution from the cantons -- an expectation which in the course of the years became a fixed principle.

During the first 20 years of the forest legislation of the Federal Government, the federal contributions paid out in the federal protective forest region of that time amounted to:

1875	Fr	12,000	(promised before the law went into effect)
1876	Fr	6,000	
1880	Fr	9,000	
1884	Fr	47,000	
1888	Fr	35,000	
1892	Fr	102,000	
1896	Fr	137,000	
1900	Fr	168,000	

These contributions include the total of funds paid out for afforestations and construction projects of every variety. By looking at the project records, one can ascertain that, for that time, the contributions were promised with a certain degree of lavishness.

The basic principle was: no avalanche construction without afforestation! This requirement encountered and continues to encounter today little enthusiasm on the part of the mountain population. The people are not very happy about reducing their pasture-lands. The first avalanche structural control operations were still of a modest size: with the aid of ditches and posts, later on with earth terraces and free-standing walls, which subsequently were back-filled, it was thought possible to hinder the sliding of snow in the starting zone. The catastrophic winter of 1887/88 showed that these measures had only little success.

2. The Revised Federal Forest Law (EFPG) of 1902

The federal law regarding forest police of 11 October 1902, brought substantial improvements to the rates of contribution. These were increased by up to 80 percent for afforestations and control projects, and at the same time created the possibility of paying a lump-sum compensation to the amount of three to five times the yearly earnings for areas withdrawn from the economy for construction and afforestation. On the occasion of the partial revision of the forest law of 14 March 1929, this so-called earning-loss compensation was increased to 10 times the annual earnings. As was shown in the sequel, this was both materially and psychologically an extremely valuable extension of the contribution possibilities. Much doubt and resistance on the part of land proprietors with regard to the necessity of afforestations and control constructions can be eliminated and valuable time gained by such measures. The revised law also brought with it for the first time a contribution for forest roads, and this was of special use in making the usually remote afforestation areas and building sites accessible.

The new forest law allowed a substantial intensification of the battle against the "white peril." Year after year, operations were carried out in the starting zones of avalanches. It is an astonishing fact that thanks to the abundant contributions made by the Federal Government it was possible even during both world wars for substantial operations to be carried out in afforestations and structural controls.

It was the goal of the contribution policy to prevent as much as possible interruptions in the operations.

At times there were some disadvantageous consequences of periods when the Federal Government was in a bad situation financially. There were a whole series of financing programs intended to apply the scanty financial resources where they were most needed. Thus, in the thirties, it was necessary at first to reduce the contributions by 25 percent and later even by 40 percent. In addition to these reduced funds, in the course of the years, credits were also substantially reduced. The cantons were on their part compelled to make similar decisions. Since 1934, the credits for afforestations and control constructions were assigned to the financing of the works of the Federal Snow and Avalanche Commission.

In the years 1920, 1922, 1948, and 1961, the administrative and technical aspects of forestry projecting were summarized and clarified by the Department of Interior in so-called "specifications for the creation of forest projects."

3. The Avalanche Winter 1950/51 and Its Consequences

Thanks to the high contributions of the Federal Government, since 1876 it has been possible to reforest and structurally control numerous avalanche paths, slopes, peaks, and starting zones. There was a general belief that in this domain no surprises were to be expected -- not to speak of catastrophes. The enormous snow quantities of the winter 1950/51, the resulting numerous avalanches, the lamentable victims of the white death, and the immeasurable material loss proved in a painful manner that natural catastrophes can always reappear. In spontaneous generosity, the people and the officials combined to stand by the victims of the catastrophe. There could be no misunderstanding about the fact that the Federal Government was confronted by the urgent task, in addition to meeting the immediate emergency, of creating the required legal foundations which would for the future exclude such destruction to the extent that it was humanly possible. As early as 6 December 1951, the Federal Council was empowered by both chambers, in an amendment of Article 1, Section 1, of the Finance Ordinance of 1939-1941 in its extension to 31 December 1954, to guarantee federal contributions in undamaged areas, such as in particular for afforestations and structural controls.

In addition, the federal law of 1902 (EFPG) was supplemented by four new articles which provided an extraordinary aid for relief of the avalanche damage of the winter 1950/51, in addition to increased afforestations and control constructions. This supplementation was as follows:

Article 37bis [second part of Article 37] covered

a. the restoration of thinned-out protective forests;

b. the construction of avalanche-deflecting walls, splitting wedges, protective spaces, and similar installations not only for securing the protective forests but also for general protection;

c. the resettlement of avalanche-endangered buildings to safer locations, and also the creation of galleries for the protection of railroads, highways, and roads whenever thereby it was possible to avoid the expense of costly control structures in avalanche starting zones.

According to Article 42bis, the Federal Government can guarantee contributions up to 80 percent for the installations listed under a and b, including the necessary roads and fenced-off areas, while for the galleries listed under c, the government can contribute up to 50 percent and for the resettlement of avalanche-endangered buildings up to 30 percent.

Article 42ter [third part of Article 42] made the federal contributions dependent upon suitable outlays on the part of the cantons.

The guarantee of these contributions was over a period of 10 years for the galleries and resettlements and for all other installations over a period of 30 years.

Following this and thanks to the measures adopted by the Federal Government, afforestations, control constructions, and the creation of galleries have increased tremendously. On the other hand, practically no use was made of the possibility of resettling avalanche-endangered buildings. The reason for the absence of the resettlements may be found in the high costs and in the proportionately low contribution rate but also in the circumstance that it often turns out to be difficult to find suitable construction sites without -- to name one of the most frequent cases -- substantially impairing agricultural operations. It is generally preferred to protect endangered individual buildings by means of deflecting constructions, terracings, etc.

From 1875 to 1928, the federal contributions paid out for afforestations and constructions of all types remained substantially below 1 million francs. In the years 1929-1935, they were about 1 million francs, but in 1936-1948 they again dropped considerably, while in the years 1949-1951 they amounted to slightly above 1 million. After 1952, the contributed sums increased abruptly: to over 4 million francs in 1954, almost 9 million in 1958, and up to what has thus far been the maximum of over 14 million in the year 1967. Although a substantial part of these contributions is also assigned to afforestations outside the avalanche area, still the development is distinctly characterized by avalanche defense construction.

New avalanche descents of substantial size in the winter 1968/69 causing considerable losses in human life and material damage caused the federal councillors, in the federal law of 21 March 1969 on the amendment of the EFPG, to reassume the federal contributions (expired in 1962) for the construction of galleries and the resettlement of buildings, the subsidy being until 1 May 1982.

This report on the subsidizing policy of the Federal Government would be incomplete if nothing were said about the federal law governing investment credits for forest industry in the mountain region, dated 21 March 1969. This law provided a way of financing the residual costs for avalanche constructions and the associated afforestations in financially weak communities by guaranteeing a loan at no interest or low interest.

In conclusion and in summary, retrospect shows that since the beginning of its forest legislation the Federal Government has on a large scale supported avalanche control projects and the associated afforestations. These operations have in the course of decades been continuously improved and adapted to the special conditions prevailing in the mountains.

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XV. POLITICAL ASPECTS OF AVALANCHE PROTECTION

(Gaudenz Bavier, Chur)

Many people have probably already asked themselves why avalanche control construction has been assigned just to the forest service. The greatest part, at any rate, of the permanent structural control and avalanche protection measures in the track and in the starting zone is to be found outside the forest and has little or nothing to do with cultivation of woodland. The reason, nevertheless, why avalanche structural control is assigned to the forest service is primarily to be understood through the historical development. W. Bauer has described this history clearly in his preceding article, to the extent that it relates to legal regulations. The principle expressed in that article: "No avalanche structural control without afforestation," i.e., without restoration of the protective forest, shows clearly and unambiguously that only the forest engineer is in a position to meet these requirements. But there is still another reason. Through the legal regulation dividing the cantonal region into suitable forest districts and their further subdivision into forest regions, an organization was created which lies like a network over the entire country and by means of which a systematic coordinated avalanche observation activity can be guaranteed as the foundation of any protective measures. And finally, at the time when the federal forest law of 1876 went into effect, Chief Forest Inspector Johann Coaz, the patriarch and founder of systematic avalanche structural control, was at the head of the Swiss Forest Service. It was he who -- at that time still cantonal forest inspector in Graubuenden -- in 1868 caused district forester Rimathe to create what was presumably the first systematically designed avalanche construction project in Europe, the "Motta d'Alp" in Tschlin at a cost of 1,603.75 francs. The project embraced 412 m' of free-standing dry walls and 17 rows of posts totaling 509 m' in length. As early as the year 1881, at the instance of the Federal Department of Trade and Agriculture, he published his fundamental work on "The Avalanches of the Swiss Alps" containing the first cartographic data for avalanches in the Gotthard region, prepared by the then Federal Forest Assistant Fankhauser. In this work the author writes:

"What led me to the study of avalanches and their structural control was my former position in connection with the Swiss Atlas and my 30 years' service as a mountain forest ranger." The activity of the forest engineer in the mountains brings him continuously into contact with the natural phenomena related to avalanche descents and confronts him therefore with the problems of avalanche protection. Hence, he is predestined, both by his function and by his education, for avalanche structural control. Hence, it is not really remarkable that this great and responsible task lies in the hands of the forest service and that also the Federal Institute for Snow and Avalanche Research in Weissfluhjoch-Davos is associated with the Federal Forest Inspectorate.

Since the first federal forest law went into effect, a total of over 13 million francs has been expended out of forest credits for [avalanche] structural control projects and afforestations with the Federal Government providing subsidies up to about 196 million francs. The following Table 1 gives information regarding the details.

In contrast to the contributions to the provision of forest access, forest consolidation, segregation for forest pasturage, etc., these subsidies are not a compensation for legally restrictive regulations affecting forest property but are a direct aid to the mountain population. It is, therefore, reasonable that the subsidizers, Federal Government and cantons, attach certain conditions to the payment of these high contributions and reserve to themselves a right of consultation. Thus, the Federal Forest Inspectorate has caused binding guidelines for avalanche structural control in the starting zone to be worked up by the Snow and Avalanche Research Institute. These guidelines take into account research over many decades and also take into account practical experience and they are primarily concerned with the requirements imposed by nature upon a control project and upon the individual installations. Designers of avalanche construction projects which are to be subsidized must adhere strictly and without exception to these guidelines. The subsidizing authorities reserve to themselves additional consultation rights with regard to operations contracting and naturally with regard to the performance of the operations.

Table 1. Auditing of Afforestation and [Avalanche] Structural Control Projects (Avalanche Structural Control Galleries) From the Year 1876 to the End of 1970. According to Data of the Federal Forest Inspectorate on 4 January 1972

Cultivation			
Area in hectares	30,879		
Deciduous trees in thousands	91,255		
Evergreens in thousands	171,675		
Total [trees]	262,930		
Total cost		Fr	80,505,881
Drainage			
Total running meters	5,009,273		
Total cost		Fr	16,250,904
Avalanche Structural Control			
Running meters [total]	184,560		
Galleries (since 1953)	8,373		
Rock Fall Structures			
Running meters	31,739		
Earth Terraces			
Running meters	560,363		
Wall Terraces			
Running meters	417,823		
Total cost		Fr	135,486,277
Stream and Terrain Construction			
Stream running meters	332,023		
Soil stabilization running meters	1,027,731		
Total cost		Fr	15,048,036
Enclosures			
Running meters	2,632,369		
Total cost		Fr	10,571,880
Road Construction			
Patrol roads, running meters	2,098,555		
Jeep roads, running meters	758,387		
Total cost		Fr	49,241,724*
Fire Protection			
Total cost (since 1958)		Fr	1,369,832
Ground Acquisition			
Total cost		Fr	10,151,493
Aggregate cost		Fr	318,626,027
Total federal funds paid out (61.52 percent)		Fr	196,014,904

* The actual forest-road construction is not included in this figure.

In the course of the approximately 100 years since we in Switzerland have been systematically producing structural control for avalanches, with these operations being subsidized by the Federal Government and the cantons, not only the nature of the construction but also the purpose of the construction as well as the nature of the object to be protected by the construction have materially changed. Before World War II, the mountain population still consisted predominantly of mountain farmers or of people closely connected with agriculture in one form or another and who were familiar with the mountain environment. The mountain farmer was primarily self-supporting. Through the winter, during the period of reduced agricultural activity, he occupied himself usually in the forest in gathering wood and transporting wood. He was familiar with the onerousness and danger of the snowy mountain winters. Winter sports continued to be confined to some relatively few health resorts and in summer, the main season, the sport centers of today are still predominantly true, tranquil spas. Mountain railways, ski lifts, and so on existed only in rather limited numbers. The mountains were in summer and in winter the almost untouched arena of mountain climbers and ski tourists.

This has changed fundamentally since then. There is now hardly a single even moderately attractive mountain in the alpine territory on which there is no railway or ski lift either existing or at least projected. Thus, today in Switzerland there are over 100 funiculars [aerial cable cars], about 70 chair cars, and nearly 700 ski lifts in operation which all serve to haul skiers of limited ability up into the mountains. This confronts the communities, the resort associations, and transportation associations and those companies operating these transport facilities with the inescapable duty to concern themselves with securing that the guests, frequently unfamiliar with the mountains, thus brought up into the highlands should be returned again to their starting point unimperiled and uninjured. But precisely the same responsible duty confronts the conductors of ski tours who, together with the people entrusted to them, visit the winter mountain world on the ski slopes. In this, avalanche protection has acquired a new and very important function hitherto unknown.

New winter sports centers have in recent years sprung up like mushrooms. In the Canton of Graubuenden alone there are about 40 winter sports centers of importance. The structure of the population has altered. The mountaineer population familiar with the mountain winter has been augmented by outsiders often completely unfamiliar with the mountains who look to the winter sports regions partly for recreation and partly hoping to make a living. With increasing motorization and the resulting expansion of the road system, the mountain regions are now easily accessible from the centers of population. Thousands upon thousands of skiers spend their vacations and weekends in the mountains. It is estimated that today there are in Switzerland about 1.5 million and in Europe about 15 million skiers and it is expected that by the year 1990 there will be a doubling of the tourist volume. In Graubuenden and in the Waadtlaender Alps today the number of winter visitors exceeds that in the summer.

The mountain farmer, originally an introvert and living in a more or less isolated and in part inaccessible region was carried along in this development. There opened up to him and particularly to the young people new employment possibilities which in certain regions were completely exploited "down to the bottom of the barrel." The land which had earlier been managed agriculturally acquired increased value as building land which unfortunately was in great measure acquired by speculators with the assistance of the native population. Large-scale overbuilding resulted and the existing health resorts turned into actual mountain towns with all their accompanying phenomena, some of them not exactly pleasant.

But it was not only the former winter health resorts which expanded but also small and even the very smallest mountain villages were attacked by the building boom. Thus, for example, a town planner familiar with conditions in Graubuenden found that in one small locality in upper Engadine in the year 1964, building sites were being sold for about 2 million francs. The spreading prosperity makes it possible for many people to build a vacation house in the mountains or to at least rent a vacation dwelling occasionally. Requests for building permits on the part of outsiders increased in the mountain communities and a frequently planless building-up of large areas formerly used by agriculture became widespread. It was unavoidable that thereby regions were claimed for development and are still being claimed which are potentially exposed to avalanches. The communities thus see themselves confronted by very difficult problems, for as the possessors of the local police authority they are responsible for order and safety within their territory. A part of this local authority consists of issuing building permits and inspecting new buildings. Thus, the communities are confronted with the question as to how they should proceed in the case of building permit requests in avalanche-exposed territory. There exist no federal regulations or laws of a binding character. The Federal Department of the Interior adopts a viewpoint which is doubtless in accord with our federalist structure, to the effect that the preparation of avalanche zoning plans is the affair of the mountain cantons, or of the communities concerned, since it is primarily a function of the communities to secure the safety of its inhabitants. But as early as 1952, the department pointed out the urgent necessity of working out avalanche zoning plans and avalanche cadastral surveys and declared unmistakably that the Federal Government would make no contributions to resettlements or to measures protecting buildings against avalanches if in the selection of the building sites no attention was paid to avalanche zoning plans or if, when such plans were absent, warnings against building projects were ignored.

It is to be hoped that by means of the legislation based upon Article 22^{quater} [fourth part of Article 22] of the Federal Constitution, on regional planning, the cantons can finally be effectively obligated also on a basis of federal law to support the segregation of endangered zones.

To be sure, it is correct that enthusiasts for building who develop avalanche-endangered regions in irresponsible carelessness and in disregard of warnings must in the event of a catastrophe bear the consequences of their improvidence. But this in no way solves the problem for as a consequence of developing such regions other people are also endangered. These may be those who are engaged in any activity in this region, whether they are visitors, vacation guests, letter carriers, etc., or possibly even rescue crews.

Thus the communities, being responsible for the safety of their inhabitants, are compelled to prevent construction in avalanche-endangered regions. For this purpose they require the building inspector's instrumentality of a map of avalanche zones or of danger zones. Thus, the avalanche zoning plan becomes part of the community zoning plan. In contrast to other zones whose designation can be freely arranged by the communities, the danger zones have a fixed delimitation given by nature which cannot and should not be arbitrarily displaced. Of course, it is undoubtedly true that in delimiting danger zones there is involved a survey which is characterized by the technical competence and personal views of the expert consultant involved, who is usually the responsible district forester. As a rule not too much margin is allowed in this survey. The survey, to the extent that it relates to the red zone involving a high degree of danger and absolute building prohibition, takes the form of relatively small boundary shifts since this zone includes regions having rather uniformly increased avalanche activity for which as a rule there exist observations and often avalanche photographs and which usually also display in the terrain unfailing signs to the eyes of the attentive and skillful observer. Somewhat greater margin may be expected in surveying the boundaries of the blue zone, in other words, the zone of less severe risk, relative to the white zone which is the unendangered region. De Quervain has expressed himself with regard to the avalanche catastrophe of 1968 in Davos as follows relative to this problem: "If one wishes to exclude all possible risk by taking as a basis of zoning not only the regular avalanche activity but also all isolated historical events then various well known localities would have to place entire regions under the ban." And again he writes: "Thus probably in the future there will remain a residual risk, whether because in the space of centuries one must accept one enormous catastrophe or because more frequently one must reckon with less intense damage. The estimation of the magnitude of the risk for various parts of the terrain is the concern of persons familiar with the locality and if possible familiar with avalanches. But the assignment of responsibility must ultimately be done by a political authority."

The assignment of responsibility by the political authority, in other words as a rule the community assembly, is not likely in the case of the red zone to be substantially different from the professional opinion of the expert advisors since otherwise this assignment would be open to the reproach of arbitrariness. An avalanche zoning plan can lay claim to accuracy only when it has been constructed completely and on the basis of recommendations of expert agencies, in other words, principally of forestry agencies. Otherwise it at least contradicts the specifications in the area of building inspection. An avalanche zoning plan based upon factually ill-supported and incomplete data would therefore have to be denied the recognition of its legality and hence denied approval on the part of the cantonal government. In this connection, it should also be asserted that the building inspection procedures of dividing a piece of property into a zone where building is prohibited because of avalanche danger and a zone of restricted building in no case justifies claims for compensation on the part of the property owner. The Federal Court has brought this out with all clarity in a recently published decision.

But this in no sense brings us to an end of the problems of the avalanche zoning plan. The quite concrete question arises whether by means of avalanche control structures it is possible to bring about a rezoning from red to blue and possibly even to white. In our opinion, the safety guaranteed by avalanche structural control being only relative and not always the same, the possibility of a rezoning into white (i.e., nondangerous region) is in very many cases excluded. On the other hand, under certain assumptions and depending upon local conditions, it is possible to give consideration to a reduction of the red (severely endangered) zone. This can have the consequence that land which hitherto was usable only agriculturally becomes revalued as building land and thus multiplies its value severalfold. In such a case, it is probably only right and proper if the owner of the revalued land should be required to pay a share of his gains toward structural control in the form of a perimeter contribution. But such a rezoning should be carried out with the greatest care and only in well founded cases -- where financial interests cannot be looked upon as the reason.

The avalanche zone plan has an incisive effect also upon insurance against natural hazards. Natural hazard policies as a rule refuse to insure structures in the red zone and in the blue zone require certain protective measures which have the effect of increasing building costs. The insurance compensation rates to relocate a building destroyed by an avalanche should be the same as construction costs at the former site. When possible, the relocation should even be demanded. It is therefore highly questionable when in an appeals case a request is made for rebuilding on the old site with the justification that with normal snowfall there is no avalanche danger. Likewise questionable -- in another case -- is the argument that the construction of a house in an avalanche-endangered region still constitutes no immediate danger to public order and safety and therefore building inspection measures are not justified. Neither can a normal snowfall be cited in judging avalanche risk nor is the immediacy of the danger of decisive significance; because avalanche danger can only be dealt with in a preventative way and it is precisely with this purpose that avalanche zoning plans are created.

We have shown in the preceding that the avalanche zoning plan is a part of the community zoning plan, in other words, must be a constituent of the regional planning. But this applies not only to zone segregation but also to avalanche protection in general. Avalanche construction in all its aspects must also be included in planning. In particular, before the erection of avalanche control structures, there must be a clarification of the social, economic, and political development of the settled area which is to be protected. On the basis of careful data collection, favorable regions should be designated for which the high cost of avalanche control projects is acceptable. This is not to be interpreted as meaning that an almost exclusively agricultural valley should simply be left to its fate and that no protective measures should be applied there. To the extent that such a region requires an expensive avalanche protection, a careful and unprejudiced check must be carried out of the development of this region to see whether sufficient possibilities exist to guarantee the population an adequate base for existence over a foreseeable period of time or whether the development possibilities are so slight that one must reckon sooner or later with depopulation. At the same time, there should also be a thorough examination of the question whether maintenance and protection of the settlements might not possibly be necessary for purely landscape-esthetic reasons. In each case it should also be determined whether resettlements might not be more advisable and in particular safer than expensive control projects. The latter course, as Bauer has already shown, is not generally very popular, first of all because of the difficulty of finding suitable building land, and then because of the difficulties which this entails in the agricultural allotment of property and not least of all also because only relatively low subsidies are obtainable for a resettlement. It is precisely in the financially very costly process of avalanche control projects, which is sustained practically entirely by public funds, that planning measures are necessary even though the latter are a ticklish subject which readily excites the emotions. It is doubtless also necessary to periodically recheck the suitability and economy of these public investments, to the extent that one may speak of economy at all. This view may seem harsh, but to us it appears indispensable that all these aspects should be thoroughly thought out if it is to be possible to obtain the existing resources and use them correctly. There is a final aspect which must not go unmentioned here. On the occasion of the avalanche catastrophes of 1951 as well as 1968, a collection was taken up in Switzerland for those hurt by the avalanches. The results of the collection were extraordinarily gratifying and impressive, being over 14 million francs in 1951 and in 1968 over 5 million francs. In this way, many victims could be quite significantly assisted at least financially. But the fact merits thinking about here that the major part of the uncovered damage consisted of insurable objects, i.e., that the collected money had to be spent for the most part for material damage in cantons in which there was no obligatory insurance, and that in cantons with obligatory insurance a large number of the buildings were underinsured. This creates inequalities in the treatment of the victims and thus leads to disagreements. In our opinion, an attempt should be made to determine whether or not as a condition to be attached to future subsidies of avalanche structural control projects, it should not be required that buildings and goods and chattel in the settled area to be protected be insured whenever possible at the undepreciated value or whether in some way or other obligatory insurance could not be introduced into such regions. It will hardly do in the case of an avalanche catastrophe to put off the owner of an uninsured or underinsured building with the advice that he should simply have insured sooner. This would be in opposition to the spirit of the public donation and besides, in such a case, the need is too great for such subterfuges to be employed. But the discontent remains and it would be a welcome event if upon those regions, too, there began to dawn the meaning of the proverb: "He who saves in time has means at need."

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English Translation of German Titles

[1] The Avalanches of the Swiss Alps.

[2] Guidelines Concerning Afforestation and Structural Control Projects in Avalanche-Endangered Regions.

[3] Legal Questions Establishing Avalanche Zones in Which Building is Prohibited.

[4] The Avalanche Zone Plan.

[5] Appeals Practice for the Small and Large Councils in the Canton of Graubuenden.

[6] Snow Science and Avalanche Control Structures.

[7] The Avalanche Catastrophe of Davos: Observations and Conclusions.

XVI. THE FOREST AS A PROTECTION AGAINST AVALANCHES (Conradin Ragaz, Tamins)

1. Importance of the Upper Tree Zone

Technical avalanche construction is not an end in itself but a means of averting dangers which arise in all places where, as a consequence of human carelessness or greed, dwellings or other facilities have been erected in regions which since the earliest times have been threatened -- but not at regular intervals -- by avalanches, which in most cases break loose far above the tree line. Great, too, are the expenditures of communities, cantons, and the Federal Government to guarantee endangered villages and transportation routes necessary security against these natural forces. In Graubuenden Canton, the majority of these projects are in progress or have already been completed. Thanks to Article 48 of the cantonal forest law of 6 October 1963 and with the aid of the danger zoning based upon that law, a restriction has finally been put in the way of further building in the endangered regions. Technical avalanche construction will, to an increasing degree in the future, be concerned with reestablishment of mountain forests which are no longer capable of fulfilling their important protective function because man has not accorded to them adequate care and nurture or because natural forces of all types such as avalanches, fire, or storm, have damaged the upper forest zone. Technical avalanche construction becomes an aid for maintaining in optimal condition the forest border zones which constitute biological avalanche protection.

If we weigh, on one hand, protective forests granted us by nature and, on the other hand, artificial avalanche construction, then we obtain the following comparative values:

a. with regard to extent:

1) avalanche construction projects and afforestation projects which are now in progress in Graubuenden Canton embrace an area of about 2,500 hectares or 1.5 percent of the total forest area.

2) the total length of the upper forest border, which lies at various altitudes and is frequently interrupted by avalanche paths, rock falls, or slides, amounts to about 1,400 km. Of decisive importance for biological avalanche protection is not the upper tree line but the upper tree zone which may be assigned an average width of 200 m. Hence it amounts to about 28,000 hectares or 16.37 percent of the total forest area of 171,000 hectares in Graubuenden.

b. with regard to cost:

1) for permanent avalanche construction, 500,000 to 600,000 francs per hectare are to be spent, out of which theoretically there arise annual interest burdens of 25,000 to 30,000 francs.

2) the protective forest is normally capable of maintaining itself substantially in the upper tree zone and with suitable access and cultivation, depending upon the tree varieties, it can even produce a modest net yield.

This comparison, which has been kept concise in view of the limited space at our disposal, gives us an insight into the extent of the upper tree zone and permits us to recognize the dominant significance of the forest for avalanche protection. The purpose of the following discussion will be to describe in more detail the unique biological community -- the forest -- from the point of view of its function as a protection against avalanches -- although it, at the same time, has many other functions.

Within the context of the total concept, it is a question of placing the proper accents in the sense that technical avalanche construction for the protection of existing settlements and transportation routes represents an urgent task for our generation, while, on the other hand, the maintenance and nurture of the forests of the upper tree zone must be looked upon as a lasting responsibility.

Figure 1. Protective forest penetrated by several avalanche paths; in such cases, artificial control structures are required in the starting zones in order to completely close the forest belt once again (photo C. Ragaz).

2. Ecology, Tree Varieties, Structure of the Forest Stand

The mountain forests, which are of particular importance for avalanche protection, lie in the boundary zone between subalpine and alpine elevation levels. On the northern slope of the canton they are at an elevation of 1,700 to 1,900 m above sea level. In the central alpine region, they are between 1,950 and 2,150 m above sea level. The following discussion is limited exclusively to this upper tree zone.

Every variety of tree is associated with quite a definite stand location which it finds suitable. Prevailing climatic and soil conditions are of primary significance. The steepness of the terrain, the disadvantageous effects of the snow cover, and erosion are also of great importance. In the region of the upper tree line, only plants and trees which possess quite special characteristics can survive the extremely difficult environmental conditions and thrive. The winter, which lasts up to 8 months, interrupts the growth of the trees during a period of maximum temperature variation and strongest mechanical stress. During the short vegetation period, there are dry periods to be overcome and the number of days which display a daily temperature average above 10°C is close to that lower limit which begins to be critical for the tree's growth. Therefore it is understandable if out of the 500 evergreen varieties existing on earth, only a few varieties are capable of penetrating to this elevation which is so extremely inimical to vegetation. Besides the larches, which discard their needles in the winter, there are mountain fir, spruce, and Cembran pine. The only representatives of the approximately 9,500 deciduous varieties are the birches, willows, mountain ash, trembling poplar and alpine alder which, with the exception of the latter, do not form a stand and are of subordinate significance for avalanche protection. Attempts to augment the tree varieties of the subalpine highland by means of evergreens from the boreal evergreen forest zone (Siberian larch, Siberian pine, and Siberian Cembran pine) which would appear to be promising considering the common features displayed by the boreal and alpine evergreen forests have thus far not let to success. The four tall evergreens which are capable of tolerating the extreme stand locations to the very end occur simultaneously as stand-forming trees only in certain locations. In broad regions, it is only spruce or the mountain fir alone or at most with a mixture of larch which participates in the buildup of the pioneer forest of the high mountain regions. On the other hand, the larch-Cembran pine climax forest in the central massif is frequently encountered where it represents the most well-adapted forest community of the highlands. The mountain forester must know how to get along with these limiting natural conditions with regard to tree varieties.

The structure of the forest stands which survive in the upper tree zone is highly variable depending upon the varieties of trees present. The mountain fir stands of the lower Engadine are characterized by the greatest uniformity and by dense stand closure.

The evergreen belt of the subalpine spruce forests is always of uniform structure whenever it has come from areas under attack by the forces of nature, from former grazing regions, or from clearings. Often the effect of human beings, because of the utilization of scattered stands over many decades (selection) has led to a stand having a stepped structure.

The larch-Cembran pine forest is very often two-layered, with the older larch forming the upper layer and the Cembran pine forming the young forest. It is evident that here the vegetation development must finally lead to the pure Cembran pine forest.

Pure, over mature, and partially broken up larch forests which have been grazed, may be encountered in places on southern exposures. As a result of intensive grazing, they are forests completely without regeneration and are no longer able to provide their protective function permanently.

The volume of the forest stands on the upper tree zone averages 200 to 250 cubic meters per hectare. The annual increment in the central Alps is 1 cubic meter per hectare and may increase on the north slope to 1-2 cubic meters per hectare.

3. The Effect of Forest Stocking on the Mechanical Behavior of the Snow Cover and Upon Avalanche Formation

Among the causes of avalanche and snow slide formation are:

a. Long sustained snowfalls,

b. unfavorable snow cover structure (layering),

c. wind transport and drift formation,

d. sudden heat waves,

e. terrain-induced tension fields.

Between tree vegetation and the snow cover, there exists a close mutual influence which is of decisive significance both for the growth of the forest and also for avalanche formation.

An ideally constructed, i.e., a healthy forest with the permanency appropriate to its age-class is capable of hindering avalanche formation upon the emergence of the above-mentioned conditions. The unevenness of the crown leads to a nonuniformity and densification of the snow cover because a part of the snowfall at first remains hanging in the crowns and often gets to the ground only after the next period of warmth. The stand space, with its boughs, branches, and needles, has a favorable effect upon the snow deposit under a strong wind, and in this way is capable of preventing undesirable accumulations of snow in otherwise unstable slope positions. A forest with a stocking of 1,000 to 5,000 individual trees per hectare can nail the snow cover fast to the ground and thereby prevent the outbreak of avalanches on the steep slope or in the tension field.

On the other hand, the snow is an extraordinary burden upon the growth of plants. Thus, the settling of the snow cover leads to mechanical damage in young plants. On the steep slope, the gliding and creep of the snow cover and the resulting snow pressure lead to bole deformations and often to the complete destruction of new plantings or young plants. Avalanches or snow slides starting above the tree line can even lead to the partial destruction of intact forests and display a tendency to penetrate ever further into the forest stands in the course of the years until finally there arises an open avalanche path. It is important to deal promptly with such a serious development, and this is possible by control structures in the starting zone, which are often not very extensive.

A long-lasting snow cover, particularly on slopes with a northern exposure, can lead

Figure 2. This favorably developed mixed high-elevation forest forms a reliable protection against avalanches (photo C. Ragaz).

to an infestation of snow mold fungus and to a shortening of the vegetation period. The snow cover forms a protection for the young plants with regard to the effects of wind, drifting snow, and grazing wildlife.

From these conditions and observations and taking into account the circumstance that the mountain forest on the upper tree line performs a number of other functions in addition, there arises the following goal:

a. Conservation and restoration of the forests of the upper tree zone, in order that they shall be able to completely fulfill their important protective functions.

b. As broad a reforestation as possible of the deforested alpine level up to the natural tree line with the purpose of strengthening the pioneer forest.

The following long-term measures appear to be suited to the realization of this goal.

4. Measures

Prerequisites for improvements in the area of the upper tree line are control of grazing, of the density of the wildlife population, provision of access, and finally, structural control to prevent snow slides and avalanches within or above the tree line. Here we are concerned with a detailed account of the forest structural measures which appear suited to an improvement of avalanche protection.

It has been asserted that every tree variety displays advantages and disadvantages with respect to avalanche protection. Therefore, a mixture of tree varieties promises to produce the best results and one should avail oneself of every possible extension of the tree variety spectrum, even employing deciduous trees.

The stand density which is necessary for an effective avalanche protection in the neighborhood of the ground, i.e., in the region of the snow deposit, can be best obtained by an ample restocking over the whole area of the stand. Hence, the greatest significance should be accorded to suitable restocking measures and increased cultivation. These restockings should be kept densely closed up to a height of 3-4 m. Subsequently, suitable measures are necessary for the formation of well-crowned, resistant individual trees.

The effect of the forest upon the snow cover conformation is very dependent upon stand height. The greater this is and the more extensive the forest stands are, the more permanent will be the effect upon the action of the wind. Therefore, it is unconditionally necessary to strive for permanent conservation of an upper layer consisting of fully grown trees. Any clearing of old trees, which would lead to decades or reduction in stand height and its effect upon the wind, is to be avoided.

In the search for that stand structure which best meets the requirements of avalanche protection, the following alternatives may be considered. Theoretically and during a limited period of time, a densely closed, single stratum stand substantially satisfies the requirements imposed from the point of view of avalanche protection. Thanks to the large number of stems per hectare and an almost completely closed crown canopy, this type of stand can substantially prevent the penetration of snow into the interior of the stand and hence can make avalanche formation impossible. But the single-stratum type of stand is not permanent so that inevitably the time approaches when felling must lead to a temporary reduction in the stand height and in the avalanche-protective effect. Forest stands with an uneven canopy are capable of taking up new snowfalls with small risk of damage and of later depositing the snow on the ground, display great advantages in the upper tree line. The stand has well-branched trees of all ages interspersed in it and is therefore very effective against the wind. Ample incident light through clearings permits the dissemination and growth of natural restocking. In the subalpine spruce forest, the selectively cut forest is the most suitable type of operation for meeting the requirements which have been set.

In the range of the larch-Cembran pine forest, one should strive for a restocking of the larch under an umbrella of old trees. The Cembran pine is suited to the desired increase in the density of the stand.

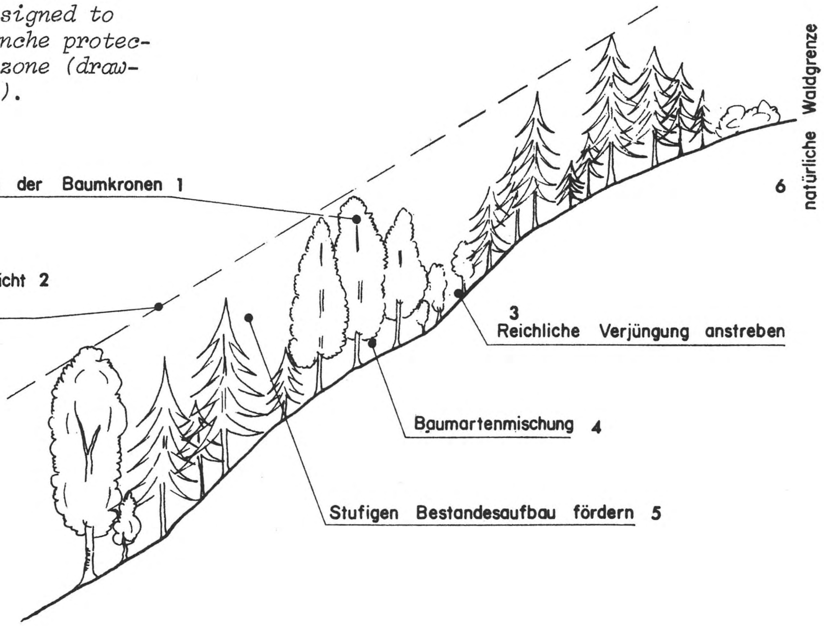
In overaged, frequently single-stratum larch grazing forests, it is indispensable to cultivate in a checkerboard arrangement in order to conserve the stock. As long as there is no control of grazing, a fence is indispensable.

The forest structural measures described and suggested have have one thing in common. They must be planned very carefully and over a long period of time. Wrong decisions can entail catastrophic results in the battle zone [upper zone] of forest vegetation, and these results can often be corrected only by elaborate means.

5. Conclusion

The conservation and extension of mountain forests implies an effective protection of the environment for the alpine area. Permanent care of these forests is on a par with the laudable efforts which are being made to maintain the purity of water and air. Every hectare of forest guarantees to our settled areas, our transportation routes, and our valuable cultivated lands, the greatest possible protection against avalanches and other forces of nature, at the least cost.

Figure 3. Structure of a stand designed to achieve a maximum avalanche protection in the upper tree zone (drawing: C. Ragaz/P. Aebli).



Key:

1. Good conformation of the tree crowns
2. Do not interfere with the height of the stand
3. Strive for ample restocking
4. Mixture of tree varieties
5. Promote graded build-up of the stand
6. Normal timberline

Figure 4. A larch-Cembran pine forest in process of developing at the upper tree line. It is already capable of a favorable effect upon the snow cover conformation and guarantees protection to the stand below (photo C. Ragaz).

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English Translation of German Titles

[1] Protective Functions of the Forest in the Mountains.
[2] The Protective and Recreational Effects of the Forest.
[3] The Avalanches of the Swiss Alps.
[4] The Effect of the Forest on the Water Balance.
[5] Regeneration in the Region of the Upper Tree Line.
[6] Flowering Plants in the Battle With Winter.
[7] The Role of the Forest in Avalanche Protection.
[8] Afforestations and Structural Control in the Upper Engadine 1875-1934.
[9] Afforestations at High Elevations.
[10] Microclimatography and Its Use in the Ecology of the Subalpine Zone.
[11] Afforestation Experiments on a Gliding Snow Slope.

OUTLOOK (Maurice de Coulon, Bern)

In the year 2000, Switzerland will have a population of from 7 to 8 million, and toward the middle of the 21st century, there will probably be several million more. Our grandchildren will perhaps work only 3 or 4 days in a week, have much longer vacations, and retire at the age of 55 at the latest. (Some will say that this is impossible for agriculture; but will mountain agriculture continue to exist at all at that time as a sector of the economy?)

More than 90 percent of the population lives today in the flat areas and has settled only a third of the country. A large part of the center of the country is already overpopulated. Even if Switzerland remains a political enclave, it will sooner or later have to integrate economically with Europe. Today people no longer pay attention to national boundaries in selecting their vacations.

Will not the alpine area in the future become to an even greater degree an attraction and a recreation area for millions of Europeans having ever more free time at their disposal both summer and winter? The beautiful landscape, tranquility, and clean air -- rare good things -- will they not be wanted in increasing measure?

In order to effectively form the development of the mountain region, this development should be much better planned and coordinated than hitherto. It is of first importance that regions should be delimited and then reference models and development plans should be worked out in accordance with which the local planning can regulate itself. (A political division, which often does not have functional boundaries can, as a rule, not be viewed as a planning unit.)

The avalanche zones form -- as is the case with all danger zones -- fixed points for space planning in the mountains. They exclude development or they limit it sharply and are hence, as a rule, segregated without compensation in the form of green zones.

The avalanche construction projects, like landscape protection and the recreation facilities, will form an integrating constituent of regional planning. As befits contemporary politics, it is of primary importance for existing residential settlements and transportation facilities to be protected from avalanches. New building land should be designated with restraint and only outside avalanche zones. The responsible authorities in this way prevent scattered settlements, reduce outlays for community facilities, and control land speculation. The investments for avalanche control constructions, in order of urgency, should be used at the locations determined by the regional planning. Avalanche construction everywhere and at any price -- for the Federal Government at any rate -- is out of the question. The funds available must not be squandered.

As a rule, before working out avalanche construction projects, it is necessary to collect socioeconomic statistics. The production of the control constructions usually requires years and often decades of labor. How will the population and the economy of the region develop in the meantime? There are limiting cases in which the suitability of certain measures is extremely questionable.

In the study of control construction projects, in future increased weight must be placed upon the evaluation of the various protective possibilities and upon checking the technical, social, and especially financial advantages and disadvantages of each variant. The decision does not lie only with the technologist: the requirements of safety and those of the national economy must be adapted to one another. How far can one go with investments for control constructions? To be sure a human life is more valuable than the most expensive avalanche control project. But can an expenditure of millions for the protection of one or two houses be justified when these houses are worth only a fraction of the construction costs? Wouldn't it often be much simpler to resettle a few people instead of carrying out difficult and expensive projects for defense against avalanches?

In studying different variants of a project, the required minimal protective function must remain the criterion. The ratio of the funds expended (input) to the result achieved (output), depending upon the variant, will turn out very differently. In general, the costs are relatively easy to estimate; in contrast, the evaluation of social utility is much more difficult, especially when one attempts to compare the different variants quantitatively (cost-use ratio; profitableness). To the extent that such estimates are possible at all, one will have to be content with approximate values and orders of magnitude. Be that as it may, the costs must, in each individual case, be established in detail and their ratio to the desired protective function must be examined (e.g., cost per person or building or per hectare of ground surface to be protected). A preliminary cost estimate cannot be justified by multiplying the length of the installation by the unit price.

In checking out the different variants, preference will be given to the one which at about the same cost has the most advantages or which for approximately the same advantages represents the cheapest solution. This variant will be of decisive importance for the project design. Only now is the detailed study begun.

In the regions of avalanche fracture, the forest -- wherever there is any possibility at all of establishing and maintaining one -- is without doubt the safest, most durable, and cheapest protective arrangement. In contrast to control construction it fits harmoniously into the landscape and at the same time performs manifold functions. Hence, the forest must be maintained in the highlands and restored where necessary; at the same time priority must be given to the afforestation of slopes exposed to avalanche risk. When the mountain forest is properly cared for, it usually restocks itself; in many places the natural restocking also extends to idle land. Avalanche construction projects can be viewed as an extension and a supplementation of forestry: hence, the forest ranger will be concerned with these projects in additional respects.

The cantons and especially the Federal Government guarantee very high contributions to avalanche construction projects. Thanks to the new investment credits such operations can be completely financed. It is justifiable to continue this supportive politics in the public interest also in the future, but the funds must be employed with more refinement and more purposefully. What criteria are decisive for determining the rate of contribution? What significance, what weight is to be attributed to these criteria? Will the Federal Government reach the point of regulating its contributions in accordance with the interests which the general public have in the enterprise concerned (increased contribution for constructions of national and regional interest, as in the protection of natural features)? Is it in every instance justifiable that the builders, who are primarily interested in the construction, should bear only a small fraction of the costs? It probably goes without saying that in the future, too, the Federal Government will examine projects very carefully, quite particularly with regard to their significance and reasonableness within the context of regional planning. A project which justifies itself only from the engineering point of view is only half a project.

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