1. Wind control structures in avalanche defence and prevention. 2. Tests with baffles at the Wattener Lizum Snow Research Station (Tyrol) in the Years 1950-1055. 3. Wind tunnel model tests with baffles

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TECHNICAL TRANSLATION 1348

ECOLOGICAL INVESTIGATIONS OF THE SUBALPINE ZONE FOR THE PURPOSE OF HIGH ALTITUDE AFFORESTATION. PART II

1. WIND CONTROL STRUCTURES IN AVALANCHE DEFENCE AND PREVENTION, BY J. HOPF AND J. BERNARD
2. TESTS WITH BAFFLES AT THE WATTENER LIZUM SNOW RESEARCH STATION (TYROL) IN THE YEARS 1950 - 1955, BY J. HOPF AND H. WOPFNER
3. WIND TUNNEL MODEL TESTS WITH BAFFLES, BY A. FUCHS

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TRANSLATED BY

A. G. PRELLER AND D. A. SINCLAIR

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OTTAWA

1968

PREFACE

The development of resources in the mountainous regions of Canada, and the associated construction of roads and railways, have increased the need for information on the occurrence of avalanches and on avalanche defence. The Snow and Ice Section of the Division of Building Research is giving attention to this need. It is compiling information on the techniques that can be used for estimating the danger from avalanches at sites typical of Canadian conditions, and developing methods of defence.

Because of site conditions and economic factors, most defence methods used in Canada have been those that can be applied in the valley or "run-out" zone of the avalanche. In countries such as Switzerland and Austria where avalanches have been a much more serious problem, considerable attention has been given to preventing avalanches through the construction of defences higher up on mountains in areas where the avalanches begin. Snow fences or baffles that control the deposit and erosion of snow by the wind are an example of such a defence.

The Federal Forestry Experiment Institute, Mariabrunn, Austria, has published the results of a series of tests on this method of avalanche prevention. The Division of Building Research is pleased to have the opportunity to make the experience accumulated in Austria on the development and use of wind control structures for avalanche defence, more generally available through the translation of the three papers contained in this publication.

The Division wishes to express its appreciation to Mr. P. Martinelli of the Forest Service, United States Department of Agriculture, for bringing these papers to its attention. It also wishes to record its thanks to Professor A.G. Preller, Colorado State University, for the translation of the paper by Hopf and Bernard "Wind Control Structures in Avalanche Defence and Prevention", to Mr. D.A. Sinclair, Translations Section, National Research Council, for the translation of the remaining two papers, and to Mr. P. Schaerer of this Division who checked the translations.

Ottawa
October, 1968

R.F. Legget
Director

NATIONAL RESEARCH COUNCIL OF CANADA

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(Ökologische Untersuchungen in der subalpinen Stufe zum Zwecke der Hochlagenaufforstung. Teil II

1. Windbeeinflussende Bauten in der Lawinen-verbauung und -vorbeugung, von J. Hopf und J. Bernard
2. Versuche mit Kolktafeln an der Schneeforschungsstelle Wattener Lizum (Tirol) in den Jahren 1950-1955, von J. Hopf and H. Wopfner
3. Modellversuche mit Kolktafeln im Windkanal, von A. Fuchs)

Reference: Mitteilungen der Forstlichen Bundes-Versuchsanstalt Mariabrunn, (60): 605-681, 1963.

Translators: Professor A.G. Preller, Colorado State University, Fort Collins, Colorado, U.S.A. and D.A. Sinclair, Translations Section, National Science Library

1. WIND CONTROL STRUCTURES IN AVALANCHE DEFENCE AND PREVENTION

by J. Hopf and J. Bernard

Abstract

The location and design of snow fences, baffles, and jet roofs are discussed on the basis of information from the literature and current experiments made by the Avalanche Service of Tyrol, Austria. Several years of observation of snow depth, location of drifts, cornices and type of vegetation are necessary before such structures can be built. Studies were made on the influence of height, density, flexibility and roughness of fences on the shape and the location of the snow deposit. Flexible fences made of pine branches and fences having low density create long, uniform deposits desired in areas to be reforested. Baffles and jet roofs on mountain ridges prevent the formation of cornices. Local conditions dictate whether a baffle that influcences the snow deposit in the vicinity or a jet roof that creates snow accumulations further down the slope, should be used.

1. Introduction

One of the most striking phenomena of the alpine snow cover is its irregularity. Trenches, hollows and shallow spots are frequently covered by the first snowfall with a snow cover that lasts into the summer. Ridges and crests are free of snow even in deep winter. It is true that at times this condition can be hidden under a uniform snow cover as the direct result of undisturbed snowfall. However, after periods with strong wind, the characteristic forms of snow deposits influenced by the terrain will again become apparent. Thus, the amount of precipitation is of less importance in determining snow depth and duration of the snow cover than the influence of terrain and wind. According to this, the wind is so significant in eroding and accumulating snow that it becomes a determining factor for avalanche formation above the timberline.

If the wind blows over the terrain with great speed, particularly over elevations, erosion takes place, while the snow, which has been picked up and carried along, is deposited again at places of lesser velocity. Thus, like water, wind has a definite transporting power whose magnitude is a function of its speed. Loose snow is more easily transported by the wind than densely deposited snow, dry snow more easily than wet snow and new snow more easily than metamorphosed old snow. Near the ground, the transport occurs with lesser speed than in higher layers. On slopes, currents blowing uphill have a lower transporting force than those blowing downhill.

A. Wind and Snow Transport

Under certain snow conditions any wind which blows with adequate velocity and intensity is capable of bringing about snow transport. It is therefore essential to know the occurrence and speed of the prevailing winds in order to plan structures which would influence them. Periodic katabatic winds are usually not considered important for a snow transport. They do not blow with the required speed during the winter. Mountain, valley and slope winds are significant for snow transport only when they occur simultaneously and are superimposed on large-scale gradient winds whose intensity is thereby negligibly increased or weakened.

By and large, an area is to be evaluated by its position in relation to the prevailing gradient wind. It must be decided, therefore, what large-scale wind prevails; for example, the Austrian mountains north of the main Alpine Ridge are under the prevailing influence of northwest winds, whose direction below the ridge level is, however, to a large extent determined by the course of the valley. In north-south valleys of the interior Alps, the south component may predominate through the influence of the foehn - for example, at the Brenner depression and Wipp Valley.

The effects of gradient winds on the terrain can be evaluated from the position of the valley in relation to the main wind direction. Valleys parallel to it are subject to strong winds. Those at right angle to it are under large scale lee effects, which also determine, to a large extent, the amount and distribution of precipitation. Large lee locations exhibit a more even snow cover, whose depth distribution is dependent, to a lesser degree, on the micro-relief; areas open to the wind, on the other hand, show great variations of the snow deposit, which depend on the micro-relief and which leads here to differentiated site conditions.

These prerequisites, together with the slope and exposure of the terrain, form the basis for the snow distribution, which in open areas above timberline can be found every year in similar form as "statistical balance between the cause and effects of the weather conditions." (Friedel 1952). Proof of this are the melt patterns which are the same every year at the time of the thaw.

This phenomenon can be seen only vaguely in the forest belt, because speed and constancy of the wind become less with decreasing altitudes and because the forest works against snow transport by lifting the wind field and decreasing the wind velocity.

Where the compensating effect of the trees is lacking, the wind reaches the ground, blows over the terrain and, depending on the micro-relief, determines the depth of the snow by erosion and sedimentation.

Snow distribution brought about in this manner has a decisive influence on the climate of small areas. Ecological series of plant communities are formed which are directly dependent on the duration of the snow cover and, thus, on the depth of the snow and the influence of the wind. Knowledge with respect to ecological series of plant communities must, therefore, be considered here inasmuch as their occurrence is to be related to the wind or more specifically, its effects - the duration of the snow cover (Fig. 156).

Thus, these plant communities designate areas where snow transport can be influenced by building obstacles for the wind. That is to say, where drifting snow can be forced to be deposited where the erosion of snow can be prevented or where the snow can be moved into safe terrain by increasing the speed of the wind.

B. The Concept of Wind Obstruction

Because wind influences snow deposition in unforested mountains, wind obstruction is a component of avalanche defence in a technical as well as in a biological respect. Thus, wind control structures influence snow distribution (quantitative effect) and quality of the snow (qualitative effect).

Disregarding the fact that both effects may occur simultaneously, wind control structures shall be divided into drift control structures and consolidation structures depending on whether the snow deposits are influenced quantitatively, i.e. through the formation of drifts, or qualitatively, i.e. through consolidation. Wind obstructions can, therefore, be added to retaining, braking and diversion structures in the inventory of avalanche control structures.

C. Fences as Afforestation Protection

In afforestation, for the purpose of raising the timberline, the wind plays a deciding role by creating extremely differentiated snow covers and, thereby, differentiated bio-climatic site conditions;it actually has damaging effect on exposed places through mechanical action and by piling up snow on lee slopes, it increases the snow pressure on young trees. Thus, an optimum zone for the growth of plants corresponds to a moderate snow depth as well as moderate wind. This usually lies in the transition from the windward area to the leeward area.

It is therefore, the task of fences in wind-exposed areas within the possible timberline to expand the area of medium snow and wind distribution toward the windward and at the same time to decrease the snow deposit in the lee of ridges and crests. This can be achieved through the installation of snow fences. These are intended to produce as even a snow cover as possible in the lee of the fence.

The levelling effect of the fences can lessen, therefore, the amplitudes of wind effect and snow cover in treeless areas, whereby the micro-climatic conditions of exposed afforestation areas are made similar to those in closed stands. The plants which have been brought in find more favourable living conditions which facilitates their growth in the years following the transplantation. Until having gained enough strength they are able to take over their own protection, at which time the fences have fulfilled their function.

II. Investigations To Date

With varying motives and under different conditions, a number of practitioners and scientists have carried out investigations on wind obstructions. Tests in open country and wind tunnels examined particularly the form, the fence density (i.e. the relationship of effective surface to total surface of a structure), and questions regarding effective range and material (Croce 1942 and 1950, Nägeli 1953, Kreutz and Walter 1956 and 1958, Gayl and Hecke 1953, Fuchs 1954, Brandtner 1955, Kaiser 1960). Besides these studies which were concerned primarily with the quantitative influence of snow distribution, observations and measurements were undertaken regarding the consolidating effect of baffles on the snow cover (Campbell 1955, Wopfner 1956).

A. Baffles

Baffles are tabular wind obstacles (Fig. 157) placed in avalanche starting areas to cause the wind to make snow scoops or depressions in the snow cover. The scoops disrupt the tensile stresses in the snow cover. Dense snow with high strength is formed around the scoops. In this way the fracturing of the snow cover can be delayed or even prevented. Without sufficient wind, the baffles are ineffective. The most favourable area for baffles, therefore, is between the windward and leeward zones, where there is still sufficient wind to make them function effectively.

Attempts to explain the effect of single baffles were carried out in the years 1950 to 1955 at the Wattener Lizum Snow Research Station in the Tyrol at an elevation of 2,000 to 2,300 metres. In order to follow the formation and disappearances of the alpine snow cover during the studies, a snow-time profile was made in which snow depths, temperature, wind, sunshine, radiation, and humidity were recorded throughout the entire winter (October through June).

The investigation, which was supplemented in following years by the construction of baffles in avalanche fracture areas, gave the following preliminary result.

1. Baffles with a bottom gap

In the case of baffles with bottom gap (Fig. 173c) the eddy field, generally speaking, does not reach deep enough to cause a scoop to the ground. This disturbs the homogeneity of the snow cover but does not completely break the stratification. Around the scoop, a ring or horse-shoe-shaped zone of consolidated snow is formed. The outer radius of this ring amounts to 6 to 8 metres with a baffle two metres wide. In the horizontal experimental field, an increase in strength up to 100 percent of the uninfluenced snow was noticed. In the consolidation zone, the snow is also denser and heavier. Toward the outside, the high strength values gradually merge with the ones of uninfluenced snow cover.

2. Baffles without a bottom gap

Baffles without a bottom gap (Fig. 157, 173e) disturb the snow cover more deeply and effectively than those with a bottom gap. The snow scoops reach deeper and interrupt the snow cover usually down to the ground. The zone of consolidated snow around the scoop extends 8 to 10 metres from the centre of a baffle three metres in width. The strength in this area was up to 180 percent of that in the uninfluenced snow. Besides this, an increase of density from 172 kg/m^3 in the uninfluenced snow cover to 263 kg/m^3 in the consolidated ring were noticed in a series of measurements at the horizontal experimental field; this corresponds to an increase of 53 percent.

Thus, to prevent the formation of slab avalanches, baffles without a bottom gap are preferred. They produce deeper eroded zones with more discontiniuties of the tension field and a higher strength of the surrounding snow. The high strength and the high density are caused by the deposition of the snow under wind (wind packing).

The best effect can be attained under the following conditions:

1) The baffles should be at right angles to the prevailing wind direction; if this direction is not known, a cruciform baffle is better.
2) Baffles having the long axis down slope are less subject to snow pressure when covered with snow.
3) The dimensions of the baffles must correspond to wind speed and the amount of snow. However, a width of five metres should not be exceeded.

According to Campbell, it is advantageous if the baffles are narrower toward the bottom.

4) Best effects are achieved with solid baffles (100% density).
5) They should be at least as high as the maximum snow depth in order to remain effective even at great snow depths.
6) The distance between the individual baffles is to be determined according to investigations to date - by using the rule that the consolidation zones of two neighbouring baffles should touch each other. This is 15 to 20 metres for baffles without a bottom gap. If the consolidation rings are to support the snow cover above it, then an abuttment has to be present that acts perpendicular to the slope, and through which the internal sheat and tensile forces are transferred into the ground. On slopes of low roughness (i.e. high gliding factors) the avalanche-preventing effect of baffles will be less than on rough slopes with low gliding factors.

Through the use of rows of baffles, avalanche fracture zones can also be separated one from another by preventing the spreading of slab fractures to neighbouring areas (Campbell 1955 and Fig. 158).

B. Drift Fences

Extended wind obstructions, (snow fence, snow wall, snow hedge, drift fence) cause a disturbance of the flow lines by creating turbulence and slowing the wind. The snow carried along by the wind is deposited in a definite pattern in front and behind the snow fence (Fig. 159). This snow deposit is dependent upon the velocity of the wind, the type of snow, as well as by the site, size, and material of the fence. The primary factor, however, is fence density. A low density results in long, shallow snow deposits. High density results in steep, short snow deposits.

The amount of deposited snow in front and behind the fence, according to Croce, is a maximum at densities between 0.25 and 0.50. Based on experiments in open country, he put the effect of drift fences in relation to height of fence (h) and density (f) into a distance formula which indicates, for horizontal terrain, the distance the fence should be from the object to be protected - for example, railways or roads:

$$A = \frac{11 + 5h}{k} \quad (+ 5).$$

In this formula, A is the required distance in metres, h = height of fence in metres and k is a coefficient depending on density which increases from k = 0.80 at f = 0.35 to k = 1.35 at f = 0.75. The factor 5 at the end of the formula is a safety factor.

Croce recommends as even a distribution of density over the entire fence as possible which was confirmed by Kreutz and Walter (1956). The latter also point to the processes leading to turbulence in the case of rigid and impermeable edge zones. According to this the loss of energy occurs more evenly with a sieve-like arrangement of openings than with a stripe-like distribution (wooden fence, metal hurdle).

Roughness with flexibility of the fence are also of particular importance for the formation of lee eddy zones and, therefore, for snow deposit according to wind tunnel investigations by Kreutz. In the case of snow fences with a low density and equal geometric porosity, greater roughness and flexibility increase the effect of protection effects on the lee side and produce more regular and longer deposits.

III. Current Experiments of the Avalanche Service

Because of the significance of wind for avalanche formation and afforestation, further investigations with drift control structures and baffles have been carried out in recent winters. The experiments investigated to what extent tests carried out on level ground could be transferred to conditions in the high mountains. Experimental structures were erected in the test areas above Obergurgl at 2,150 - 2,250 metres (Ötztal), at the Paidaer Sonnberg at 1,900 metres (Sellraintal) and at the Metzenrücken at 2,000 metres (Zillertal).

The following questions were of primary concern:

A) Effective range of snow fences.

B) The relation of snow fences to vegetation communities, and protective effects on afforestation.

C) The effect of induced snow deposition on snow distribution on avalanche slopes.

D) Comparison of baffles and jet roofs for the prevention of cornices.

A. Effective Range of Snow Fences

The question of the effective range of snow fences was studied to some extent during the current experiments; particularly since the distance formula given by Croce:

$$A = \frac{11 + 5h}{k} \quad (+ 5)$$

was determined for fences approximately two metres tall and in low country so that it still had to be examined for varying height of fence in the mountains.

Croce also wanted to determine the maximum length of a deposit with his formula (the factor 5 at the end of the formula is a safety factor) while the Avalanche Service was rather interested in the average range of snow fences.

In the above-mentioned test areas, approximately 12 different types of fences have been erected in recent years and the snow cover was examined within their range of influence. The fences were of various flexibility, roughness, heights (1 - 4 metres), and densities (0.40 - 1.0). These factors showed the following effects on snow deposition.

1. Influence of flexibility and roughness. Highly-flexible structures (for example, movable stone pine Zirben fence give a long, uniform deposit even with small amounts of snow so that it offers good protection for afforestation even in early winter or poor snow winters. Thus, given equal density, flexible structures produce an effective snow deposit in a shorter time. Through flexibility, the structure adapts better to varying wind velocities (Fig. 159).

Roughness of snow fences, similar to flexibility, increases the leeward effect. Slat-type structures (wood fence), should be built in two planes, 10 to 15 cm apart, with half the total density in each, because in this manner a deceleration zone is obtained in the fence (Fig. 160). However, this is only the case if the fence is perpendicular to the wind. If it is at an angle to the wind, the effective density is lowered.

2. Influence of fence height. In the case of fences up to 4 m tall, the length and height of the deposit is dependent upon the height and density of the fence, provided there is sufficient wind and snow. In general, the depth of the deposit is limited by the height of the fence. The higher the density of a fence, the sooner the snow deposit reaches fence height. Where protection of afforestation is the goal, the snow depth optimum for the plants, together with the amount of snow available, determines the height of the fence.

If a fence is situated in terrain where the wind blows uphill, the wind is conducted upward more strongly and the deposit in the lee of the structure exceeds the height of the fence (Fig. 161). When the terrain slopes the other way, the opposite effect may be noticed.

Raising the fence from the ground (gap at the bottom) results in shifting the deposit to the leeward. Thus, the snowing-up of the fence can be prevented.

3. Influence of density. Density of the fence is the most important factor determining the nature of the deposit. Fences of high density first cause a short, steep deposit in the lee since the wind is conducted over the structure and causes a counter-eddy close to the ground. A decrease in density results in a longer deposit (Fig. 162). In the case of high fence density, the deposit near the fence quickly reaches the height of the fence and then gradually pushes leeward-similar to a cornice, so that the differences between fences of various densities (0.50 - 0.90) are largely obliterated after large amounts of snow in late winter.

The experiments showed that from a technical standpoint a slat-like arrangement is the most favourable type of fence. Vertical slats have the advantage of making the upper edge of the fence rough and permeable, and in this way prevents unfavourable turbulence and eddies. These fences are also more durable because they are less vulnerable to pressures due to settlement and creep when they are covered with deep snow.

From what has been said, the effective range of snow fences - as was shown by Croce - is primarily dependent upon their height and density (Fig. 163). The evaluation of the experiments resulted in the following empirical formula for the average length of the lee drift (L) of snow fences with heights (H) of 1 to 4 m and densities (f) starting with 0.4:

$$L = \frac{5H}{f}$$

Investigations on the relationship of length of drift and slope angle showed that the length of the lee drift decreased with rising terrain and increased with falling terrain. Careful evaluation of the experiments to date gave the following the relationship for a slope angle of ±20 percent:

$$L = \frac{5H}{f} \cdot \left(1 \mp \frac{p}{100}\right)$$

p = slope angle in %

The comparison between the formula $L = \frac{5H}{f}$

and Croce's formula $L = \frac{5H + 11}{k}$

results in good correlation for fences 2 m and 3 m high, but it results in higher Croce values for 1 m because of the constant 11 and lower ones for fences 4 m high.

As has been pointed out, the denser the snow fence, the faster the maximum height of the deposit is reached. Since the amount of snow trapped depends on the length and height of the deposit, the question arises, what is the most favourable density in order to reach a maximum deposition? Observations show that with a low fence density (under 0.4) the height of the deposit does not always reach that of the fence. Thus experience shows that

0.50 to 0.70 is the most favourable fence density for achieving maximum deposition on the lee side of the fence.

B. Snow Fence in Relation to Vegetation and Afforestation

The plant communities shown in Figure 156 develop in wind-exposed shady locations in the subalpine zone of the central Alps, depending on the micro-relief and the duration of the snow cover. For reasons already explained, the optimum area for stone pine afforestation lies in the Vaccinietum uliginosi zone and reaches in part to the Rhododendretum ferruginei zone of medium snow cover. Snow fences with medium density placed in advanced areas of Alectorietum during the winters of the experiment kept the otherwise bare ridge snow-covered during the entire winter, thus the area favourable for afforestation was enlarged and the amount of snow in the Rhododendretum zone was diminished (Fig. 165). In the protection of these fences, an experimental afforestation of stone pine and larch was carried out, which may be compared with a planting on the neighbouring unprotected ridge.

Ram profile studies showed that the hardness of the snow deposited behind the fences was much higher than that of snow deposited on horizontal areas, uninfluenced by wind. The hardness values observed in the course of one winter showed and average relationship of 3 to 1. In the case of a flexible fence made out of stone pine branches (height 2 m, density 70 percent), the zone of this greater hardness started at 3 to 4 m on the lee side of the fence and faded out at 8 to 10 m (Fig. 159). This is the zone of greatest snow depth in the lee of the fence, which is also the last to be free of snow in spring.

Solid fences are therefore less appropriate as drift control structures for afforestation, since they produce steep and short deposits and, because of strong eddies, an irregular reduction of wind velocity, while fences with low density are more suitable because there the snow deposit is more regular and covers a larger area.

C. Effects of Snow Accumulation by Fences on the Snow Deposit on Adjacent Avalanche Slopes

Investigations in zones influenced by snow fences have shown that the upper part of lee slopes were relieved of snow in amounts approximately equal to those that were deposited behind fences immediately outside or above the avalanche slope, provided the terrain was suitable. This was particularly obvious where, prior to the construction of fences, cornices had formed on the lee slope. These could be prevented almost completely through the erection of snow fences on the windward slope (Fig. 166).

An advantage of this type of cornice prevention is that the snow which forms the cornice is deposited before it reaches the edge of the ridge. This method requires, however, an area in front which is as long as the effective range of the fence. Baffles or jet roofs have to be used (Fig. 166) where this area is not available.

D. Prevention of Cornices through the Use of Baffles and Jet Roofs

This method is applicable where there is no possibility to retain the drifting snow before it reaches the lee slope, that is to say, on crests and narrow ridges. In this case baffles and jet roofs have the effect of transporting the snow over the crest to the slope below.

Baffles: The best effect is achieved if these structures are erected directly at the edge of the terrain break (Fig. 167 and 168). They should be solid and a gap at the bottom up to 1 m high is advantageous. Baffles are not to exceed 3 m in height, 4 m in width and the space between them should be not more than 4 m (or one time the width of the baffle).

The advantages of baffles for the prevention of cornices is that the snow that drifts over the crest is distributed uniformly on the lee slope over a long distance (Fig. 168).

Jet roofs: The most effective drift-control structure for the prevention of cornice formation is the jet roof. It is a roof-like structure which is strongly inclined toward the slope, and has a gap at the bottom. If this jet roof is placed at a break in the terrain, that is to say, at the base of the cornice, the wind is accelerated under the jet roof and the snow is transported to the lee slope (Fig. 169).

Because of the flow of air close to the ground, the area below the roof remains free of snow to just slightly snow covered.

For best results, the roof should have about the same inclination as the slope lying behind it and the gap on the lee side should be 1 to 1.5 m high (Fig. 170 and 171). The height of the jet roof on the windward side depends on the width of the roof, which can be considered sufficient at 4 m. The length of the jet depends on the shape of the terrain: it may be long in regular terrain reduced when the terrain is irregular, and the space between roofs should not exceed 4 m. A solid roof is the most favourable from the standpoint of aerodynamics, however, small gaps (up to 2 cm) between the boards have the advantage of keeping the roof free of snow.

Due to the jet effect, an avalanche slope can be kept free of snow for a distance of 10 to 15 m below the ridge (Fig. 169). The jet roof has the disadvantage of transporting snow to the avalanche slope below, where it causes an unintended increase in snow depth. The deep snow could cover the uppermost supporting structures and overloading may result. When baffles are used, on the other hand, snow depth on the highest part of an avalanche slope is still tolerable.

The use of jet roofs or baffles requires, therefore, an accurate evaluation of the conditions of terrain, snow and control structures. Without a doubt, the jet roofs will be preferred where the transported snow can be deposited on a safe area of the slope with low incline.

IV. Summary and Design Considerations

Wind and snow distribution are deciding factors for avalanche formation. It is possible by erecting wind control structures to alter the factors at certain places so that avalanche formation is retarded or minimized. To do this a knowledge of the uninfluenced wind and snow distribution in the control area is required.

The design of structures should be preceded by several years observations of the snow conditions in the accumulation and fracture area of the avalanche. Observations of snow depth are required; when erecting the depth guages; the shape of the terrain and the vegetation should be taken into consideration. These measurements together with observations of melt patterns produce a picture of the usual snow distribution. Together with a connection which allows for catastrophic snowfalls, they are the quantitative basis for technical preventive measures. This correction can be ascertained by comparing the measured snow depths with the long-range observations at a base station in the neighbourhood (cf. Eidgen, Inspektion für Forstwesen 1961: Richtlinien für den permanenten Stutzverbau) (inspection for forestry 1961). Guidelines for permanent supporting structures). (Available in English as Station Paper 71 of the Rocky Mountain Forest and Range Experiment Station).

The direction from which the intense - and thus snow-transporting-winds blow can be seen from the cornices and can be estimated even in the summer from the vegetation. Wind-exposed sides of small knolls show, for example, wind-tolerant lichen growth, while next to it Loiseleuria procumbens can be seen. Conclusions regarding wind conditions near the ground can be drawn from the size and variation of these areas.

These observations provide the possibility of evaluating the effectiveness of wind-control structures. The application of wind-influencing structures will not be as far reaching in the case of avalanche control as in the case of avalanche prevention. In the latter case, we are dealing primarily with the protection of afforestation and therefore not such a high degree of safety is required. In avalanche control, because of safety requirements, wind-control structures serve primarily to decrease the load on supporting structures. The location of the structures to protect afforestation has to be deduced from the distribution of the plant communities within which a protective effect is to be achieved. In the central alpine zone of igneous rock, at and above the timberline, this is the Alectorietum and the Loiseleurietum zones. From the standpoint of wind-control technique, this is followed by the possible area of consolidation structures (baffles) while the low-wind Rhododendretum zone is left to avalanche-supporting structures.

The effective range of snow fences can be determined from the empirical formula:

$$L = \frac{5 \cdot H}{f} \text{ (H = fence height, f = fence density)}$$

To determine the conditions of a given site, snow fences are to be erected at representative spots and observed for a winter. The snow distribution, as changed by the fences, is to be mapped and from this final locations of the fences are to be derived and the effect on supporting structures is to be evaluated (reductions of costs through reduction in the height of structures).

Snow fences with high density first cause a short deposit, which does not grow leeward until the snowfall increases. Reduction in density results in a longer deposit. The choice of density and height of snow fences depends largely on local conditions and the desired effect. Fences with vertical slats are advantageous, because the permeable zone at the upper edge furnishes a better effect. These fences are also more durable, because they are less vulnerable to pressures due to settlement and snow creep when they are covered with deep snow (Fig. 173a and b).

Flexibility of snow fences results in increased beneficial effects, particularly with small amounts of snow. Three-dimensional arrangement of the solid material in a fence is favourable if the main wind is perpendicular to the fence. According to experiments to date, the greatest deposit in the lee of fences is achieved with a density of 0.50 to 0.70.

To prevent cornices by the use of baffles and jet roofs, a few preliminary structures should be put up to see what their effects will be on snow distribution on the adjacent lee slope before supporting structures are built. Usually a more favourable snow distribution on the slope is achieved with baffles than with jet roofs (Fig. 173c and d), which keep the highest part of the slope free of snow, but allow more snow to accumulate farther down.

The structural analysis of the structures must take into consideration wind pressure relative to the effective surface. From this follows a relation between cost of the structures and density.

Baffles which are intended to consolidate the snow cover in the avalanche fracture area and prevent the fracture (Fig. 173e) should be erected in such a way that an intensive eddy formation is guaranteed. The preliminary construction of a row of baffles from the windward to the leeward and observations for one winter will provide information on wind effects. The baffles should face the main wind direction, have 100 percent density and be 1 m higher than the snow cover. The width should not exceed 5 m; it is advantageous for the baffles to have reduced width toward the bottom. The spacing should be 15 to 20 m. Slopes having low friction are less suitable for baffles than slopes with low gliding factors.

The materials for snow fences, jet roofs and baffles are determined by the required life-span of the structures.

Degree of Safety

Wind is the determining factor for drift structures and baffles. They do not function when there is no wind, but such a situation is rarely encountered in connection with snowfall above the timberline, according to records at Weissfluhjoch Ilavos (2650 m), Lizum/Tyrol (2000 m) and Sonnblick (3100 m) (Fig. 172). The snowfalls which caused the catastrophic avalanche occurrences in 1951 and 1954 were accompanied by strong winds at the ridges at elevations between 2000 m and 3100 m. This was observed at the Sonnblick Summit Station and at the Weissfluhjoch Ridge Station, as well as at the Lizum Valley Station.

A high degree of effectiveness and safety in influencing local snow distribution can be attained by the correct choice of material, size, density, and location of drift structures. They are effective as soon as wind occurs. In the complete absence of wind the snow cover will have the desired homogeneity. However, calm, occurring on slopes where baffles have been installed to consolidate the snow cover renders these structures useless and destroys the safety effect. Not even on slopes well exposed to winds is there complete safety. Snowfall accompanied by intensive wind results in the rapid growth of the snow cover, whereby the stresses which eventually lead to its fracture become larger. Only an increase of strength in the baffle area equal to the increase of tensile and shearing stresses in the entire snow cover would assure complete safety. Such congruity, however, is by no means assured, particularly since the properties of the snow play a decisive role: very cold and dry new snow - as in the catastrophic avalanche of 1954 in the Vorarlberg- has very poor cohesion.

The application of baffles will therefore remain limited to relatively small fracture zones in wind-exposed areas, where there is a tendency for snow slab fracture due to wind action and where no very great valuable objects are threatened.

Because of the uncertainty of its premises, this control method will have to be regarded as an occasional supplement to avalanche supporting structures rather than a substitute for them.

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Mean duration of a continuous snow cover →

Mean snow depth in April →

Direction of prevailing wind →

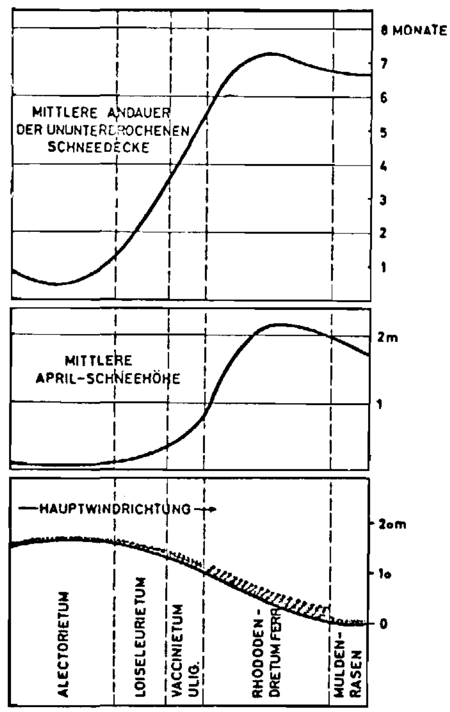

Figure 156

Schematic description of subalpine plant communities of the ecological wind-snow series as a function of the microrelief and snow cover according to measurements in the Obergurgl experimental area 2,200 m elevation, west exposure, for the years 1954-58 (Turner 1961)

Figure 157

Formation of strong snow scoops around baffles without bottom gaps in the highest fracture zone of the Paida avalanche (1900 m) in the Sellrain Valley

Figure 158

The fracture zone of a snow slab was reduced in width by four experimental baffles. The fracture line of the slab clearly traces the consolidation zones of the baffles. Twenty metres below th baffles (not visible on the picture), the snow fractured at the ridge (northern rib of the Obergurgl experiment area)

Figure 159

Deposit behind snow fences made of stone pine and juniper branches (height 1.8 m, density 50%)

Figure 160

Deposit behind the snow fence (height 4 m, density 60% in staggered arrangement advances to the lee (Paida experimental area)

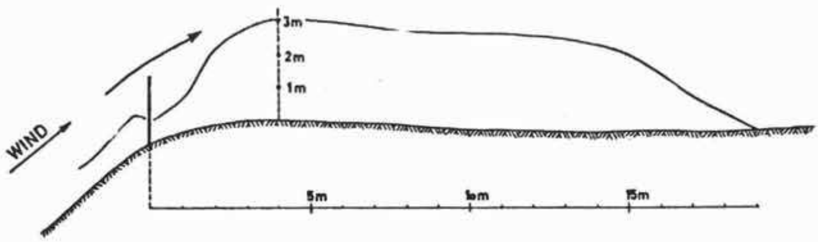

Figure 161

Strong uplift of the upslope wind (foehn at the North range near Innsbruck, 2,250 m) caused a deep deposit in the lee of the fence (height 2 m, density 60%) up to a depth 1 1/2 times as high as the fence

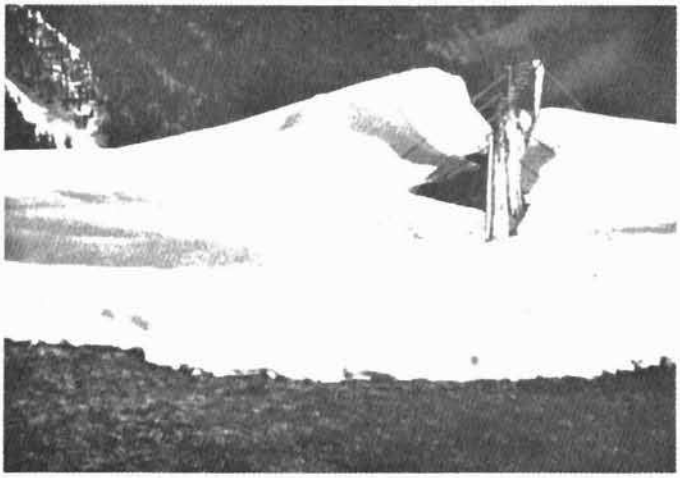

Figure 162

Snow deposit at fences of varying density (in front 50%, farther back 80%) made of vertical metal strips

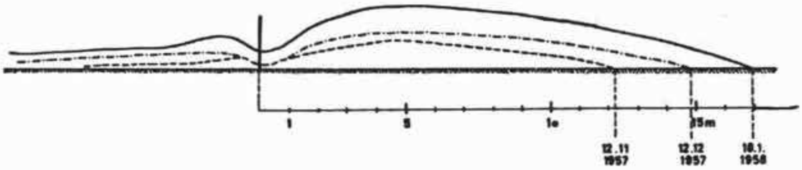

Figure 163

Buildup of the snow deposit near a snow fence (height 1.8 m, density 50%)

Figure 164

Saturated deposit behind a snow fence (height 2 m, density 80%) on the "Daunmoräne" near Obergurgl (2,230 m) after strong uplift of the upslope wind

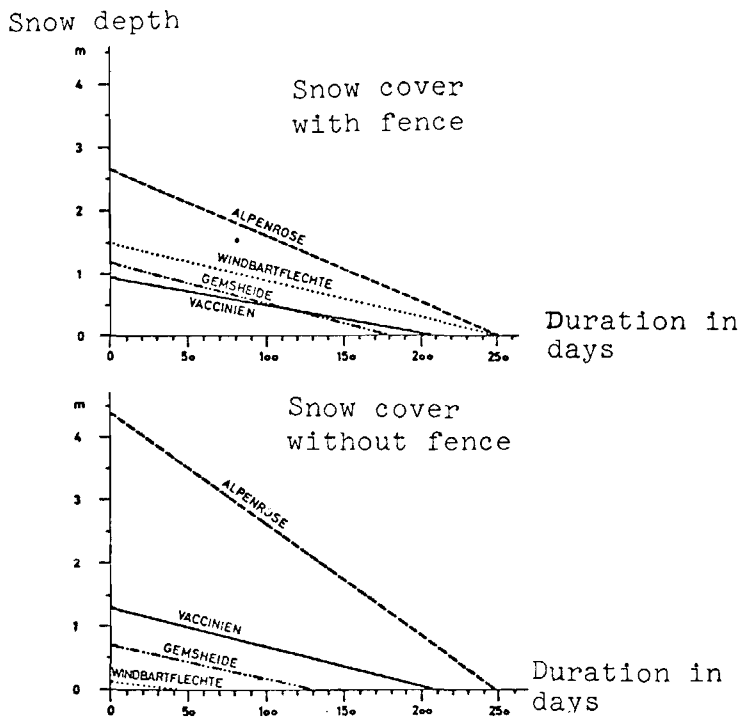

Figure 165

Influencing of a snow cover on a central alpine slope with various plant communities by erection of a snow fence (height 2 m, density about 70%) (according to Aulitzky 1963)

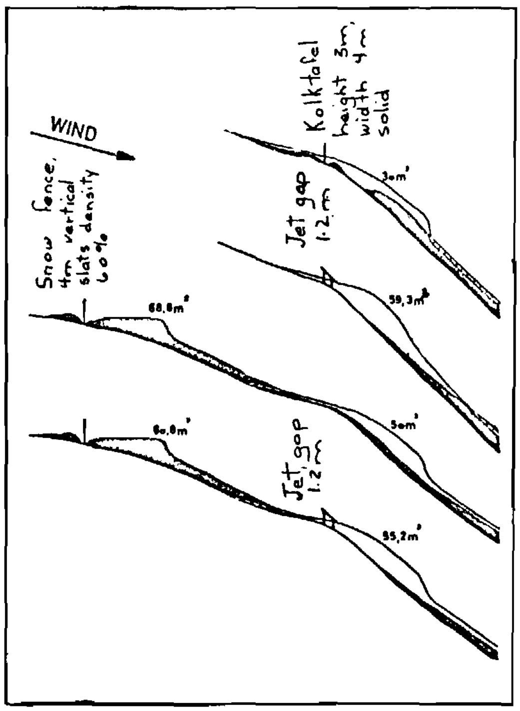

Figure 166

Snow distribution before and after erection of drift control structures (baffles, jet roofs, snow fences). White: snow distribution before erection. Black: snow distribution after erection

Figure 167

Baffles with a bottom gap for the prevention of cornice formation at the edge of a plateau (experimental terrain Wattener Lizum)

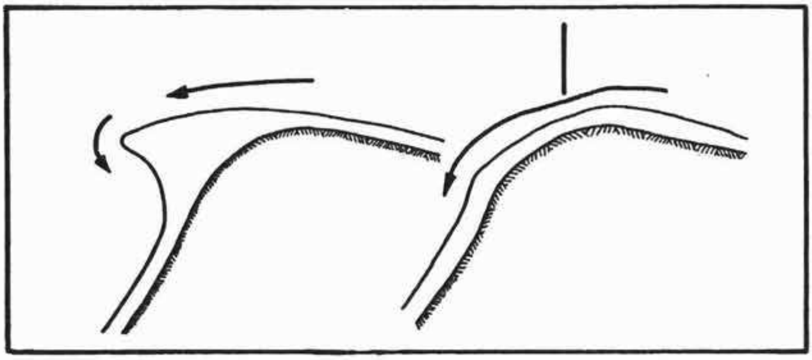

Figure 168

Snow distribution before and after erection of a baffle with a bottom gap for the prevention of cornice formation at a break in the terrain

Figure 169

Cornice prevention using jet roofs in the Paida experimental area. The drifting snow is transported far down the lee slope

Figure 170

Jet roofs maintain the highest area of a fracture zone free of snow and prevent formation of cornices

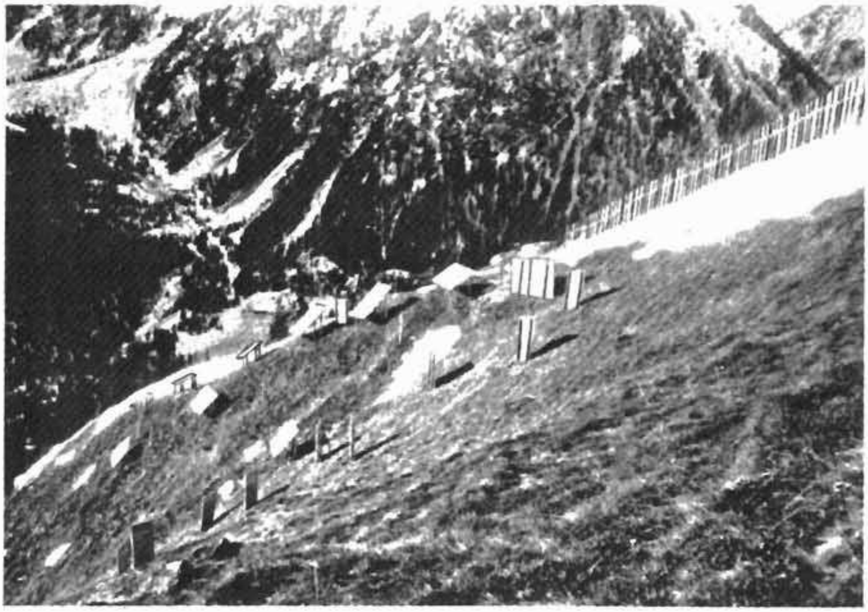

Figure 171

Example of wind-control structures at an avalanche site (Paida experimental area 1900 m) showing baffles (highest fracture zone), jet roofs and baffles (cornice edge), and snow fence (level approach terrain)

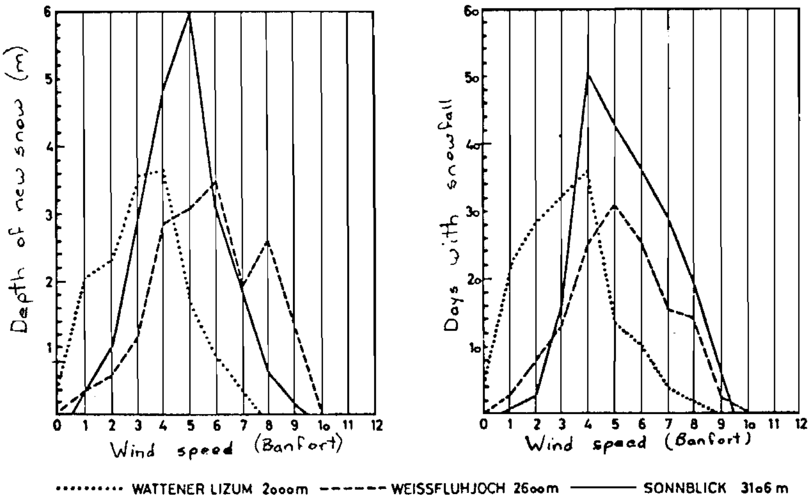

Figure 172

Wind speed during snowfall. Left: new snow depths at various wind speeds. Right: wind speed during days of snowfall. After measurements in January and February of the years 1950-55 at the Wattener Lizum Snow Research Station, the Swiss Federal Institute for Snow and Avalanche Research Weissfluhjoch/Davos (Winter Reports Nr. 14-19) and at Sonnblick (Yearbooks 1950-55, of the Central Institute for Meteorology and Geodynamics in Vienna)

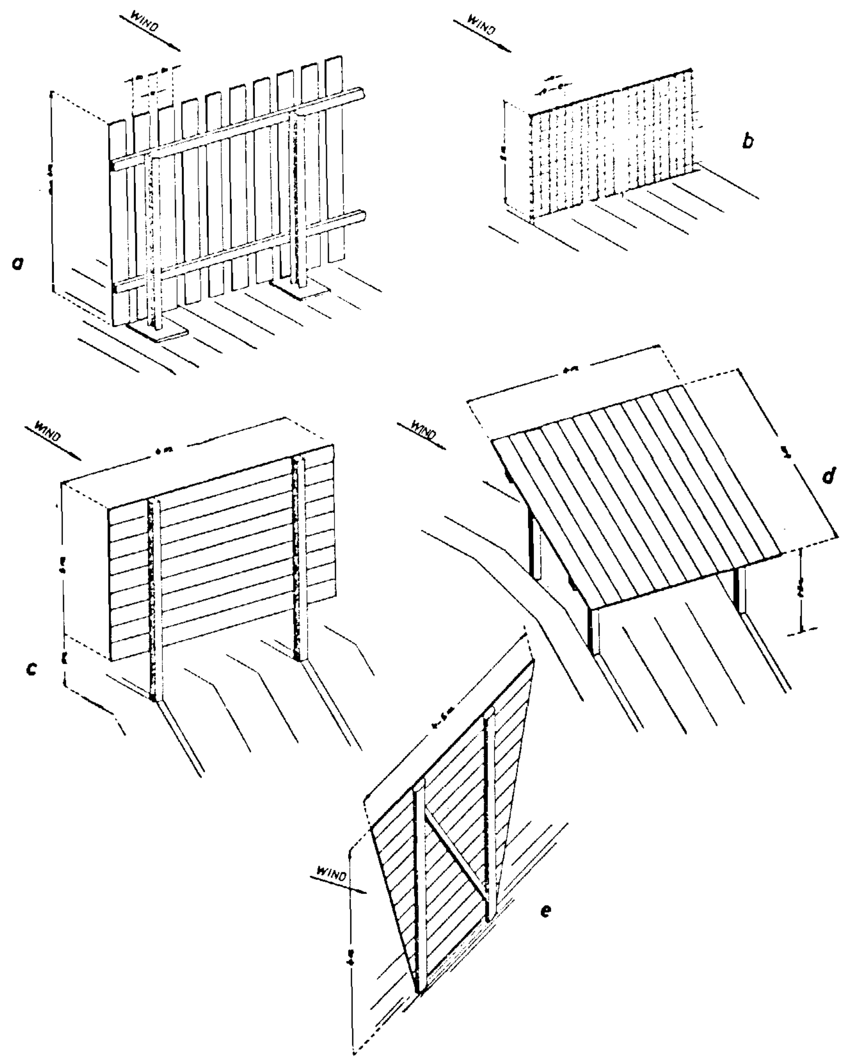

Figure 173

Some types of wind control structures for influencing the snow cover quantitatively and qualitatively:

a) snow fence of wood, density 0.67
b) snow fence of metal, density 0.50
c) baffle with a bottom gap for the prevention of cornices
d) jet roof for cornice prevention
e) baffle for consolidation of the snow cover in the fracture zone

2. TESTS WITH BAFFLES AT THE WATTENER LIZUM SNOW RESEARCH STATION (TYROL) IN THE YEARS 1950-1955

by H. Wopfner and J. Hopf

Abstract

Various types of baffles were erected on a horizontal test field, on slopes and on mountain ridges. The hardness, density and stratification of the snow in the vicinity of the baffles and the size of the snow scoop formed by wind action were observed. The tests proved that simple boards on mountain ridges prevent the formation of cornices. The best location and most efficient size of such baffles are given. Observations on slopes indicated that the snow cover was consolidated around baffles without a bottom gap, and the occurrence of slab avalanches was reduced. Baffles with a gap had insufficient effect and actually favoured the formation of slab avalanches.

I. Introduction

Following a suggestion of Dipl. Ing. Leo Handl, Innsbruck, a study was initiated in the winter of 1950-51 at the Wattener Lizum Snow Research Station (Fig. 174) into the effects of baffles* on the snow cover. Years ago Handl had used such panels for the prevention of cornice formation in the Pagge Valley (Arlberg region) (Handl 1955).

The use of baffles in avalanche prevention had come about as a result of observations on the snow fences which had long been used to prevent snow drifts on railways and highways (Welzenbach 1930). These observations had shown that when properly placed such fences can greatly influence the morphology of the snow cover by deflecting the flow of the air. Moreover deposits of snow in the immediate vicinity of snow fences always show greater strength than the uninfluenced snow cover.

Starting from such observations, the idea developed of disturbing the homogeneity of the usually even snow deposits in the fracture zones of snow slab avalanches with wind barriers in the form of baffles, and at the same time consolidating the snow cover in the vicinity of the baffles. It was believed that consolidation of the snow cover and disruption of its homogeneity would inhibit the start of slab avalanches.

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* Translator's note: The Austrian term "Kolktafel" means literally "eddy panel". The Swiss "Stautafel" = dam panel and "Treibschneewand" = barrier to drifting snow. The word "baffle" in English seems to me to render all these ideas adequately.

The aim of the present report is to show the effects of individual baffles on the snow cover from the results obtained to date. Then, from the effects of the individual boards the logical conclusions will be drawn for the practical application of baffles in avalanche prevention. The tests occupied the period from 1950 - 1955. They were conducted by Dr. Alfred Fuchs (Director of the Lizum Snow Research Station), Dr. Helmut Wopfner and Josef Bernard, at the latter's suggestion. Dipl. Ing. W. Hassenteufel directed the programme as a whole.

The investigations had two separate aims. One was to prevent the formation of slab avalanches and the other was to prevent the formation of cornices with the aid of baffles.

At the start of the tests the experience with snow fences was indeed available (Croce 1942, Welzenbach 1930), but in the investigation of baffles for the purpose of preventing slab avalanches new ground had to be broken.

The principal action of the baffle was expected to be the consolidation of the snow cover in the eddy zone. However, what caused this consolidation? Was it brought about by a vector (wind) governing the grain form? Were there any correlations between the shape of the baffle and the consolidation effect, and what was the influence of the location? These and many other questions had to be clarified before any conclusions could be drawn. When we consider in addition that a winter in which the snowfall is light can partially or wholly jeopardize the test results it will be readily understood why the present results have been rather a long time in preparation.

II. History and Description of Tests

The baffle tests at the Wattener Lizum Research Station were begun in the winter of 1950-51. As a test terrain a 30 to 35° slope to the west of the station was chosen, on which snow slab fractures were known to occur once or twice a winter. We shall refer to this slope hereafter as the baffle test slope (Fig. 175). In the first winter three simple baffles with 75% board density* and 1.2 m bottom gap (type A in Fig. 177) were erected on the test slope. The snow distribution was observed in the vicinity of these boards and snow and ram profiles were recorded from time to time in the wind-eroded zones (Bernard 1952). Other test baffles, again with 75% density but of larger size, were erected on an avalanche slope to the east of the Patscherkofel Weather Station.

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* Translator's note: The board density (Füllungsgrad) is the percentage of the total area of the board that is covered with wood or other material.

In 1951-52 the tests on baffles for the prevention of slab avalanches were continued. So that the boards would respond equally to all wind directions, they were given a cruciform cross-section (Fuchs 1952). The bottom gap was increased to 2 m and a board density of 100% was adopted (type B in Fig. 177; see also Fig. 175) and the snow cover was investigated for hardness (ram resistance) and specific gravity. On the horizontal standard test field two turret-shaped wind barriers, each 4 m high, were erected. Temperatures were measured in the wind-eroded zone at the southern turret (the measurements were carried out by thermistors, readings being taken twice daily), while at the northern turret the stratification in the wind-eroded zone was studied (Fuchs 1952). In the winter of 1952-53, four new cruciform baffles were erected on the baffle-test slope. So that the influence of the bottom gap on the shape of the wind-eroded zone could be studied under conditions of maximum uniformity and minimum disturbance, cruciform baffles of various width and various bottom gap were also erected on the horizontal test field (5 baffles with gaps of 1.50 - 3.20 m; Fig. 176), as well as the baffle test slope. Hardness, stratification and densities were recorded in the vicinity of all baffles both on the test slope and on the horizontal field. At one baffle on the horizontal field (bottom gap 2.00 m) the temperatures in the wind-eroded zone were again measured as in the winter of 1951-52.

In the autumn of 1953 model tests were carried out by A. Fuchs and H. Wopfner in the wind tunnel of the Vienna Technische Hochschule (Fuchs 1954). The purpose of the tests was to study the flow conditions about a baffle as a function of the angle of attack, wind speed and bottom gap.

In 1953-54, baffles of various forms were erected on the test slope, but the test arrangement on the horizontal field was left unchanged from the previous year. In addition a second horizontal test field was set up on the so-called "Oberer Ausmelkboden". Here tests were made on three simple baffles (bottom gap 1.70 m, density 100%) at various angles of attack (60°, 90°, 120°), and on a vertical baffle with no bottom gap. The snow cover was again studied with the conical ram penetrometer during this winter in the vicinity of the individual baffles. Four simple baffles were also set up in 1953-54 on the Pluderling slope and their action was observed.

In 1954-55 the baffle test slope was left vacant so that the hardness of the snow unaffected by baffles could be studied. During this winter two cruciform baffles, one of them tapered and the other with a 2 m bottom gap, were erected on the horizontal test field; two additional tapered baffles (type D in Fig. 177) were erected on a slope to the southeast of Mt. Mölser. Ram and snow profiles were recorded in the area influenced by the baffles.

In addition to the baffle tests for the prevention of slab avalanches, tests with baffles for the prevention of cornice formation were carried out in the winters of 1950-51 and 1951-52 on the northwest rim of a plateau, situated WSW of the station (Fig. 178 and 179), and on which a large cornice builds up every winter. Each winter three simple baffles with a bottom gap were erected (type A in Fig. 177, gap 80 cm). During the first winter the boards were set up on the eastern part of the plateau rim, and in 1951-52 the western part was selected. In both winters the test areas were subjected to special continuous observation following longer periods of foehn. Snow cover measurements were carried out from time to time. There were no observations of the snow strength (ram profiles, etc.). In tests of this kind, where the effects are so visibly clear, photographically recorded observations were found to be sufficient.

In the winters from 1950-51 to 1954-55, 23 baffles were erected on slopes, 17 baffles as well as 2 turret-like wind barriers on horizontal tests fields, and 6 baffles at the top of a cornice-forming precipice. At these structures, a total of 863 ram profiles, and 182 snow and density profiles were recorded.

In the present report it is not possible to present all the quantitative material collected during the different winters either graphically or in the form of tables. This would make the report unnecessarily long. Graphs have therefore been included only where they appeared necessary in order to illustrate the text.

III. Terminology

A. Explanations and defintions

Angle of attack: Angle between the direction of the wind and the baffle. Values of 0 to 90° are to windward, 90 to 180° to leeward.

Bottom gap: Open space between surface of ground and bottom edge of the baffle.

Density: Effective baffle area expressed as a percentage of total baffle area (including unfilled gaps).

Boundary face texture: Texture produced by processes localized at boundary faces and explainable only in terms of the symmetries of these processes. Here it applies specifically to the boundary between the air and the surface of the snow.

Eroded zone or snow scoop: Any obstacle opposed to the wind causes turbulence around it, as a result of which a depression is formed in the snow cover around the obstacle. Such a depression is called an eroded zone or snow scoop

Depth hoar: Aggregate of cup-shaped snow crystals (hollow forms); final stage of constructive metamorphosis. It is encountered chiefly near the ground.

Wind-packed snow: Snow that has been consolidated by wind action. The consolidation is the result of close spacing of the snow grains owing to ajustment with respect to grain form; typical boundary face texture with predominantly monoclinic symmetry. Actually no packing in the sense of compression is involved, but the expression "wind-packed" is now so firmly established that it has been retained here. A better expression would be "wind-consolidated snow".

B. Types of baffles:

The nature of the subject under investigation was such that in the course of the tests very different forms of baffles had to be tried. At the beginning of the tests it was not at all clear which form would be most effective for the prevention of cornice formation on the one hand, and for the prevention of snow slab avalanches on the other. It was first necessary to try individual forms and study their effect on the snow cover. Model tests, such as the investigations of the flow conditions about a baffle in the wind tunnel, provided valuable hints, but final confirmation had to be left to the test under natural conditions. Thus, the simple baffle with bottom gap and 75% board density (type A, Fig. 177) proved effective for the prevention of plateau cornices on the first try, whereas other forms, e.g. type C, Figure 177, did not meet the demands made of them under the given conditions.

In order to show briefly the evolution that has taken place in the forms of baffles, the most important forms that have been used to date are reviewed in sketches A to F of Figure 177. The dimensions of the baffles illustrated in Figure 177 were as follows:

A Total height 320 cm, baffle dimensions 400 x 200 cm, bottom gap 120 cm, density 75%.

B Total height 400 cm, baffle dimensions 200 x 200 cm, bottom gap 200 cm, density 100%.

C Total height 430 cm, baffle dimensions 230 x 230 cm, bottom gap 200 cm, density 100%.

D Total height 350 cm, baffle dimensions 200 x 200 cm, length of tapered part 150 cm, density 100% when made of wood, about 80% when made of aluminium.

E Total height 300 cm, baffle dimensions 300 x 300 cm, no bottom gap, density 100%.

F Total height 300 cm, bottom edge length 200 cm, top edge length 300 cm, no bottom gap, density 100%.

IV. Tests with Baffles for the Prevention of Cornices

Falling pieces of cornices may start loose snow or slab avalanches on the slopes beneath. By erecting a wind barrier near the edge of the terrain that causes the cornice to form (ridge, plateau rim, etc.), the deposit zone for drifting snow is moved far enough to leeward that there is no longer any formation of a cornice. In place of the cornice there will be a snow scoop that is open downwind behind the barrier.

Our tests, which, as already stated, were conducted at a plateau rim WSW of the station, fully confirmed the above considerations.

At the northeast plateau rim of the test terrain, where a steep drop occurs, an immense cornice with an overhang of 2 - 3 m used to develop every winter (Fig. 178), mainly as a result of strong foehn winds. In the winter of 1950-51 three baffles of type A (Fig. 177) were set up at the eastern side somewhat to windward of the plateau rim.

In the sections where no boards were erected a large cornice developed as usual, but on the part of the plateau rim where baffles were provided no cornice formed (Fig. 179).

The control test carried out in the western part of the test terrain in the winter of 1951-52 produced exactly the same result.

These tests were carried out with baffles having a bottom gap. E. Campell (1955) got the same favourable result using boards without a gap (type F, Fig. 177). For the prevention of cornices, therefore, it does not seem to matter very much whether the boards used have a bottom gap or not. This is easily understood, since the most important effect consists in the formation of an eroded zone.

V. Tests with Baffles for the Prevention of Slab Avalanches

A. Ram Resistance of the Snow Cover in the Vicinity of the Baffle

1. Comparative measurements of ram resistance on the baffle test slope

The main effect of the baffle was expected to be the consolidation of the snow cover in the eroded zones. It thus appeared obvious that the strength of the snow cover around a baffle should be one of the first factors to be measured in order to determine to what extent the baffle actually consolidates the snow and where the maximum consolidation takes place.

The most suitable instrument for such investigations is the rammsonde. With a proper choice of height and frequency of blows a sufficiently detailed profile may be obtained which gives a very good picture of the snow cover structure with respect to ram resistance. When the ram profile is compared with a snow profile obtained for the same area the internal structures of the layers of different ram strength can be reliably inferred. Furthermore the mean ram strength of every profile (gross strength) can be calculated and lends itself particularly to comparison.

Ram profile records for a cruciform baffle witn a bottom gap (upper right-hand baffle in Fig. 175) on the baffle test slope in the winter of 1952-53 revealed for the first time which zones of greater consolidation could be attributed to the baffle.

In the winter of 1953-54 ram profiles were recorded parallel and perpendicular to the line of steepest gradient for two baffles of different types. In both cases the profile series ran through the centre of the snow scoop.

Since no suitable terrain was available for an absolute quantitative comparison between slopes with and slopes without baffles (this would require a large enough slope which would be completely uniform in respect to wind exposure), an attempt was made to get at least a qualitative comparison. For the winter of 1954-55 the baffles were removed from the test slope and rammsonde readings were taken at the same locations as in the winter 1953-54. The results of the ram resistance comparisons for 1954 and 1955 between the slope with and without baffles are shown graphically in Figures 180 and 181.

Before we discuss the results of this comparison, a few words are in order about the limitations of such a comparison. Although the mean ram resistance of the horizontal test field was the same in both winters, the values are not quantitatively comparable for a slope under intensive lee effect, such as the baffle test slope, where the strength values and their distribution depend primarily on the force and direction of the wind. It is possible, however, to compare the variation of strength values about a baffle with the variation that occurs in the same place with no baffle.

The terrain in which the profiles for Figure 180 were observed (northern part of the baffle test slope), is a shallow, concave slope with its axis dropping at approximately 30° towards the northeast. In the upper part the slope flattens off and merges gradually into a gently curved dome. Its northern and southern boundaries consist of very flat ridges. The principal wind directions are south to southwest for foehn winds (predominantly downhill) and north to northeast during snowfalls (predominantly uphill) (Fig. 175).

The ram resistance in the vicinity of a cruciform board with bottom gap on the test slope (in the foreground of Fig. 188) were recorded on March 24, 1954. They were converted to mean ram resistances and represented in profiles 5 (in direction of contour line) and 7 (in fall line). For comparison the mean ram strength values obtained on March 11, 1955, at the same places are also shown in series 6 and 8 (Fig. 180).

The curves of the undisturbed profile series 6 and 8 ascend gradually from the leeward edge of the slope (SE and SW respectively) towards the centre of the slope and reach a maximum at the end of the lee effect. Thereafter they descend. However, the ram resistance values obtained in the snow under the influence of the baffle (profile series 5 and 7) show very pronounced maxima about 8 m in front of and behind the baffle (centre of snow scoop) and a minimum in the actual snow scoop zone. The lowest strength values were observed under the baffle.

The values of Figure 181 were obtained under the same conditions as those of Figure 180. Unlike the case of Figure 180, however, the baffle around which the ram profiles were recorded in March, 1954, was a simple braced board with a bottom gap (type C, Fig. 177, in Fig. 188 to the right in the background). The baffle stood perpendicular to the fall line. The test terrain was the southern part of the baffle test slope. This part of the slope is more concave than the northern area. The trough axis coincides with 35° towards ENE. The essential difference, however, consists in the southern boundary, formed by a very torturous, intermittently rocky, glacier-scoured ridge, in the lee of which a very large "snow shield" (in Paulcke's sense of the term) is deposited. The main wind directions are south (across hill and downhill) during foehn weather, and north to northeast during snowfall (mainly uphill).

The ram profiles were again recorded, in the vicinity of the baffle on March 25, 1954 (profile series 1 and 3) and on the vacant slope on March 12, 1955 (profile series 2 and 4). The values from the two profiles are compared in the same manner as in Figure 180. In the profile line SW - NE the curve of mean ram resistance from March 3, 1952 has also been included for purposes of comparison (series 0). This series was taken not in exactly the same place as series 3, but about 5 m to the west.

For the area represented in Figure 181 a similar result is obtained to that for the values of Figure 180. Let us first consider the series SW - NE (fall line). They show the now familiar strength maxima in front of and behind the baffle, and the pronounced minimum in the centre of the snow scoop. The curve for the unprotected slope shows a maximum in the lee of the edge of the slope, after which there is a drop and then a gentle arc downhill. The second maximum in the northeast part of the area cannot be entirely explained by the conditions prevailing on the slope.

The curve of series 1 (SE - NW) again shows the maxima to the windward and in the lee of the baffle, with the minimum in the middle of the snow scoop. The extremely high values of series 2 (March 12, 1955) in the southeast part of the area, i.e. just in the lee of the slope edge, are noteworthy. We observe a very rapid increase of ram resistance there, immediately in the lee of the edge. The extreme peak of series 2 is probably due to the lee effect of the slope edge during foehn*.

Again in Figure 181 the maximum consolidation values in the vicinity of baffles occur between 6 and 10 m from the centre of the snow scoop, in most cases 8m.

2. Investigations of ram resistance on the horizontal test field

From the many series of ram profiles that were recorded in the three test winters of 1952-53, 1953-54 and 1954-55, in the vicinity of baffles on the horizontal test fields (Melkboden and standard test field), two typical ones have been selected (Fig. 182). On a horizontal test field, strength variations due to terrain irregularities are largely eliminated, although, as experience has shown, even gentle undulations are sufficient to change the values. In other words, as a result of modified conditions of depositing

* In the early part of the winter of 1954-55, like that of 1952-53, there were more foehn storms than usual.

the strength values obtained can no longer be ascribed wholly to the influencing of the snow cover by a baffle (cf. the northern part of profile series I, Fig. 182). Moreover, one must bear in mind that the test results from a horizontal field can be compared only qualitatively, not quantitatively with those from the baffle test slope.

To characterize the conditions first a profile series recorded about a cruciform baffle with a bottom gap on the Melkboden horizontal test field on March 18, 1954 was selected*. In Figure 182 the ram profiles are given for each baffle in a series through the centre of the baffle and parallel to the main wind direction at that point. In addition, the mean ram resistances were represented graphically (as in Fig. 180 and 181).

The profiles in the scoop zones of baffles with a bottom gap show results similar to those observed in the series of profiles from the baffle test slope. Here again, just outside the rim of the snow scoop we encounter those peaks in the curve of the mean ram resistance which characterize the annular region of maximum consolidation. Corresponding to the low values of the normal profile the peaks in the vicinity of the consolidation ring here, moreover, are not as high as on the baffle test slope. Taking the values of the normal profile (mean ram strength from 6 ram profiles = 9 kg) as 100%, then the maximum increase of consolidation in the baffle area is about 100%.

The strength curve in the vicinity of baffles with no bottom gap differs but little from those described above. Northeast of the baffles the peak of the mean ram resistance is somewhat higher and is further away from the scoop centre; on both sides of maximum consolidation the curve descends somewhat more slowly than that of the board with a bottom gap. On the windward side of the baffle (southwest), however, the maximum consolidation is less pronounced. This might be due to the fact that the Melkboden test field lies at the northwest end of a narrow upland valley running from southwest to northeast, so that at the baffle locations southwest winds are almost the only effective ones. Northerly winds are of little importance.

The mean ram resistance here from four profiles was 7 kg. The maximum increase of strength was about 180%. There are no strength values for the scoop itself because there was no snow in it.

The observations show a semicircular zone of maximum strength on the northeast of the baffle (mainly the lee side) (Fig. 183). The radius of the semicircle is 6 to 9 m. A marked bulging of this consolidation zone towards the baffle is noteworthy.

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* The baffles had the following dimensions: boards on the horizontal standard test field: 3 x 2 m, bottom gap 2 m, total height 4 m. Baffles without bottom gap on the Melkboden test field: height 2.20 m, width 3 m.

The longitudinal axis of this bulge is approximately parallel to the prevailing wind direction. Thus it is situated in the zone of maximum turbulence in the lee of the baffle, the so-called vortex train zone (Fuchs 1954). A regular trough is gouged out by this vortex train in strong winds, running from the baffle in the lee direction and, ascending from the bottom of the scoop, after a certain distance that depends on the size of the board and the wind speed, it reaches the surface of the snow. This depression, which only occurs in typical form where the bottom gap is small or is absent altogether, is called a vortex trough or vortex lane. The place at which the vortex trough reaches the surface of the snow coincides approximately with the bulge in the zone of consolidation. It has already been mentioned that on the Melkboden test field southwest winds are practically the only effective ones, which may explain why the consolidation zone of the vortex trough is particularly well expressed here. It could not be determined whether the tongue-shaped consolidation zone extending eastward from the southern edge of the baffle can also be attributed to the same vortex train (vortex trough).

3. Results of ram profile observations

Let us now briefly summarize the results of the ram resistance investigations of the snow in the vicinity of baffles.

In all the cases investigated an annular or horseshoe-shaped zone could be discerned around the baffle in which the ram resistances reach a maximum, i.e. in this region the ram resistance values are higher than in the uninfluenced parts of the snow. The radius of this consolidation ring varies between 6 m and 10 m. In general, the radius was greatest for baffles without a bottom gap (types D and E, Fig. 177). It decreases with increasing bottom gap. The annular zone of greater strength may also be open in one direction. This happens when there is only one effective wind direction.

The maximum increase of consolidation over the standard profile on the horizontal test field was about 100% for a baffle with a bottom gap and approximately 180% for one without a gap.

There are no absolute comparative figures for strength increases on the slope. According to careful estimates, taking into account exposures and wind diagrams, the increase of strength should be 30 to 50%.

These numerical values, cannot be regarded as rules either for the horizontal field or for the slope. Consolidation is the result of wind effect. It is the sum of all wind action occurring in the course of a winter and can therefore be just as irregular as the sequence of the various wind periods.

B. Stratification and Specific Gravity of the Snow in the Snow Scoop Zone

Information can be gained on the causes of the firmer zones surrounding a baffle in a circular or horseshoe configuration from the distribution of the specific gravity and the stratification of the snow cover. Fuchs (1952) showed that around a baffle with a bottom gap there is a horseshoe-shaped zone in which the snow has a higher specific gravity than the snow around it. (The arithmetic mean over the entire depth of the snow cover was taken.) This zone was 6 to 8 m distant from the centre of the snow scoop. It thus coincides with the zone in which the maximum mean ram resistances are observed.

The specific gravity of the snow in the consolidated zone was 0.510 to 0.518, whereas on the less influenced slope it was 0.460 to 0.470 (Fig. 184).

The differences near a baffle without a bottom gap (type D, Fig. 177) in the horizontal test field, recorded in March 1955, were even greater. For the normal profile a specific gravity of 0.172 (arithmetic mean) was obtained, compared with one of 0.263 in the consolidation zone of the baffle.

In order to explain this phenomenon, the stratification was studied in the snow scoop zone. The results show that the reason for the consolidation and increase of specific weight is to be found in the way the individual snow layers were deposited during wind. Between layers showing comparatively little consolidation we observe lenses or tongues of highly consolidated snow. These firmer strata correspond to the "wind-packed" snow laid down on the snow scoop surface during each wind period. The maximum thickness of such layers is always observed at 2 - 6 m outside the snow scoop rim. From this deposit zone the thickness of these "wind-packed" layers decreases to a few cm both inwards towards the scoop and outwards. Thus the layer coincides in its position with the zone of maximum ram resistances or the zone of maximum specific gravity. It is altogether possible, indeed probable, that the individual wind-packed layers vary in strength axially, i.e. longitudinally. In the snow scoop zone, of course, they are subject to entirely different conditions of accumulation than in the open field, and accordingly the degree of packing will vary.

In principle the result is the same whether it involves snow scoops around baffles with or without a bottom gap. Where there is no gap the tongue-shaped consolidated layers extend only to the rim of the snow scoop, where they are eliminated by erosion during subsequent wind periods. Consolidated layers can only be observed in the vortex trough.

C. Creeping of the Snow in the Snow Scoop Zone

In January 1953, on the avalanche slope to the west of the station, in the vicinity of a baffle, 85 vertical holes were drilled through the snow to the ground and were filled with sawdust. At the beginning of April the sawdust columns were exposed by digging and their departure from the vertical due to creeping was determined. As a measure of the creep the tangent of the angle of departure of the column from the initial vertical position was chosen. Despite considerable scattering of the values, the following picture emerged: above the baffle, on the windward side, there is a zone of strong creep at an average distance of 10 m from the baffle. In the lee of the baffle immediately adjacent to it there is a zone of less creep extending for about 12 m. The effect of the baffle thus appears to be a strong reduction of the creep from the windward to the lee.

D. Snow Temperatures and Depth Hoar Formation in the Snow Scoop Zone

In sunny weather the daily fluctuations in the surface layers of snow extend to a depth of about 50 cm. Long periodic fluctuations (periods of cold, prolonged foehn) extend deeper. This zone may be imagined as approximately parallel to the surface of the snow in a snow scoop zone. Owing to a lack of insulation by the snow the frost penetrates the soil here and is subject to considerable fluctuations. No depth hoar forms in the snow scoop, since the depth of snow and temperature gradient needed for recrystallization are lacking.

E. Avalanche Fractures in the Vicinity of Baffles and Their Causes

The foregoing sections have dealt with the immediate effects of baffles on the snow cover, i.e. the manner in which a baffle affects the stratification, specific gravity and ram resistance of the snow. The effect of the changes in the snow cover due to baffles could be determined only in a purely empirical way by observation. Thus the start of loose snow and slab avalanches and the formation of creep ruptures were subjected to especially close observation. Such observations are at least as important as measurements. Only when both kinds of results are brought together can a complete and final picture be obtained.

As already mentioned, baffles of various types had been erected experimentally on the baffle test slope from the winter of 1950-51 to that of 1953-54, but all of them had bottom gaps. In each of these winters fractures of snow slabs of various size were observed in the vicinity of the baffles. The initial fractures always occurred in the immediate vicinity of baffles, either at the upper or lower edge of the snow scoop.

As an example of slab avalnche is described here, which occurred at the baffle test slope on December 30, 1952 between 9 and 10 a.m. (Fig. 185).

During a strong south wind (5 to 6 Beaufort) in the night of December 29 to 30, wind-packed snow was deposited on the loose new snow (snowfall period: December 20 - 23). On the lower part of the slope the wind-packed layer was 3 to 5 cm thick. The thickness increased gradually in the uphill direction and reached 35 to 40 cm at the point of fracture. In the examined snow slab the wind-packed layer had slipped off and taken the loose snow beneath with it. The fracture itself ran from the upper rim of the snow scoop of the middle baffle (baffle 2 in Fig. 185) to the lower rim of the snow scoop at the baffle above it to the west (baffle 3 in Fig. 185). The area above the fracture was divided by fissures into large slabs, which, however, did not slide down. At the time of the fracture, the snow scoops were already well formed.

In the first two winters no great importance was attached to these fractures, but thereafter it became more and more evident that they must be associated with the baffles. A full insight into the relationships was only gained in the winter of 1953-54 from observations on the baffle test slope and the Pluderling slope.

In this winter, in addition to the regular baffle test slope, four simple baffles with bottom gap of 2 m had been set up on the Pluderling slope. The Pluderling slope has a slope angle of 40 to 45°, is slightly concave to the northwest, and can be regarded as a definite avalanche slope (Fig. 186). After heavy snowfalls from January 9 - 12, 1954, small slab avalanches started at each of the three baffles on the morning of January 13 (one baffle had been destroyed by a rockfall in December). Shortly afterwards a large snow slab the whole width of the slope broke off above the baffles (Fig. 186). The same process was observed after a snowfall on March 7, 1954. After all these observations the formation of avalanches in the vicinity of baffles with bottom gaps could no longer be regarded as coincidental.

This phenomenon may be explained by the special form of the snow scoop around a baffle with a bottom gap. The scoop is never dug out to the ground. Its form is such that the transition from the unaffected surface of the snow cover to the centre of the scoop is a gently rounded one. With this form of snow scoop there is no interruption of the stratification, only a change of thickness within the individual layers os snow (Fig. 187). With increasing depth of the snow the uphill sides of the scoop become steeper and steeper. As a consequence tensile stresses arise in the upper layers of snow with their maxima at the rim of the scoop, i.e. at the transition of the slope. When these tensile stresses exceed the strength of a snow layer, the latter breaks off. This process is illustrated in Figure 188, where 15 cm of new snow deposited on a wind-packed base has slid around all three baffles on the baffle test slope. The fracture lines of these snow slides resemble that of snow slabs. Their positions correspond to the zone of maximum tensile stress.

These tensile stresses increase with increasing depth of the snow and increasing steepness of the snow scoop rim. With continued development of the snow scoop, the upper rim of the scoop may become so steep that the continuity of the layers is broken. The form of the scoop is then similar to that of a snow scoop around a board without a bottom gap.

At the baffles without a bottom gap that were tested in the winter of 1954-55 in Lizum (type D, Fig. 177), avalanche fractures were not observed in the snow scoop zones.

Although the latter statements are based only on the observations of a single winter, they are confirmed by Campell's (1955) observations, which gave quite similar results.

The difference in the behaviour of baffles with and without a bottom gap can therefore be explained by the difference in the form of snow scoop.

The scoop around a baffle with a bottom gap is never hollowed out to the ground. The transition from the normal surface to the scoop is gradual and rounded, so that there is no interruption in the stratification, but only a reduction in the thickness of the layers.

The snow scoop around a baffle without bottom gap is almost always hollowed out to the ground. The rims of the scoop are sharply delineated and the stratification is radically broken.

Whereas, as already stated, the change of gradient at snow scoops around baffles with a bottom gap promotes the development of tensile stresses within individual layers in the snow scoop zone, such a development is hardly possible in snow scoops around baffles without a bottom gap. In the sharply delineated snow scoops which are hollowed out right to the ground, the stratification is broken. Thus the important factor for the development of tensile stresses is absent, namely the change of slope and change of depth. On a uniformly inclined slope the snow scoop behaves in a "quasi neutral" manner.

F. Tests on the Patscherkofel

J. Bernard had already carried out tests with baffles on the Patscherkofel in the winters of 1949-50 and 1950-51 on the avalanche slope east of the meteorological observatory. The location chosen for these tests was very exposed to the wind (foehn), which was able to blow against the baffles without hindrance. The conditions for baffle tests were thus ideal. In the vicinity of the baffles periodic measurements were made of the snow depth, the length of the vortex trough and the depth of the snow scoop.

The Patscherkofel tests showed that the snow scoop effect is fully realized, even with very thick snow deposits in the lee of the baffle, when the following two conditions are satisfied: the baffle must be the right size and the place of erection must be fully exposed to the wind.

The test baffles on the Patscherkofel were 6 m high and 4 m wide. They had no bottom gap and were of only 75% density.

Figure 189 shows such a baffle at the end of March 1950. At this time the snow scoop still extended down to the ground. On the uphill side it was 2.20 m deep. The rims of the scoop were sharply delineated from the snow cover and in the downhill direction they constituted the side boundary of the vortex trough. The latter attained a length of 23 m, and in its vicinity the snow was always firmer than in the undisturbed part of the snow cover on either side.

The Patscherkofel test showed that baffles cannot be dimensioned to any one specification, but must be adapted to the conditions at the site where they are to be erected (wind, depth of snow and slope angle).

VI. Summary and Future Prospects

The most impressive results are those obtained from the baffles tests for the prevention of cornices. When no cornice formed in the vicinity of the baffles during two test winters, this is a clear indication of their positive effect (Fig. 178 and 179). The tests showed that cornice formation can be prevented in the vicinity of baffles by means of simple baffles with a bottom gap of 1 to 1.20 m and a density of 75 to 80% (type A in Fig. 177). For this purpose the baffles should be placed directly at the cornice root or up to 1 m from the edge of the ridge. If there is a distinct prevailing wind direction, the baffles should be erected perpendicular thereto. Otherwise they may be put parallel to the ridge. The distance from baffle to baffle will depend on whether cornice formation is to be prevented entirely or the cornice is merely to be "cut up", i.e. broken up into separate pieces. In the former case the distance between baffles may be up to 100% of the baffle width. Simple baffles are entirely adequate for cornice prevention. On cornices at ridges with comparatively gentle profiles, Campbell (1955) got very good results also with baffles with no bottom gap. He set up his boards right at the edge of the ridge, or slightly to leeward.

In contrast to the tests for the prevention of cornices, in which good results were obtained with comparatively simple means, the tests with baffles for the prevention of slab avalanches were more complicated. A more or less complete picture could be secured only by considering both measurements and direct observations.

Baffles with a bottom gap produce an annular or horseshoe-shaped consolidation of the snow cover. This ring has a radius of 6 - 8 m. In the snow scoop zone itself the strength of the snow remains below the normal value of the undisturbed snow cover (Fig. 180, 181, 182). The snow-scoop shape is a continuous one; the turbulence field is not deep enough to hollow out the scoop to the ground. When the bottom gap is increased the snow scoop gets shallower and loses its typical form. Actually the scoop disturbs the stratification of the snow cover without interrupting it. Moreover, owing to the particular form of the snow scoop around baffles with a bottom gap, tensile stresses arise at the rims of the scoops, as a result of which baffles with a bottom gap can actually contribute to the formation of avalanches (Fig. 185 - 188).

At baffles without a bottom gap a consolidation with its maximum 8 to 10 m from the centre of the snow scoop is again observed. (The distance depends on the position of the baffle relative to the slope, the size of the baffle, the wind velocity and the angle between the wind direction and the baffle.) The deeply hollowed out snow scoop disrupts the homogeneity of the snow cover much more sensitively and effectively than in the case of the baffle with a bottom gap, and the snow cover is usually removed to the ground (Fig. 187, 189)

The effect of baffles in slab avalanche fracture areas lies first of all in the disruption and break-up of the stress field, and secondly in a support function due to consolidation. Both types of baffles cause a consolidation of the snow cover, but only the board without a bottom gap breaks up the stress field. The breaking up of the stress field is assured only when the snow cover is interrupted, but this can be expected only in snow scoops around baffles without a bottom gap.

It may thus be stated that baffles without a bottom gap are preferable for the prevention of slab avalanches. Besides the mentioned advantages, the use of baffles without a bottom gap removes the thorny question of the size of the gap.

It was found in the tests that baffles that are either too wide or too narrow will not fully answer their purpose. If the baffles are too wide the lateral vortex fields cannot meet and a space remains in the centre of the baffle where snow accumulates. The baffle then behaves like a snow fence. On the other hand, if the baffles are too narrow the diameter of the snow scoops will be correspondingly small and the latter will "drown" more quickly in snow. More baffles will be needed for a given area than if the baffle dimensions are larger.

The optimum baffle width is between 3 and 4 m. The height has to be adjusted to suit the expected snow depths; the baffle should stand 1 m higher than this maximum. According to Campell's reports and our own experience (type D, Fig. 177) it is advantageous to make the baffle narrower at the bottom than at the top.

Whether simple or cruciform baffles should be used depends on the local prevailing wind conditions. In most cases a principal wind direction can be found which determines how the snow is deposited. In such cases cruciform baffles are not required. They are appropriate, however, when no prevailing wind direction can be established.

Model tests in the wind tunnel have shown that the flow pattern is largely independent of the wind force, the angle of attack (between 90 ± 20^o) and the bottom gap, provided the latter is not less than 1/3 the edge length of the baffle (Fuchs 1954).

The maximum effect is obtained with baffles of 100% density, which produces a maximum disturbance of the flow field.

The effectiveness of a baffle is wholly dependent on the local wind conditions. An effect can be expected only where the baffle is exposed to strong winds.

It follows that baffles cannot be effective everywhere. Where wind and snow distribution are unknown, these must be observed for at least one winter.

Using a board width of 3 to 4 m, the optimum effect will be achieved by staggering the baffles at intervals of 15 to 20 m, so that the consolidation zones of the individual baffles will be continuous. The baffles, being relatively rigid objects, will perform a certain supporting function and at the same time the stress field of the snow cover will be broken up into separate partial stress zones by the snow scoops. As a consequence of this, however, new local stresses can arise. If the consolidation rings - as "reclining arches" - are to support the snow cover above them, there must be an abutment acting at right angles to the slope and transmitting this force to the ground. There must therefore be no sliding of the snow cover on the ground.

To assume that baffles provide a means of combatting avalanches for all situations would be overshooting the mark. The prime condition of their functioning is the wind, which together with the obstacle (baffle) produces the snow scoop, the break-up of the snow cover and the consolidation in the vicinity of the baffle. Baffles are ineffective whenever snow is deposited without wind. Although this seldom happens in high alpine regions, the possibility must not be overlooked.

However, no success can be expected when baffles are hardly ever, or only sporadically, exposed to unimpeded winds. Their applicability is therefore restricted to certain areas between windward and lee.

Given proper erection, on the other hand, baffles can be used successfully against cornice formation. At places where cornices form, wind always prevails, at least during the periods when the cornices are building up. For without wind, no cornices will arise and the baffles need be effective only during formation of the cornices.

Hence, while baffles are very useful for the prevention of cornices, they are only occasionally effective against slab avalanches, and even then some avalanches may still occur.

Considerable light has been shed on the effect of the individual baffle on the snow cover, but adequate experience in the practical implementation of baffles is still lacking. Campbell (1955) was the first to use baffles in an arrangement corresponding to their effect, for combatting slab avalanches, and to report on his experience. The latter was wholly satisfactory.

The main effect of baffles is to reduce the stress peaks in the snow cover by consolidation, so that the frequency of occurrence of slab avalanches is at least reduced. However, they cannot prevent loose snow avalanches resulting from special weather and terrain conditions.

Many problems remain to be solved. It would be interesting to determine, for instance, the minimum wind force at which baffles are still effective. The question of how far to leeward a baffle can be erected without "drowning" in snow (i.e. without the accumulated drifting snow exceeding the scooping-out effect of the wind around the board) must be examined further. Finally, there must be close coordination between research and practical work with a view to final clarification of the problem.

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Figure 174

Lizum Snow Research Station, 2,000 m above sea level, in the Wattentale near Innsbruck. Looking southwest towards the Tarntaler peaks.

Figure 175

Baffle test slope in the winter of 1951-52 with four cruciform baffles on the southern part of the slope. In 1950-51 and 1953-54 test baffles were erected on the right-hand part of the slope as well. Looking northwest; direction of prevailing wind from left to right (foehn)

Figure 176

The horizontal standard test field in the winter of 1952-53 with cruciform baffles of various width and various bottom gap.

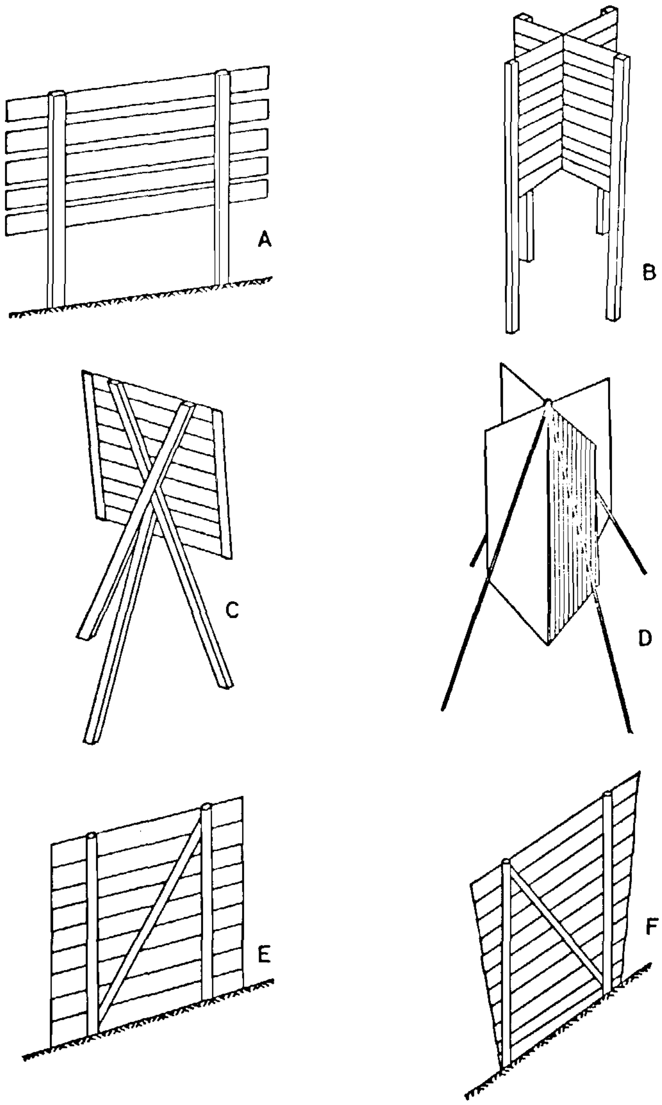


Figure 177

Types of baffles.
A: Simple baffle, 1.20 m bottom gap, 75% density;
B: Cruciform baffle, 2 m bottom gap, 100% density;
C: Simple braced baffle, 2 m bottom gap; D: Cruciform baffle with tapered bottom, made of wood or of structural steel mesh with interwoven aluminium foils and central anchor rod.
E: Simple baffle without bottom gap, rhombus or square shape, density 100%; F: Swiss form of baffle after Haefeli and Campbell, no bottom gap, 100% density

Figure 178

Rim of plateau on which the tests were carried out with baffles for the prevention of cornice formation; in winter of 1952-53 without baffles. The continuous cornice is clearly recognizable

Figure 179

The same area as in Fig. 178 in the winter of 1950-51. Cornice formation has been prevented by three baffles erected at the edge of the plateau. The vertical arrow points to the place where the cornice is interrupted; cf. cornice formed at the same place in Fig. 178. The control test in 1951-52 at the point marked X confirmed the result of the test winter of 1950-51

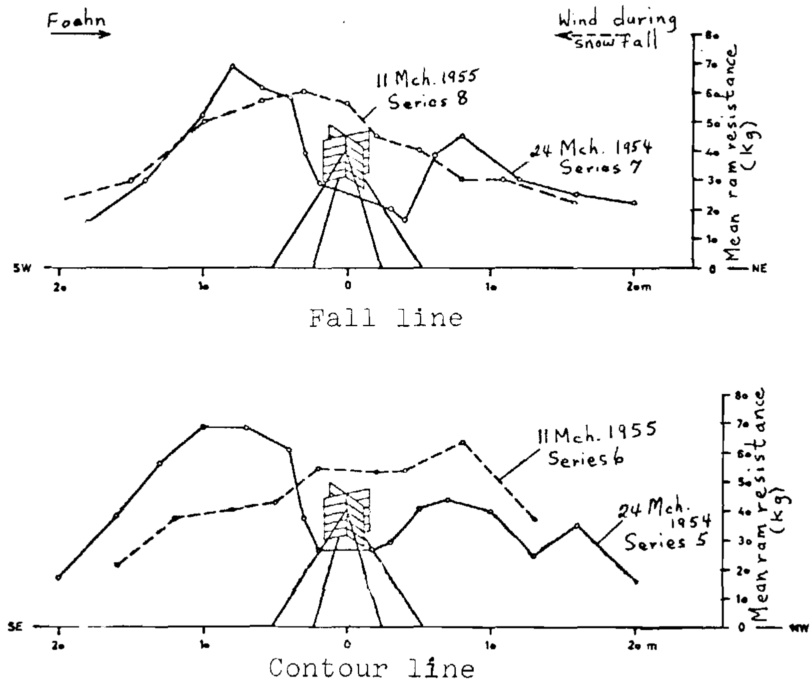


Figure 180

Comparison of mean ram resistances on the baffle test slope with and without the baffles erected, in the years 1954 and 1955 (cruciform baffle with bottom gap). Profile series 5 and 7 with baffle, series 6 and 8 without

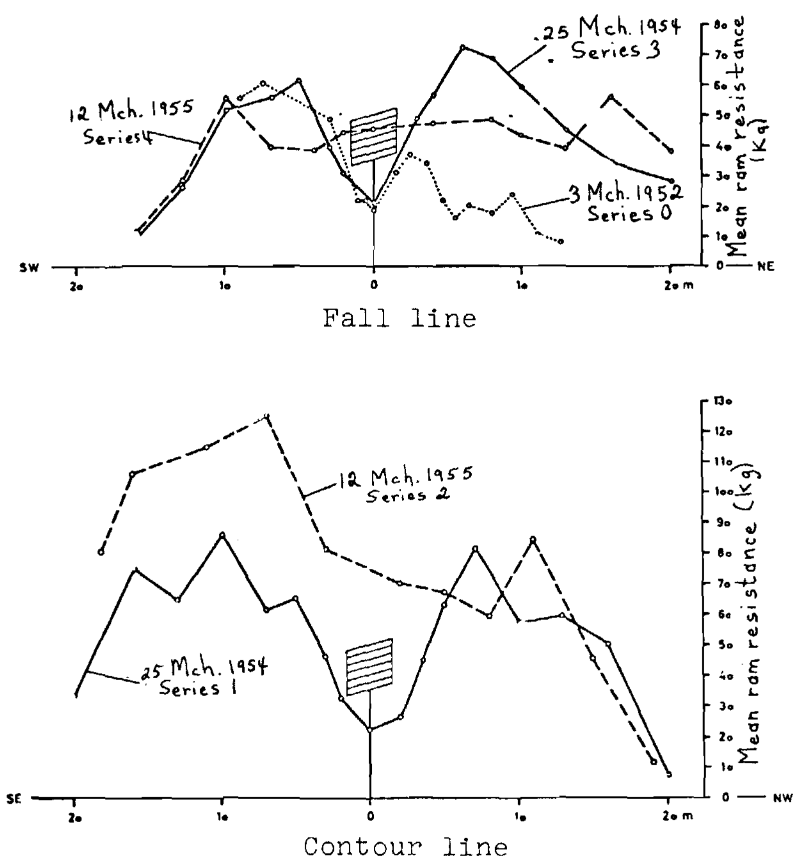


Figure 181

Comparison of mean ram resistances on baffle test slope with and without the baffles erected, in the years 1952, 1954 and 1955 (simple baffles with bottom gap). Profile series 0, 1 and 3 with baffles, series 2 and 4 without

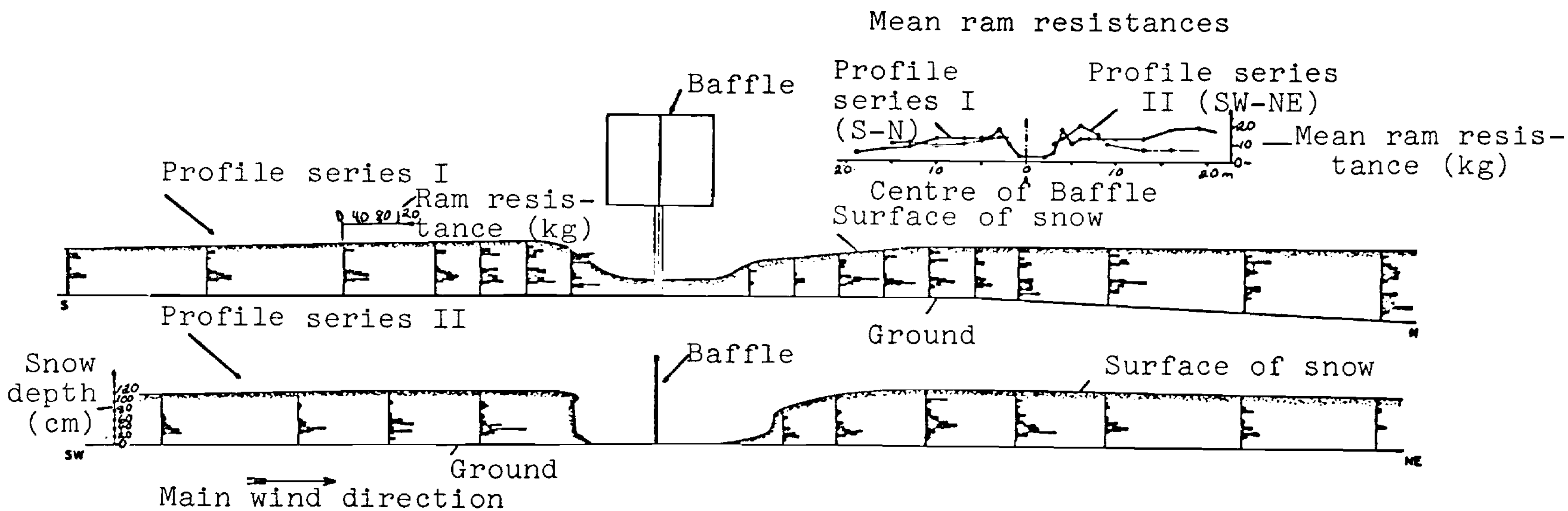


Figure 182

The ram resistances about a baffle with a bottom gap, and about one with no bottom gap. Profile series I: cruciform baffle with a bottom gap of 2 m; standard test field, March 29, 1954. Profile series II: simple baffle without a bottom gap; Melkboden test field, March 18, 1954

Pile of stones

Creek

kg Mean ram resist.

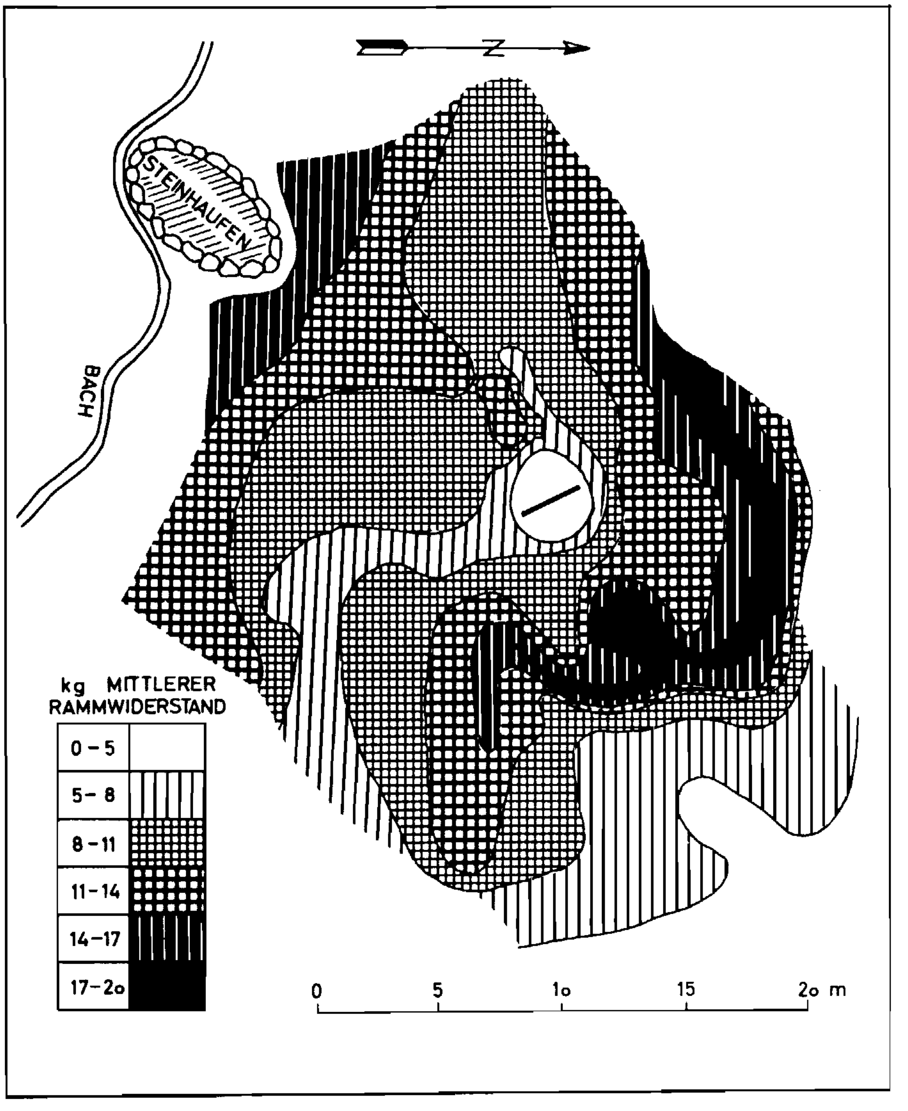


Figure 183

Distribution of mean ram resistances about a baffle a bottom gap on 18 March, 1954 (Melkboden horizontal test field). The lines of equal ram resistance were plotted from 72 measuring points. The horseshoe-shaped zone of greater ram resistance in the lee of the baffle (main wind direction southwest), due to the effect of the baffle, is clearly recognizable. The pronounced bulging of the consolidation zone towards the baffle is presumably due to the so-called "vortex lane". The zone of greater snow strength in the southwest part of the figure is caused by the pile of stones shown there

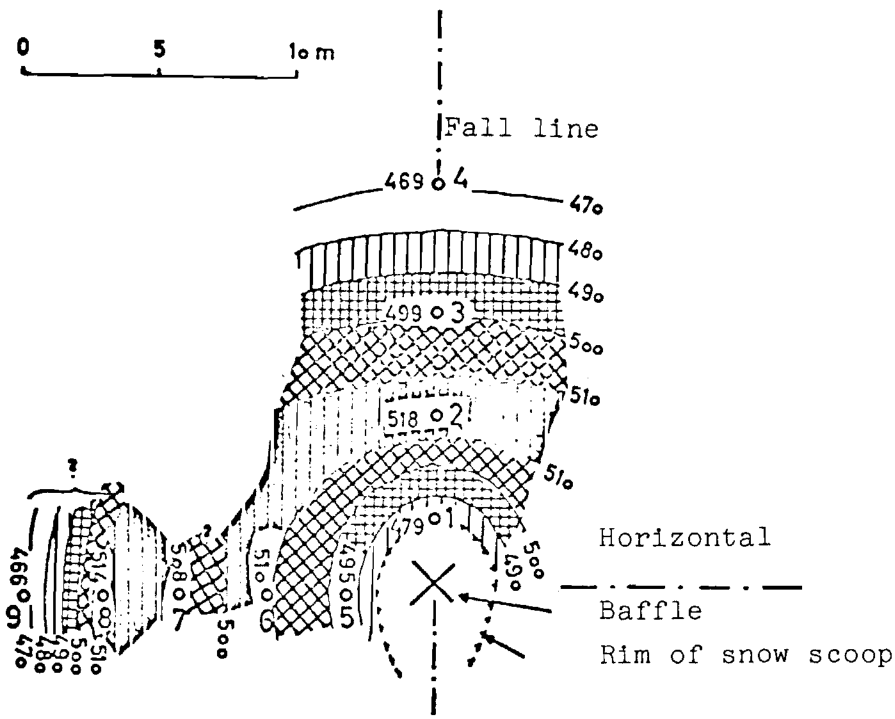


Figure 184

Snow density profile in the vicinity of a baffle on April 30, 1952. Profile observation points indicated (with no. and mean density in g/dm³). The appropriate lines of equal density are plotted and the hatched zones constitute 10 g stages. A generally horseshoe-shaped zone of greater density is found.

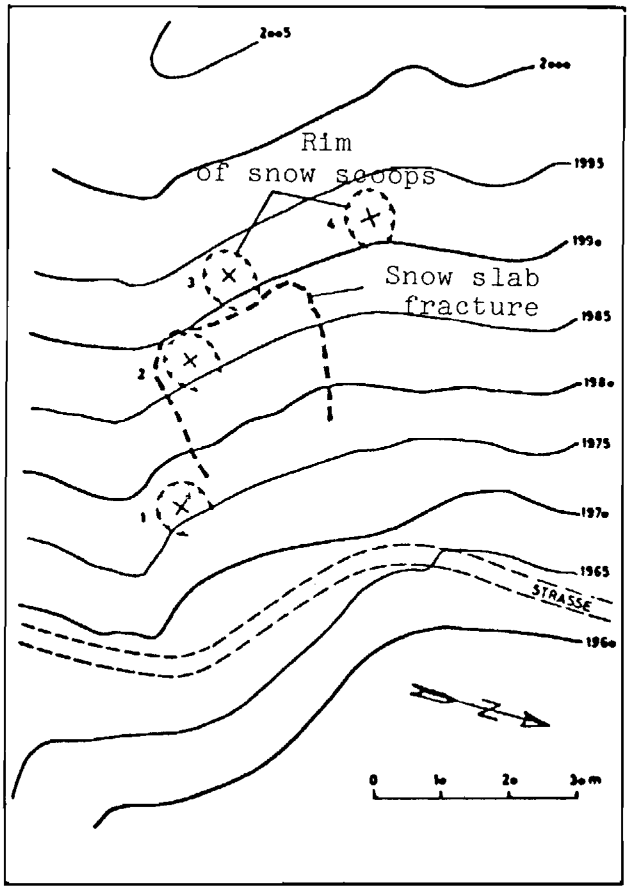


Figure 185

Sketch of the snow slab fracture on December 30, 1952 in the vicinity of two baffles on the test slope. This fracture can be attributed to the combined effect of the tensile stresses at the top edge of the snow scoop of board 2 and those at the lower part of the snow scoop rim of board 3

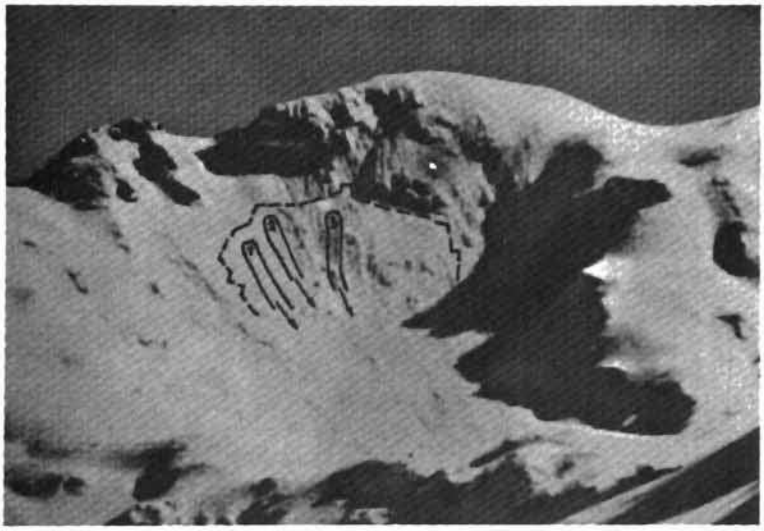


Figure 186

The Pluderling with avalanche slope on which there are three baffles with a bottom gap. The events of January 13, 1954 are drawn in. The three smaller avalanches around boards 1, 2 and 3 started first and shortly afterwards the large slab avalanche (outlined by the broken line) occurred

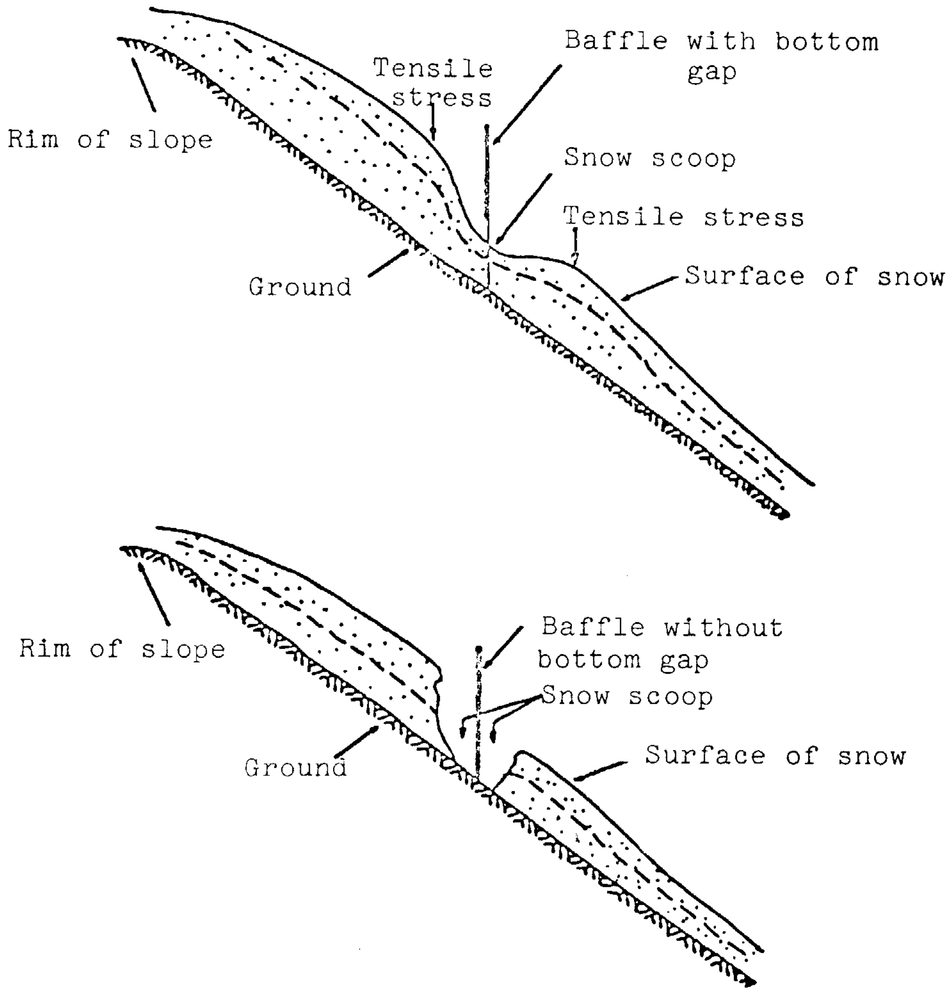


Figure 187

Above: Section through a snow scoop around a baffle with a bottom gap. The scoop shows rounded forms with gradual transitions. On the rims of the scoop the snow layers are deposited more and more steeply with increasing snow depth, resulting in the development of tensile stresses in the upper parts of the snow cover.

Below: Section through a snow scoop around a baffle without a bottom gap. The scoop is sharply defined and reaches the ground. The stratification in the snow cover is interrupted by the snow scoop. Main wind direction is left to right.

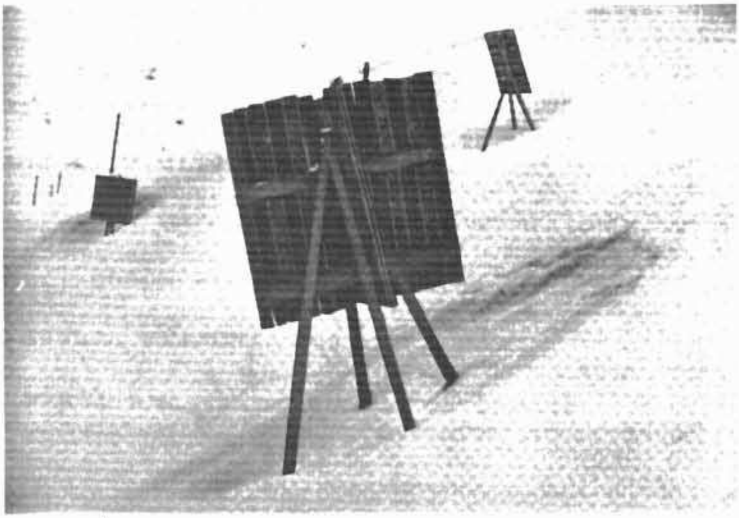


Figure 188

The baffles on the test slope in the winter of 1953-54. 15 cm of new snow were deposited on a wind-packed layer. This top layer has slid down around each of the three boards. The fractures, which closely resemble snow slab fractures, correspond to the zones of maximum tensile stress at the top edge of the snow scoop

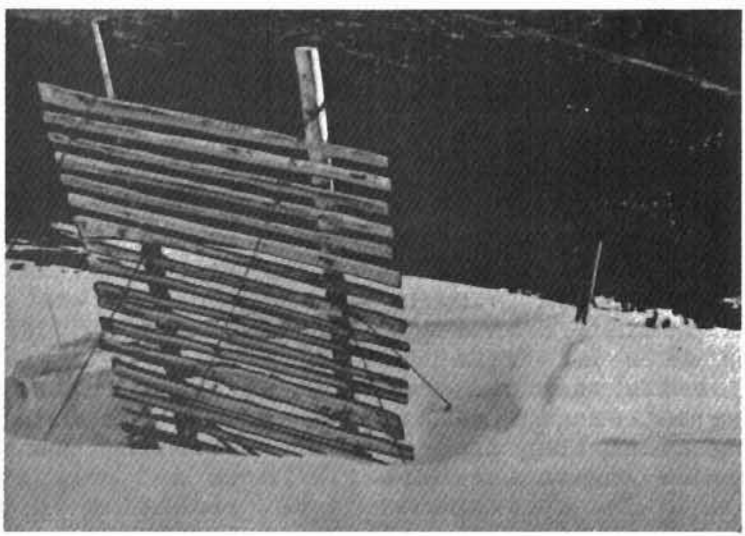


Figure 189

Test baffle on the Patscherkofel. The picture clearly shows the sharply defined snow scoop (typical form of snow scoop for boards without a bottom gap) and the long vortex trough

3. WIND TUNNEL MODEL TESTS WITH BAFFLES

by. A. Fuchs

Abstract

The objective of the study was to determine in a wind tunnel the most effective position and shape of a baffle for controlling the deposit of wind-blown snow in avalanche accumulation zones. Baffles were modeled to a scale of 1:10 to 1:20. Flow lines, extent of vortex zones, and wind speeds were observed around baffles of rectangular, triangular and cruciform shape. The tests indicated that the flow pattern was largely independent of the wind speed, gap at the bottom and the shape of the board, but was dependent on the inclination of the baffle when it was at an angle of less than 70 degrees to the floor of the tunnel.

This paper is a digest of the "Report on model tests with baffles in the wind tunnel" by Univ. Doz. Dr. Alfred Fuchs (August 1954).

I. The Setting up and Execution of the Model Tests

At the beginning of our investigations the questions arose as to the most effective position of the baffle in relation to the wind direction, and the most favourable shape of the baffle. Because of changing wind conditions outdoor tests would have been difficult to evaluate and very time-consuming. For this reason we made tests with models in the scale of 1 : 10 to 1 : 20 in the return circuit wind tunnel of the Vienna Technische Hochschule (Professor Magyar Institute) with a view to finding rules that might be applicable to our fullscale tests. With the wind tunnel we were able to control and vary all the factors that were of interest to us. We attempted to determine the effects of wind barriers on the flow lines and the eddy zones, and to measure the relative speeds as a function of initial wind speed, shape of baffle, angle of attack in relation to the wind and bottom gap.

The test setup will now be described briefly:

In the accessible test section of the wind tunnel the air flows vertically downwards. A hardwood fibre board, acting as a floor was placed parallel to the flow in such a way that there was no turbulence created around it as long as no obstacle was placed in the flow. The baffle models were secured to the floor board or to a holding device on the opposite side of the tunnel, and could be adjusted as desired.

The flow lines and turbulence zones around the obstacle were made visible with the aid of short, white woollen threads which changed position with changes in the flow. The disposition of these threads is best seen in Figure 194: between two rods of a frame very thin wires were stretched (helical springs on one side) 1 dm apart, and these in turn bore 9 cm long white threads, again 1 dm apart. This wire lattice with the threads could be installed at different distances from the floor board.

During the test the threads were photographed simultaneously from two directions (at an angle in front, and from the side, Fig. 194).

To denote the individual threads the wires were lettered and the vertical rows of threads were numbered.

The speed measurements were carried out with a small Pitot tube that was fastened to a rod and held next to the threads. The correct position of the Pitot tube at any given time was determined by the position of the thread.

The unmodified incident flow speed was measured at intervals of time by a permanently installed Pitot tube.

II. Evaluation and Presentation of the Results

The speeds v were obtained from the pressure differences Δp measured by the Pitot tube, by applying the simplified formula

$$v = 4\sqrt{\Delta p}.$$

(Air pressure and temperature were neglected, since in the final analysis only relative values were involved.)

The speeds v were converted to percentages of the incident wind speeds v_o. The latter was taken as the mean of the individual values measured in the course of a series of tests.

The relative values of v were plotted on mm graph paper in the scale of 1 : 10. The ranges of similar relative speeds were grouped together in 5% steps and the boundary lines between the steps (isotachs) were drawn. The high-speed regions were coloured blue while the slow ones were furnished with brown hatching.

III. Test Results

A. The flow pattern around a square baffle on a plane floor

For these tests we used a square baffle of 25 cm side. It was supported by a holder at its upper edge which was guided in a hinge device that could be clamped tight. The angle of attack of the board could thus be varied. The bottom gap was adjusted by moving the entire supporting apparatus.

The purpose of this series of tests was to study the flow pattern around a baffle as a function of various factors (angle of attack, bottom gap, wind speed), under conditions corresponding to those of early winter, i.e. when there would be very little scooping out of the snow cover. The plane floor creates simple conditions; here the effects of the cited factors can best be clarified.

1. Effect of the angle of attack

In the investigation of this matter the baffle model was set up in the wind tunnel in seven different positions relative to the incident flow direction, inclined 30 to 120°. In all the tests the bottom gap was 20 cm; the wind speed v_o was 11 m/sec. The relative speeds v were measured in four planes at 7 cm, 13 cm, and 20 cm above the floor and at the baffle centre, i.e. 26 - 33 cm above the floor, depending on the angle of attack.

In considering the flow pattern we start at a baffle setting of 90°, i.e. perpendicular to the flow. The schematic longitudinal section of Figure 190 A shows a more or less symmetrical arrangement of the flow lines in relation to a horizontal plane near the centre of the baffle. Even the true, sharply differentiated eddy region with a reverse flow (Fig. 190 F; hereinafter called simply "vortex zone"), and the immediately following region where there is considerable turbulence but the flow directions do not depart radically from the general flow direction (called "turbulence zone" for short) show an almost symmetrical arrangement in relation to the mentioned plane. The vortex zone is about 75 cm long; the length of the turbulence zone could not be determined owing to the lack of space in the wind tunnel.

The distribution of relative speeds in the immediate vicinity of the baffle is shown by the isotachs in the longitudinal sections, Figure 191, and in the horizontal sections, Figure 192.

In Figure 192, 7 cm above the floor, there is a comparatively fast region of oval section, the core of which is situated 30 cm behind the baffle. In the higher layers this fast region, which is continuous near the floor is divided into two lobe-shaped regions at the edges of the baffle. These two regions are separated from each other by the turbulence zone. The three-dimensional shape of this faster region can be recognized from a glance at all sections (Fig. 191 and 192).

In front of the baffle the air piles up. This constitutes a slower region, the shape of which is again evident from the sections. Its core is directly in front of the baffle (Fig. 191 and 192).

A second, slower region immediately follows the turbulence zone (in which no velocities were measured). It is elongated in shape, in the longitudinal direction. In the tests only its forward part could be measured (Fig. 190-192).

Now, if the angle of attack is changed 15° in both directions from the plumb (upstream: 75°, downstream: 105°, the resulting flowline patterns are very nearly mirror images of each other (Fig. 190 B and C). The tip of the vortex zone moves slightly downwards or upwards. The distributions of isotachs scarcely differ one from the other or from the isotach distribution for 90°.

While there is very little change in the flowline pattern for a 15° inclination from the vertical, at 30° the change is already somewhat greater (Fig. 190 D - angle of attack 60°, and Fig. 190 E - angle of attack 120°). Again the flowlines and vortex regions are very nearly mirror images of each other, but the length of the vortex zone is now only about twice the side length of the baffle. Generally speaking, at a 60° angle of attack there is a definite drop and at 120° a definite rise, hence a separation from the floor. However, the isotachs are again very similar to those for angles of attack of 75 and 105°.

Two series of tests at angles of attack of 45 and 30° were intended to show the appearance of the flow pattern at still larger baffle inclinations. In practice such angles will rarely occur. It was found that the vortex zone becomes considerably smaller with increasing angle: the turbulence zone also becomes narrower. Vortex trains appear on both sides of the baffle (Fig. 190 F and G).

The smaller the angle of attack, the smaller the differences in the relative speeds.

While at 45° the isotachs are still more or less similar to those at angles of 60, 75, 90, 105 and 120°, at 30° they show a very different pattern with small differences of speed.

Towards the angle of attack 0° (baffle parallel to the flow) the influence of a theoretical two-dimensional baffle on the flow would be zero.

If we planimeter the areas of the vortex zone in Figure 190, convert the values to percentages of the baffle area and plot them against the angle of attack, we get the curve shown in Figure 193.

The relative size of the turbulence zone increases with increasing angle of attack, at first slowly, then rapidly, and between 90 and 105° it reaches a maximum. As the angle of attack increases still further the curve descends steeply and reaches zero again at about 180° (= 0°). Note that between 71 and 114° the longitudinal section of the vortex zone is more than

300% of the baffle area; between 65 and 119^{o} it is more than 250%. The flat peak of the sinusoidal-like curve shows us that in the region of 90 ± 20^{o} the flow pattern remains constant with respect to the vortex zone.

2. Effect of the bottom gap

To clarify this question, several series of tests were made. The wind speed was kept constant at 11 m/sec, and different bottom gaps were tested at angles of attack of 30, 45, 60, 75 and 90^{o}. The following bottom gaps were chosen for investigation: 7, 13, 20 and 27 cm. A board without gap was also tested at an angle of attack of 90^{o}. The lattice and threads were installed at various distances from the floor up to the bottom edge of the baffle, and in some cases also up to the centre of the baffle, and were photographed from in front and from the side. No speed measurements were made.

It was found that the bottom gap had very little influence on the flowlines or on the regions of turbulence for all angles of attack.

In the horizontal sections, in various positions (from the bottom edge of the baffle upwards) the conditions remained generally constant, whether the gap was 7 cm or 27 cm. In other words, the flow pattern around the baffle above its lower edge changes very little when the baffle is brought nearer the floor by a distance equal to 1/3 its side length. Below the lower edge of the baffle the flow pattern is influenced by the boundary conditions near the floor when the gap is decreased. No investigations were made with a bottom gap less than 7 cm.

The flowlines and regions of turbulence are not shown in this report. Figure 190 would give the approximate pattern if the base line were displaced. For example, in Figure 190 A, when the gap was reduced by one half, the turbulence zone would reach the floor 2 cm behind the board.

3. Effect of the wind speed

The flow pattern (without wind speed measurements) was investigated for a constant bottom gap of 20 cm, angles of attack of 45, 60 and 90^{o} and incident wind speeds of 2, 6.9, 11 and 16.2 m/sec. The lattice and threads were suspended in 5 - 7 positions up to 5 cm above the top of the board, and photographed. In all, 85 pairs of photographs were taken.

In the range of velocities investigated, the flow pattern was largely independent of the wind speed in all cases.

B. The Flow Pattern About a Square Baffle in a Depression

By mid and late winter deep snow scoops will have formed in the snow around baffles on open terrain. The flow conditions in the vicinity of such a depression were investigated in a special series of model tests. The shape of the depression in nature differs depending on the winds and their sequence. In building the model we chose the form most frequently observed for a continuous prevailing wind direction. The depression was set about 12 cm deep in the floor board. The square baffle had a side of 25 cm and its lower edge was 2.5 cm above the floor board.

The baffle was tested in the depression at angles of attack of 60, 75, 90, 105 and 120°. The incident wind speed was unvaried at 11 m/sec. The lattice work with threads was suspended at distances of 2.5, 7 and 13 - 15 cm (baffle centre) from the floor and was photographed from two directions. Velocities were measured at the same points for all series of tests.

At the bottom of the depression the flow conditions were investigated without the lattice. Instead 5 cm long threads were attached to needles stuck in the floor. The threads were 3 cm above the floor. The speeds measured here could not be included in the isotach diagram owing to inadequate density.

When we compare the results with the flow pattern about a baffle over a plane floor area, we see that the vortex zone is shortened in the lower regions (centre of the baffle and below). It is shortened in its higher parts also (upper edge of the baffle) at angles of attack of 105 and 120°, but is elongated at 75 and 60°. This is due to the ascending air coming from the depression, causing the vortex zone to rise somewhat.

Within the depression there is a flow parallel to the surface. On the windward side of the board, however, a small vortex zone with very low speeds forms in the corner of the depression.

The isotach patterns are all very similar. Hence, as in the case of the series with no depression (Fig. 190 - 192), the baffle setting makes little difference.

Accordingly, it was found that although the flow pattern about a baffle in a depression differs somewhat from that around a baffle on a plane floor, it nevertheless resembles the latter closely with respect to the isotach pattern.

C. The Flow Pattern Around Triangular Baffles Over a Plane Floor and Comparison with Rectangular Baffles of Equal Area

Based on the idea that for a shallow snow cover a small bottom gap has a good effect, but that it may easily become plugged with snow in mid-winter, baffles in the shape of isosceles traingles with their apices towards the floor were investigated in the wind tunnel. In other words, when the base angle is fairly large the sides of the triangle make a sort of bottom gap with the floor in the form of re-entrant angles on both sides of the board. This would result in a bottom gap that would be equally effective regardless of the depth of snow (Fig. 194).

In the model tests in the wind tunnel, isosceles triangles 20 cm in height were employed with the following base angles: 30, 45, 60 and 75°. They were installed with the spices touching the floor board (Fig. 194). In order to get a comparison with rectangular baffles four rectangles of height 20 cm with areas equal to those of the four triangles, i.e. they were of different widths, were studies in a second series of tests (Fig. 194).

The lattice with threads was suspended at 5 cm intervals from the floor and photographed from two directions. The relative speeds were measured always in the same rows of threads. In the case of the rectangles the speed measurements were made only on the widest and on the narrowest baffle.

At first glance the vortex regions and flowlines appear quite similar for both triangular and rectangular baffles. However, when we draw the boundaries of the vortex zone in the individual horizontal sections, we see that for the triangular baffles this zone is narrower near the floor and that its maximum width occurs at the level of the top horizontal edge of the baffle. In the section transverse to the flow, the vortex zone has the appearance of a triangle standing on its apex with its sides bulging considerably.

With the rectangular baffles the maximum width of the vortex zone is near the floor. Above this it gets narrower and ends in the form of a vault. The length of the vortex zone is approximately the same for both baffle shapes.

For the triangular baffles the horizontal sections show a similarity, although the isotachs appear to become denser with increasing base angle of the baffle (i.e. greater speed differences in a small space).

The rectangular baffles show a similar isotach pattern in all sections.

It is evident that the differences between the two forms of baffles with respect to the isotachs and the size of the vortex zone are not very great. The form of the vortex zone for triangular baffles shows similarity to the form with baffles having a bottom gap, so that a similar effect can be expected in snow.

D. The Flow Pattern Around Cruciform Baffles

Figure 195 shows the isotachs about a cruciform baffle with incident flow in the direction which bisects the direction of the baffles. In the horizontal section through the centre of the baffle we see the familiar pattern with two faster regions on both sides of the baffle and slower ones in front of it and behind it. The longitudinal section through the centre of the board also gives us a pattern very similar to the other series of tests.

SUMMARY

The purpose of the model tests was to study the flow pattern about baffles as a function of various factors. In nature such studies would have taken a great deal of time, since the direction and speed of the wind cannot be controlled.

The results of the investigation reveal the following rules:

1. The flow pattern is largely independent of the wind speed.
2. For a given cross-section area of the baffle the flow pattern does not depend greatly on its shape, provided the differences of shape are not too great (e.g. square - elongated narrow rectangle; the baffles being compared must have the same basic shape, e.g. both isometric or both more oblong).
3. In the range of $90^{\circ} \pm 20^{\circ}$ the angle of attack of the baffle has little effect on the flow pattern. Outside this range the conditions change increasingly.
4. The flow pattern about a baffle is independent of the bottom gap provided the latter is not less than 1/3 the edge length of the baffle.

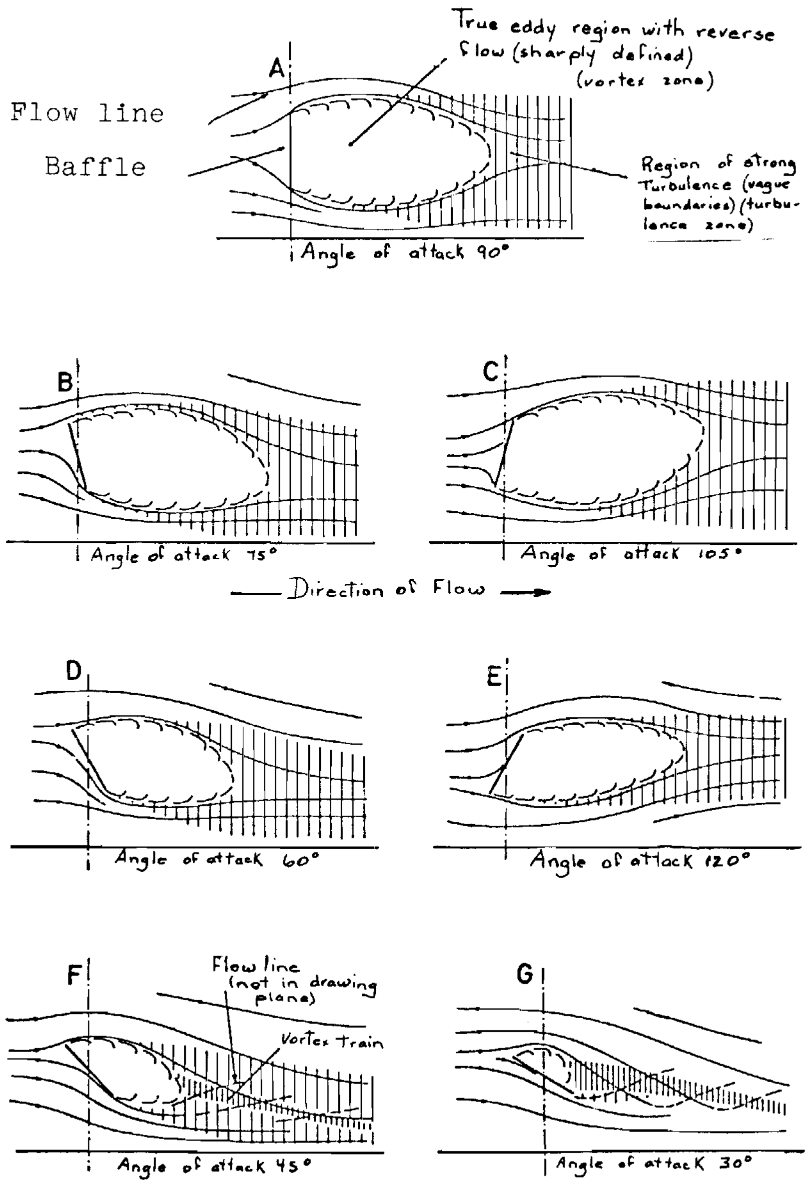


Figure 190

Effect of the angle of attack on the flow pattern about a square board of 25 cm side with a bottom gap of 20 cm. The flow line patterns have been obtained from the photographs; roughly schematic drawings. They represent the longitudinal section 5 cm from the centre plane

Angle of Attack 90^{o}

Longitudinal Sections

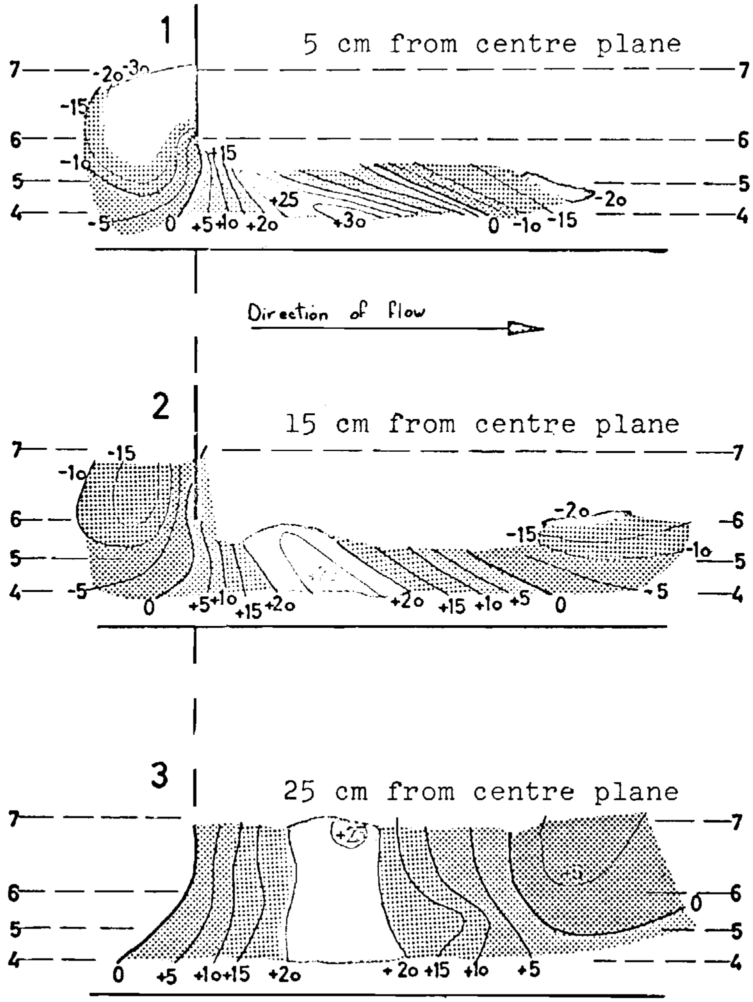


Figure 191

Lines of equal wind speed (isotachs) around a square baffle of 25 cm side at different longitudinal sections (5, 15 and 25 cm from centre plane). Angle of attack 90^{o}, bottom gap 20 cm. The speed zones are indicated in percent of incident wind speed (light hatching: faster, darker hatching: slôwer). The location of the longitudinal sections (1, 2, 3) is shown in Figure 192

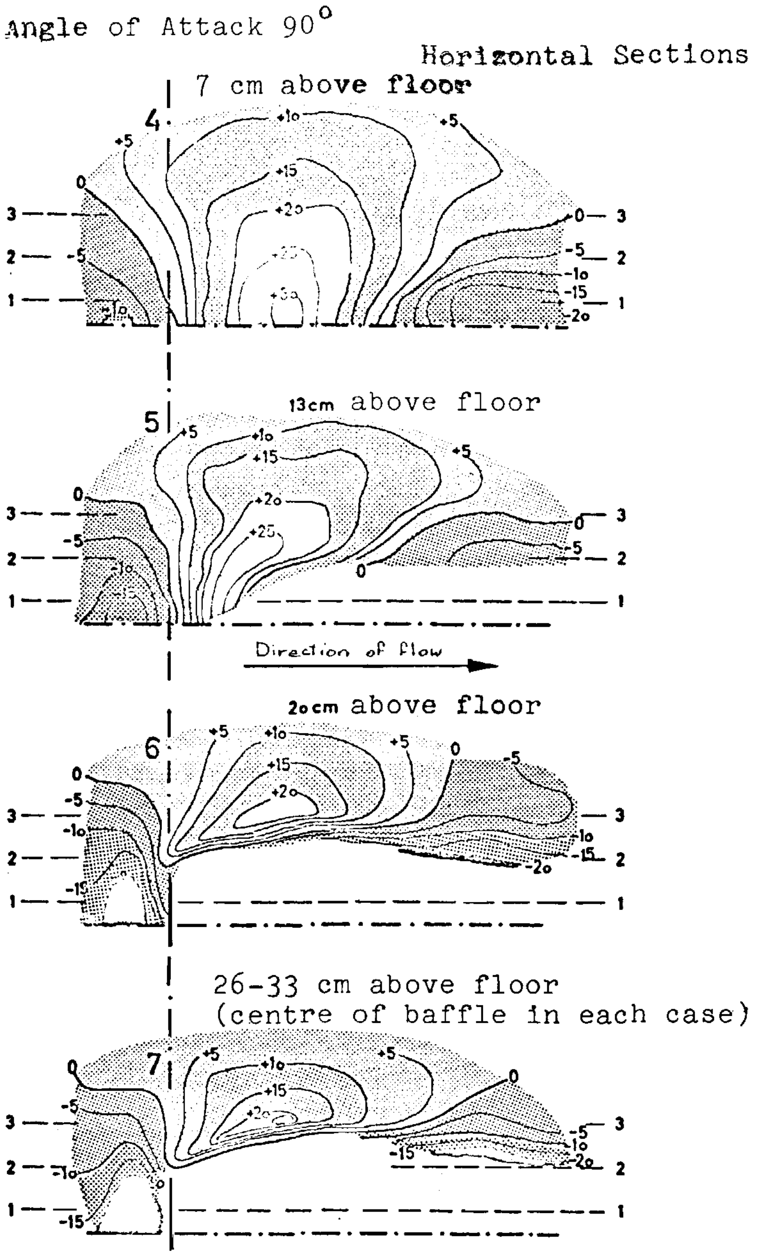


Figure 192

Isotachs in horizontal sections (7, 13, 20 and 26-33 cm above floor). Other data as for Fig. 191. 7, 6, 5, 4 denotes position of horizontal sections shown in Figure 191

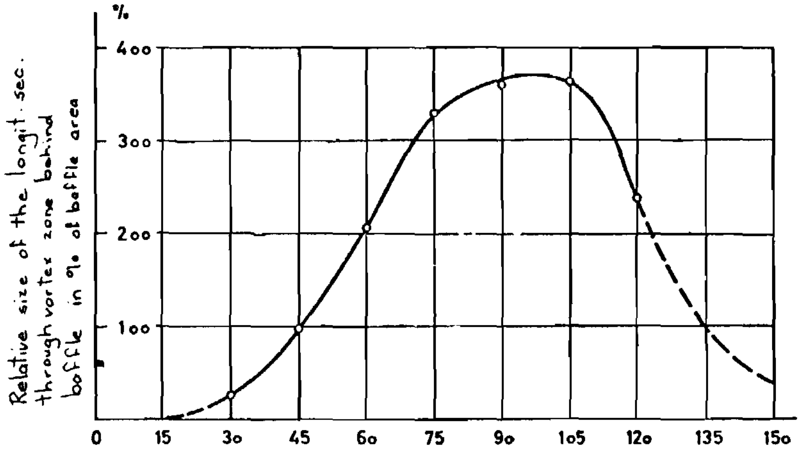
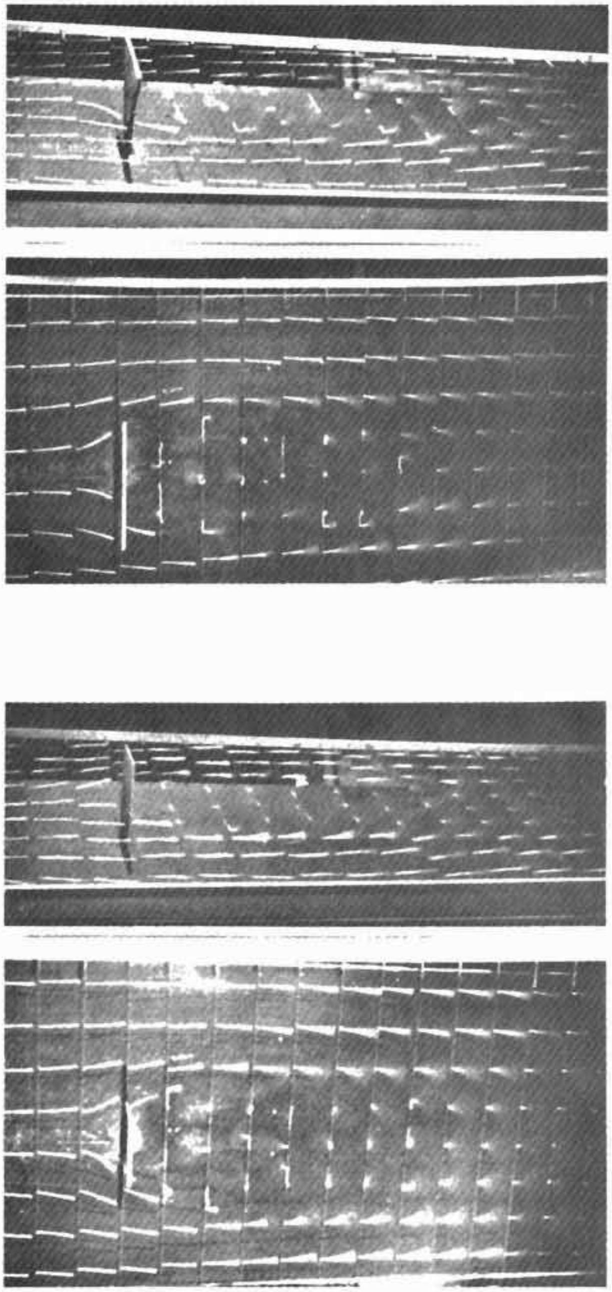


Figure 193

Relative size of the longitudinal section through the "vortex zone" (longitudinal sections in Fig. 190) in % of baffle area as a function of the angle of attack. The vortex zone is the region with reverse flow produced on the lee side by the baffle



Tafel = baffle

Figure 194

Photographs of test series with triangular baffle (base angle 75°) compared with rectangular baffle of same area. Lattice with threads 10 cm above the floor. For both baffles the pictures are simultaneously taken pairs

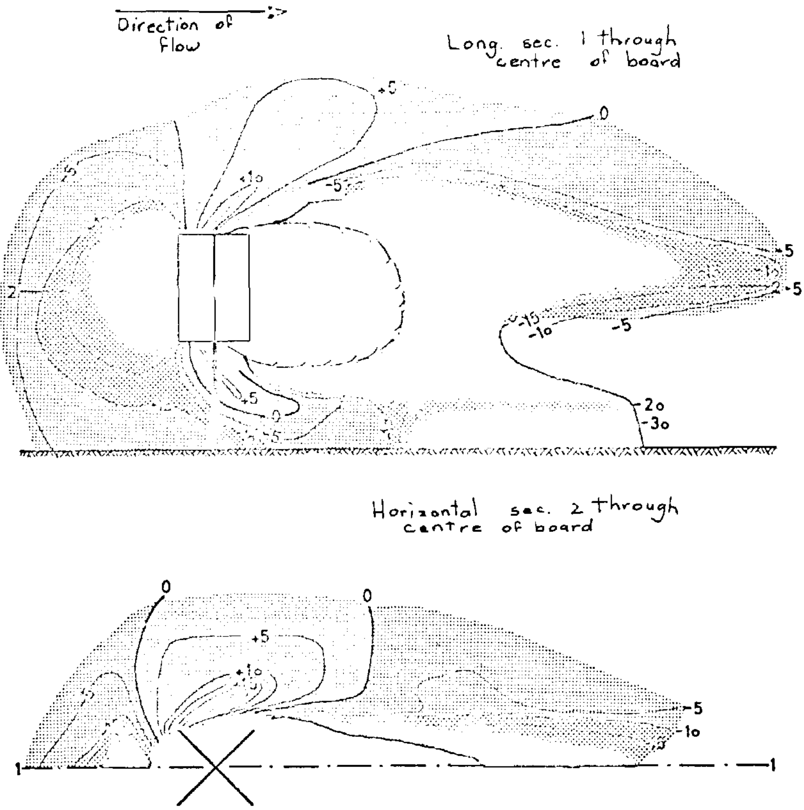


Figure 195

Isotachs around a baffle of cruciform cross-section in longitudinal and horizontal sections through centre of board. The lines demarcate the zone of equal speed v, expressed in % of incident wind speed v_o. Staging of isotach: up to ±20%, 5% intervals; beyond this, 10% intervals. Colour staging: up to ±20%, 10% intervals; beyond ±20% the colour is uniform (light hatching: faster, dark hatching: slower). In the horizontal section only the left half is shown.