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PLANNING DEFENCES AGAINST AVALANCHES

BY
P. A. SCHAEERER

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Planning defences against avalanches¹

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Protective measures against snow avalanches must be effective, practical, and as economical as possible. The information concerning the objectives of an avalanche defence, the terrain, and the characteristics of the avalanches, required for the design of the defence system, is outlined. A discussion is presented of the economical and operational factors that must be considered in the analyses of alternative defences and in choosing the optimum method.

Les mesures de protection contre les avalanches de neige doivent être efficaces, pratiques et aussi peu onéreuses que possible. Le mémoire souligne les renseignements requis pour la conception des systèmes de défense en indiquant les objectifs attendus des mesures défensives, le terrain et les caractéristiques des avalanches. Suit ensuite une discussion des facteurs économiques et d'opération qui doivent être envisagés dans l'analyse de moyens alternatifs de défense et dans le choix de la méthode optimale à utiliser.

Problem

In planning protection against avalanches the objective is to find the most effective and practical defence method at the lowest possible cost. It is usually necessary to choose from several alternatives. The information required for making a decision and the steps that must be followed are summarized in Fig. 1.

Terrain Analysis

Problem areas must be identified by making an inventory of avalanche sites (Frutiger 1964; Frutiger and Martinelli 1966). Because time is usually not available for locating them by observations carried out over several winters, avalanche paths must be identified from studies of terrain and vegetation.

Certain types of terrain are more likely sites of avalanches than others. Steep slopes, cliff banks, rock outcrops, the leeward side of ridges, and gullies are potential areas for avalanches. The occurrence of an avalanche, however, depends not only on terrain but also on local climate. In southern British Columbia the following rule of thumb may be applied: Leeward open slopes having an incline of more than 30° tend to produce avalanches; slopes on the windward side having inclines less than 35° have none, or very few.

In the heavily timbered valleys of western

Canada scars in the forest indicate where large avalanches have occurred (Fig. 2). Many flow through light timber and around trees without breaking them, but broken branches on the uphill side of trees, damaged scrub and small trees, broken wood scattered on the ground, all are possible evidence of avalanche occurrences (Fig. 3).

Avalanche paths through forests and over

FIG. 1. Flow of analysis.

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FIG. 2. Avalanche site. Avalanches start to slide on the cliffs at the top of the open area.

terrain that is suspect can be recognized on air-photos. A first terrain analysis should be made by interpretation of such records. This should be supplemented by observations from a helicopter and on the ground in critical areas.

Types of Avalanches and Frequency of Occurrence

Planning and design of avalanche defences require information on the size, type, and frequency of the avalanches expected to occur. Observations of avalanches and weather in previous years are useful, but the assumption that what happened in the past will also happen in the future is unreliable. Growth or loss of forests, man-made modifications of terrain, or changes of climate over long periods of time can influence future avalanche activity. Such possibilities should be kept in mind.

There are three possible approaches to ob-

taining a picture of past avalanche activity. They are not ideal, but they do supplement each other and are best used in combination.

a) Avalanche Observations

Observations on the spot and the recording of avalanches as they occur are most reliable, but they are time-consuming. Weather and safety considerations may also prohibit visiting the areas during and immediately following cycles of avalanche activity. By the time travelling conditions have improved, many small avalanche deposits may be covered with new snow and escape detection. A survey between snowstorms does not, therefore, always give the full picture. Most old avalanche deposits can be recognized in the snowmelt season by the texture and color of the snow. The best time for observations if the area cannot be visited during the winter, then, is when about half of the natural snow has melted.

FIG. 3. Trees damaged by avalanches.

Avalanches have been classified by criteria such as weather factors responsible for their formation, form of fracture, nature of motion, type of snow, and size (de Quervain 1965; U.S. Forest Service 1968). A complete description should contain all characteristics, but the occasions are rare when one can observe the whole sequence of an avalanche and obtain all the information. Usually its character must be determined from traces such as deposited snow. Experience has also shown that only a well-trained observer is able to make a reliable, full description of an avalanche. Because of these difficulties, complete classification should be attempted only for research. For purposes of planning avalanche defence, it would be adequate to record: date; location of starting zone; type of snow (dry, wet, damp); location of the tip of the avalanche deposit; size, expressed either by the width, length, and average depth of deposited snow or as "small," "medium," "large," or "major," relative to the size that usually occurs at the site; and effects, such as broken trees and wind blast.

Once in 10 to 22 years there appears to be a winter, or a series of winters, with more frequent and larger avalanches than usual

(Kahn 1965; Schaerer 1962; Toushinsky 1965). As short observation periods could fall into a cycle of low avalanche activity, it is necessary to include about 25 years of observations to be certain that the large and infrequent avalanches are also recorded. It is scarcely possible to wait this length of time before making decisions on an avalanche defence, but in a developed area such as a valley served by a road, railway line, near settlements, or in ski areas, historical data can be obtained from local people. Maintenance foremen have proved to be the most reliable sources of information; statements from casual observers must often be treated with caution. The continuous recording of information concerning avalanche occurrences required for development purposes has been initiated in many countries, and in Canada it is carried out in problem areas such as Glacier, Banff, and Jasper National Parks; the Salmo-Creston Highway; on railways; and along the Kemano-Kitimat powerline.

b) Observation of Vegetation and Geomorphology

A study of avalanche traces allows conclu-

sions to be drawn concerning their size and frequency. Studies on vegetation must be made with caution because local climate, soil conditions, and forest fires influence the growth of trees and plants. Inferences from tree growth at avalanche sites must only be made after comparison with trees at sites undisturbed by avalanches.

Rock debris brought into a valley by avalanches can supply historical data on the frequency of avalanche occurrence and where they have deposited snow (Peev 1965; Briukhanov *et al.* 1966). This method was developed in the U.S.S.R. and finds useful application in a dry climate where there is little vegetation, where avalanches slide on the ground and where they do not occur every year. Geomorphological observations have not been useful as yet west of the Rocky Mountains. An abundant vegetation covers rock debris and large avalanches often slide on a snow surface and contain no debris.

c) Weather Observations

Weather observations of the past allow estimates to be made of conditions favorable to the formation of avalanches. If they cover 20 or more years, they provide a fairly good picture of the average avalanche activity. The drawback is that weather observations may be inaccurate because they are usually made in a town some distance from the avalanche sites and may not contain information on wind speed and direction.

A basic requirement for application of the method is to know the conditions that produce avalanches. A mathematical model for predicting avalanche occurrences from weather and terrain observations has not been developed, and the method must rely on a skilled human brain. A man who has a broad knowledge of avalanches and is experienced in avalanche hazard forecasting can recognize from weather observations when avalanches will probably occur in a given terrain.

A combination of methods (a) and (c) improves the ability to estimate avalanche occurrences. Avalanche and weather observations made simultaneously during one or more winters allow correlations to be developed that can be applied to weather observations of the past,

and such correlations improve with increasing number of years.

Objective of Avalanche Defence

The objectives of a defence are to protect human lives, protect property, and keep open transportation and communication lines. One of the most important tasks, and often the most difficult, is to define the degree of protection that must be achieved. Safety under all circumstances is possible, but the cost is usually high. In most cases it is more economical to choose a defence with a lower protective value and to assume a calculated risk.

The risk or the avalanche hazard may be defined as the probability or chance that a person or object may be struck by a moving avalanche. It is a function of the number of avalanches that occur each year and the duration of exposure to them. The hazard must further be qualified by the damage that would result, and this would be determined by the type and size of avalanche as well as the type of object and its location in relation to the moving avalanche.

The tolerated risk defines the acceptable standard of defence; the standard of defence describes what can be allowed to occur and its frequency. Whenever possible the standard should be expressed in well defined, quantitative terms. The following examples indicate how it may be expressed.

a) Occupied Buildings

Avalanches that could destroy the building must not reach the site under any circumstance.

b) Unoccupied Buildings

Once in 10 years an avalanche that produces light damage may reach the building. Avalanches that could cause extensive damage must not reach the site more frequently than once in 30 years.

c) Roads

Avalanches that produce windblast and deposit snow dust on the road must not occur more frequently than twice per year. The probability that a vehicle will be buried in an avalanche must not be greater than once in 50 years. The duration of road closure because

of high avalanche hazard or avalanche snow removal is to exceed 12 h only once in 5 years.

One of the difficulties in defining a standard is the lack of experience and the uncertainty about the consequences of avalanche accidents. It would be desirable to have drafted a list of generally accepted standards.

Definition of Alternatives

Avalanche defence methods are discussed in the literature (Mellor 1968; U.S. Forest Service 1968; Fraser 1966; Frutiger and Martinelli 1966; LaChapelle 1966(a)). The following should be considered from an economic and operational point of view:

- a) Avoidance of dangerous areas. Attention should be given to locating roads, buildings, and ski runs so as to minimize the danger from avalanches; it may even be more economical to relocate a structure than to introduce defence measures.
- b) Measures that require extensive investment of capital but offer a high degree of safety and require no work during the winter: supporting structures in the starting zone; galleries (snow-sheds); large diversion dams; walls and wedges in front of isolated objects; reforestation.
- c) Measures that require moderate investment but do not offer protection under all circumstances. No maintenance work is usually required during the winter: snowfences and wind baffles in the accumulation area; berms (benches) in the starting zone; arresting dams and mounds in the path of the avalanches; and small diversion dams.
- d) Measures that require little capital investment but do require manpower and introduce operating cost during the winter: controlled release by hand-placed explosives, gunfire, helicopter bombing; test skiing and protective skiing; and restriction of access to dangerous areas (the enforcement of restrictions of access would usually involve little direct operating cost, but that due to loss of time and business could be high).

Analysis of Alternatives

a) Constraints

A first selection from the large number of defence methods is made by a process of

elimination. Every method has its limits of application. Terrain, weather, the types and numbers of avalanches that occur, available manpower, all impose constraints that can usually be recognized. Defence methods that cannot be used because of physical, organizational, or other limitations must be excluded from consideration. Some of the most common constraints are:

The starting zone is higher than the natural treeline and cannot be reforested.

Space is not available for the construction of a diversion dam.

There is no space where avalanches can run out harmlessly after being diverted by a dam.

The bearing strength of the soil is inadequate to support the impact pressure of avalanches on walls and wedges.

Structures could be endangered by avalanches that are released by explosives.

The starting zone of the avalanches is behind mountain ridges and cannot be reached by artillery.

Weather does not allow flying when avalanches should be controlled by explosives dropped from a helicopter.

b) Model

The most promising methods of defence (that have no limitations of applicability) may be analyzed by use of a model or preliminary design of the defence and an investigation of how it would affect any avalanches that could be expected to occur. The model may be a sketch of a defence structure or the assumption of an organization that enforces restrictions and applies explosives. Judgment is used to predict the outcome of various avalanche situations known from records or estimated from weather observations. The technique is similar to a war game on paper.

One could also use computer simulation, particularly when the avalanche occurrences and weather observations of past years are recorded on magnetic tape or punched cards. It does not usually take much time to investigate typical avalanche situations, however, and the time saved by using a computer could easily be lost in writing the program for the particular situation.

Model analysis can yield information on the

protective value of alternative defence methods. Protective value is most conveniently expressed by the hazard that would still exist following introduction of defences. All alternatives must be rejected or the design improved if model analysis indicates that the minimum standard of defence will not be met. For alternatives that do meet the standard it will be necessary, as a next step, to estimate cost and intangibles.

Cost estimates must include all direct and indirect capital and operating costs. Capital costs are initial expenses for structures, earth work, artillery pieces, instruments, communication systems, search and rescue equipment. Direct operating costs are the annual expenses for the maintenance of structures, purchase of explosives and ammunition, salaries of personnel, removal of snow deposited by avalanches. Indirect operating costs result from loss of business when restrictions are enforced or avalanches cut communication lines.

Not only protective value and cost but also organizational, psychological, political, and other considerations influence the decision for an avalanche defence; additional intangible factors include:

Control by explosives and restrictions require trained personnel available on a 24-h basis during the winter, but there may be little requirement for them in the summer. Many organizations prefer not to maintain special staff, particularly where avalanche problems are small. They would favor permanent structures rather than control by explosives.

Restrictions to traffic may have serious consequences on a production schedule.

Restrictions to public traffic may be undesirable for political reasons.

Snowsheds limit the allowable height and width of vehicles; restricted vision and icy pavements inside the snowsheds increase the possibility of traffic accidents.

Structures may adversely affect the natural beauty of the area.

Use of explosives may affect wild life.

Optimization

The defence that has the lowest ratio of cost to protective value represents the optimum solution. The main objective of an avalanche defence is safety, but it is difficult to express safety in quantitative terms and even more

difficult to express it in terms of money. Decision-making processes common in operations research cannot be readily applied. Similar problems are encountered when several projects of road improvement are compared, or military experts have to decide between alternative types of armament. No satisfactory criterion by which alternative defence methods can be ranked has yet been found.

The most practical way of making a decision is to list alternative methods and their characteristics: hazard (protective value), cost, intangibles. The choice is relatively simple where there are two methods having almost equal cost. The project with the higher protective value will be chosen. Alternative projects with very high protective values (e.g., a gallery vs. retaining structures) can be decided by cost. Decisions are more difficult where there are great differences among hazard, cost, and intangibles. This would be the case if protection of a road by a gallery, having high capital expenses but providing full protection, were compared with control by explosives, requiring only the cost of operations but including the risk of uncontrolled avalanches and closure of the road. A solution could be obtained by attaching an arbitrary price to possible accidents and road closures, adding this price to the cost of the defence, and comparing the projects on a cost basis. The effectiveness of a defence can be measured in terms of money and a cost benefit analysis made in cases where avalanches cause only property damage and pose no threat to life (LaChapelle 1966(b)).

The defence that is finally selected must be designed in detail and include such factors as location of structures, their dimensions, the selection of targets for artillery fire, and the drafting of a snow safety plan.

Summary and Conclusions

New roads, mines, and ski areas are being established in the mountains of western Canada, many of them in avalanche terrain. Before a defence against avalanches can be planned it is necessary to know their characteristics and the locations where they may occur. As observations of past avalanche occurrences are not always available, information must be obtained from terrain and weather observations. Experience must be gained in collecting this type

of information and in using it for predicting the avalanche hazard.

Avalanche defence is chosen by optimizing performance, cost, and intangibles of various defences, taking into consideration the limits of application of each method. Restrictions and snow stabilization by explosives are used most frequently in North America. Their great advantage is low capital investment and flexibility. Explosives are applied either by hand-placed charges in areas such as ski areas that are easily accessible; by firing various types of artillery pieces; or by dropping charges from a helicopter. For either restrictions or explosives to be effective and economical it is necessary to make snow, weather, and avalanche observations and to assess the probability of avalanche occurrence continuously. Developing methods of avalanche hazard forecasting and training personnel are, therefore, one of the most important tasks in avalanche control in North America.

Defence structures are chosen when restrictions would be intolerably long, where terrain makes use of explosives impossible, when cost and inconvenience of explosives are high, or at isolated avalanche sites. The literature deals extensively with the layout and design of supporting structures because this type of defence has been used to great advantage in the alpine countries of Europe. These comprise large walls, fences, or nets arranged to retain snow and prevent avalanches from falling. The relation between labor cost and material cost is different from that in North America where mountain areas are not as densely settled as in Europe and the benefits derived from protection by supporting structures have a lower value. For these reasons, supporting structures are less economical than other structures on this continent, except in special cases. Direct protection of an object by dams, galleries (sheds), deflecting mounds, and wedges has proved to be more practical.

The Division of Building Research of the National Research Council is conducting a program of observations with the object of establishing criteria for the planning and design of avalanche defences in western Canada. Studies are carried out at Rogers Pass concerning the relation between terrain, weather, and characteristics of avalanches, and experience

is being collected on the performance and economics of defence methods. This information is available for application to avalanche defence projects.

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