Avalanche Forecasting in Iceland and Norway: Proposed Guidelines for Implementation and Operation of Local Avalanche Forecasting

Krister Kristensen and Magnús Mar Magnússon
Norwegian Geotechnical Institute, P.O. Box 236, N-6880 STRYN, Norway
Phone: +47 5787 7370, Fax: +47 5787 7371, e-mail: KRISTER.KRISTENSEN@sprint-norway.sprint.com
Icelandic Meteorological Office, Bustadarvegi 9, IS-150, Reykjavík

Key Words: Avalanche, Forecasting, Iceland, Norway

ABSTRACT

A proposed procedure for the implementation and operation of local avalanche forecasting programs in Iceland and Norway has been worked out in co-operation between the Icelandic Meteorological Office and the Norwegian Geotechnical Institute. The objective of forecasting programs in this context is to provide the basis for decision making on the local level in avalanche danger situations, specifically, the evacuation of people from housing areas. The avalanche forecasts should ideally provide information about the release probability in specific avalanche paths and the expected magnitude of the avalanches. The proposed procedures aim to ascertain that avalanche danger evaluations are being done consistently and that they are based as much as possible on objective and quantifiable observations.

INTRODUCTION

Following serious avalanche accidents in the north-western part of Iceland in 1995, a formal co-operation between the Icelandic Meteorological Office (IMO) and the Norwegian Geotechnical Institute (NGI) was established. The Nordic Ministerial Council decided to support a three-year research and development co-operation between Iceland and Norway. The aim of this co-operation is to strengthen the effort to prevent avalanche accidents in the two Nordic countries in the future. The present report concerns the local avalanche forecasting sub-project, which is one of the four projects that the co-operation will concentrate on.

The situation in Norway, and particularly in Iceland, is that a potential for serious snow avalanche damage has become evident in several communities during the last few years. In a short term perspective it is not possible to protect these areas with structural avalanche protection measures or to move the constructions. Thus, for several communities, avalanche forecasting and evacuation is the only mitigation option at this time.

GENERAL FRAMEWORK

Objectives

Local avalanche forecasting in this context means forecasting of avalanche danger in specific avalanche paths or runout zones. The objective of a local avalanche forecasting program is to provide the basis for specific decisions in avalanche danger situations. The avalanche forecasts should give information on the release probability in specific avalanche paths and the expected magnitude of the avalanches. The danger evaluation should be based as much as possible on objective and quantifiable observations. Nevertheless, it is important to acknowledge the fact that avalanche forecasting is not perfect, and that the success rate in predicting avalanches will not be 100%.

Legislation

The law relating to snow and avalanche protection in Iceland has recently been revised, and now gives the responsibility of all aspects of avalanche safety to the Ministry of the Environment and one of its institutes, the Icelandic Meteorological Office (IMO).

In Norway there are at present no laws specifically demanding the implementation of local avalanche warning and forecasting programs. According to the **Report to the Parliament** (Stortingsmelding) **no. 9, 1972**, the national responsibility for doing avalanche research and providing specific advice on avalanche safety is given to the **Norwegian Geotechnical Institute (NGI).**

The above means that local forecasting programs will be operated somewhat differently in Iceland and Norway. In Iceland, both the actual forecasting and the decision making are centralised to the IMO, while in Norway the forecasting is for the most part done at the local level with assistance from the NGI when required. The final decision making is considered a task for the local authorities in Norway.

POSSIBILITIES AND LIMITATIONS

At present, there are no universally accepted procedures for local avalanche forecasting. Avalanche forecasting is traditionally done by experts using their knowledge of snow stability and their experience with avalanche situations. They use quantitative weather and snow data, as well as several other non-quantifiable observations, to arrive at conclusions about the avalanche danger. The exact manner in which this information is processed is not well established.

The highest success-rate in avalanche danger evaluation seems to be obtained by experienced forecasters using statistics to support their more or less subjective expert opinion. The development of the 'nearest-neighbour' and other statistical models for pattern recognition in weather and snow data, have improved the possibilities for the forecaster to use data bases of previous observations. This also makes it easier to document the basis for the evaluation.

The measured parameters should have some relevance to the snow stability in the avalanche starting zone. As there are no well developed methods for direct measurement of the stresses or the propagation of fractures in the microstructure of the snowpack prior to avalanche release, the parameters used have only an indirect relationship to the processes in the snowpack in the avalanche starting

zone. In addition, the measurements usually have to be done at some distance from the avalanche starting zones.

The strategy of many local forecasting operations is therefore to measure what parameters seem most relevant, and that are also possible to measure in practice. The snow stability, which in most cases means the avalanche activity and results from stability tests, is then closely monitored. After a period of time, statistical relationship between these measurements and the snow stability can be established. With the use of machine learning systems like neural networks, computer programs can also be trained to use several types of information without any assumptions on the form of the relationships between the different input variables (Stephens et al. 1994). Nevertheless, long term databases of high quality are critical to these forecasting techniques. Efforts are also being made to integrate knowledge-based (expert-) systems with machine learning systems.

Monitoring of the avalanche activity is often difficult. When no damage is done, because of weather conditions and visibility, it is often difficult to record the exact time of an avalanche, and sometimes it is not even possible to ascertain whether it has run or not. This fact is poses a serious problem for reliability of statistical models like the nearest neighbour. To remedy this problem to some extent, each forecast period, can be given an 'a posteriori' rating of the avalanche danger based on the observed snow stability and avalanche activity in and near the forecasting area.

In some cases, neither data on local weather nor an avalanche record may be available. In these cases, only very general criteria for new snow accumulation and wind speed can be utilised. In cases were some catastrophic avalanches can be dated, it may be possible to work out initial avalanche criteria based on analyses of the synoptic situations during these events.

Reliability

How reliable are avalanche danger forecasts? The evaluation of the performance of a forecasting program will depend on what forecast periods that are considered and what the resolution of the danger scale used is. Discriminating between 'avalanche and non-avalanche days' for a large region during the winter is obviously easier than determining the snow stability in specific starting zones on a daily basis using a five degree scale. Verification results that have been published, show success scores ranging from around 60-80%. The results also show that the danger rating is more often too high (Föhn and Schweizer, 1995).

It is thus important to acknowledge that in every assessment of avalanche danger there will always be a degree of uncertainty. Some causes of avalanche release may not be within what is practically possible to observe or predict. In addition it is not always possible to guarantee the quality of the input data used.

To ensure the long term quality of local level avalanche forecasting program, it is important to identify the ways in which the program can fail to reach its objective. When one disregards the inherent uncertainty in the avalanche forecasting problem, the overall reliability of the system will depend on a number of conditions. The ability to observe and store relevant snow and weather data on a continuos basis and to acquire reliable weather forecasts are basic requirements. In addition there must be an ability to analyse the data and the weather forecasts. It must be possible communicate reliably to those who are responsible for the decision making and to those who are responsible for implementing the decisions. Finally, these have to respond correctly and at the right time to the forecast avalanche danger. Failure in any of these parts may in the end seriously affect the outcome of an avalanche occurring in the area for which the forecasting program has been implemented.

Risk reduction

What is the reduction of risk that can be expected when implementing a local forecasting program? For in the calarge, catastrophic avalanches, which is the type that usually has to be considered when habitations are threatened, the return interval of actual accidents may be quite long. This is because the avalanches themselves often have a signs of avalanche hazard are often abundant in the eyes of a trained forecaster. long recurrence interval, often 100 years or more. In some climatic regions it may be reasonable to assume that avalanches of this type are more predictable than avalanches with shorter recurrence interval, because the extreme avalanche situations will appear more obvious to the forecaster. On the other hand, the low frequency may also mean that only a limited amount of data, or no data at all, connected to the release of these extreme avalanches are available.

If one considers the case of an error rate of 20% for the forecasting program and an average recurrence interval of 100 years for catastrophic avalanches, the average recurrence interval period for unforeseen avalanches would be in the order of 500 years. Thus, in certain cases, an avalanche forecasting program may reduce the risk to individuals to acceptable levels. However, in many cases one also has to consider that the collective risk, or the sum of individual risks endangered by the same event, may not be acceptable. One also has to consider that material damage usually cannot be prevented by a forecasting program. Depending on the recurrence intervals and the consequences of the avalanches, a forecasting program could be either temporary or permanent, although for most permanently populated areas it will usually be seen as a temporary mitigation until permanent measures have been implemented.

GENERAL PRINCIPLES

The forecasting procedure can be roughly divided into two main tasks, i) the evaluation of the avalanche danger at present, and ii) the prediction of how the avalanche danger will develop in the near future.

The general procedure of avalanche forecasting can be described as in Fig 1.

Evaluation of the present avalanche danger

For the snow stability evaluation, a certain minimum amount of snow and weather data is required. Using automatic weather stations it is possible to measure air temperature, wind speed and direction, precipitation and new snow accumulation on a continuos basis with short measuring intervals.

In addition, periodic and intermittent data from manual and visual observations done by a trained snow observer are required. The observations are done as often as required depending on the weather and snow stability situation and they include snow stratification profiles, snow stability tests, avalanche activity and snow distribution in the starting zone(s). Additional observations outside formal data collection procedures can also contribute valuable information.

The selection of instrument sites is important with regard to the representativeness of the measurements. Ideally, the observations are made in or very close the starting zone itself. Wind and snow transport are measured on wind exposed sites, while snow accumulation usually is measured in areas that are neither subject to wind erosion nor accumulation. The snow distribution in the starting zone(s) is usually done by visual inspection, but may in some cases be done with automatic snow height sensors. Precipitation is usually measured at a valley site.

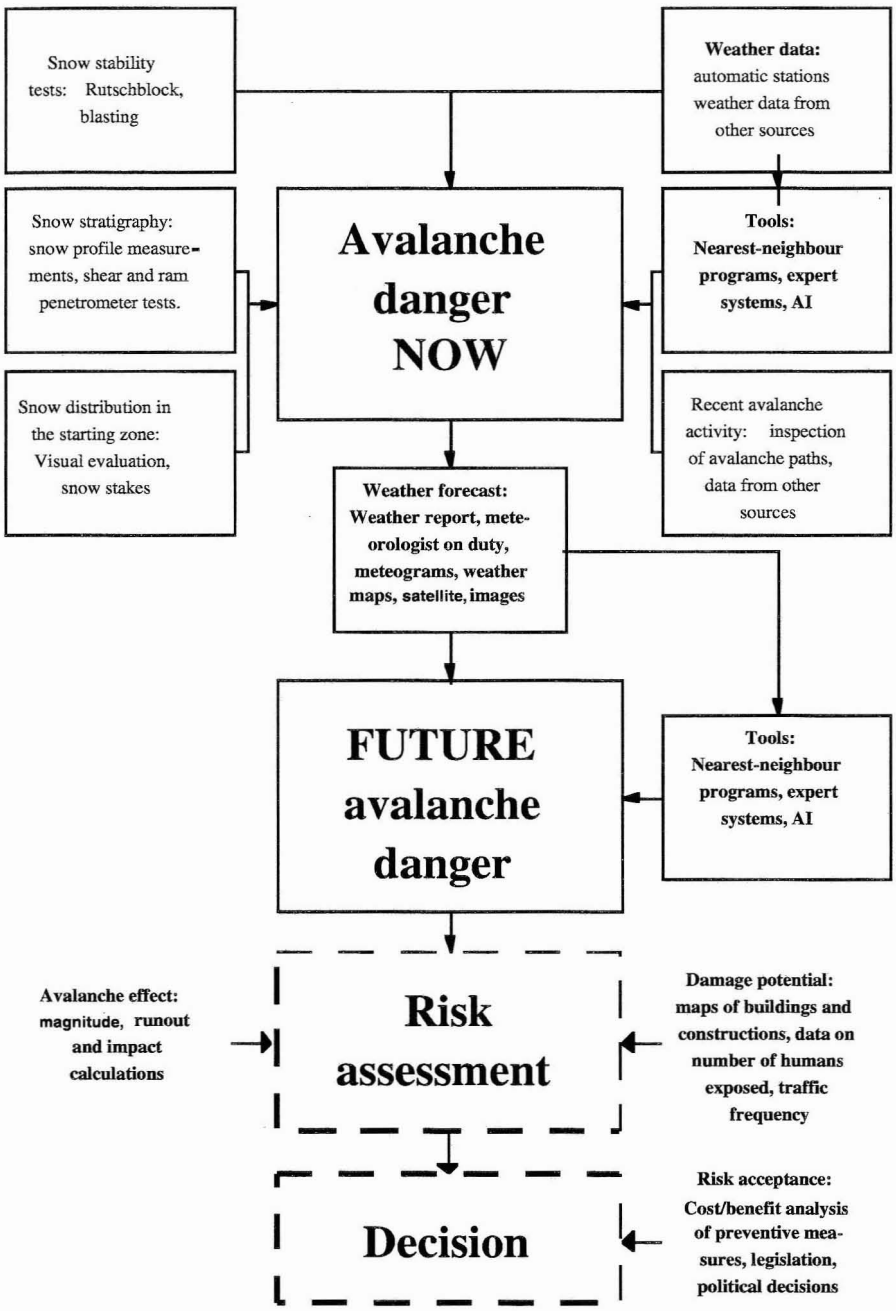


Figure 1. Outline of an avalanche forecasting procedure with input data and their possible sources.

The snow stratigraphy and stability evaluations take place at specific now study plots, which are representative with respect to altitude, aspect, inclination and snow distribution.

Based on the weather and snow data above, avalanche criteria and model output, the present avalanche danger is estimated. Avalanche danger can be seen as the product of the avalanche release probability and the expected volume of the avalanche. The larger the expected volumes are, and the more unstable the snow cover is, the higher the avalanche danger. The five degree avalanche danger scale adopted by the European Working Group of Avalanche Warning Services expresses the avalanche danger in these terms.

Evaluation of future avalanche hazard

The development of the danger situation is assessed on the basis of the present avalanche danger and an evaluation of the weather forecast. Input data to the models consist of both observed and predicted parameter values. This requires high quality local weather forecasts showing the development from hour to hour.

Verification

In order to evaluate the performance of a forecasting program, one also has to be able to verify the forecasts in hindsight. Quantified verification is often difficult since the stability of the snowpack in the starting zone cannot be readily determined, unless an avalanche actually is released. For the lower danger scale degrees, the snow cover can often be unstable even if this does not cause natural avalanche releases. The verification of the danger evaluation can be based on observations of avalanche occurrences and snow stability tests. If possible, information is also obtained from outside sources like road maintenance personnel and the public. When each forecast period is over, it can also be given an a posteriori rating of the avalanche danger based on these observations.

RISK AND DECISIONS

The term risk includes three basic parts that are multiplied to quantify the risk level. Risk can be split into three basic factors; 1. the danger, or the probability for a certain event, 2. the probability of damage in case of the event, and 3. the magnitude of extent of damage. The residual risk is the product of the three factors after they have been minimised as far as possible. The collective risk is the sum of all individual risks of all threatened persons or objects.

An avalanche forecasting program in connection with habitations will not affect the first factor, the probability of an avalanche release. It can, however, reduce the probability and the extent of damage in case of an avalanche, mainly in terms of human lives or injuries spared, if the appropriate measures are taken.

In a risk analysis, one also has to consider the ability to make accurate avalanche danger evaluations. To keep the risk permanently low, it must be possible to forecast avalanches continuously with a high degree of precision and to use a sufficient safety margin when decisions are made.

However, there will always be a certain residual risk. To find out whether this residual risk will be within what is tolerable, one will usually refer to the accident statistics of other, similar aspects of life. The residual risk will in the long run have to match this.

Decision Making

In cases when different options exist, the decisions are ideally based on a cost/benefit analyses to compare the justification of the measures.

When a forecasting program is the main preventive measure against avalanches, the risk to humans lives, can only be reduced if appropriate measures are taken at the right time. In the case of habitations this will mean the evacuation of the threatened areas. Evacuation of people can cause considerable logistic problems and can be time consuming. It is often desirable to use a safety margin, and an evacuation should preferably be in effect before a dangerous situation has developed. However, if the evacuation has to be in effect for too long a time or if there are too many unnecessary evacuations, the decision makers may lose credibility among the public and the media. This often puts the decision makers in difficult situations. The decision making should therefore be performed by authorities with the necessary legal authorisation and political support. Since the risk perception among the public may be quite different from the decision maker's, public education is be important.

Because of the considerable pressure that can be put on the decision makers, it is necessary to have a plan that determines what specific precautions are to be taken during the different levels of danger.

RECOMMENDATIONS

The following are recommendations for the implementation of local avalanche forecasting programs for inhabited areas in Iceland and Norway. In Iceland the Icelandic Meteorological Office is required by law to implement and run the local level avalanche forecasting programs for habitations. Forecasting is done as a public service financed through government funds. In Norway local programs are mainly carried out by the municipal authorities, who will also finance the program. Assistance from the NGI is normally given on a contract basis. It is suggested that in the future, local forecasting programs for habitations in Norway should be supervised by the official avalanche institute in Norway, the Norwegian Geotechnical Institute.

Implementation

Avalanche forecasting programs in Iceland and Norway should preferably be implemented at a specific site after an avalanche mapping, a risk analysis, and preferably a cost/benefit analysis of alternative safety measures have been performed.

It is recommended that a local avalanche forecasting handbook, complete with observation guidelines and recording standards for weather, snow and avalanches is prepared in the Norwegian and Icelandic languages during the coming year. The handbook should contain the translations of the international classification schemes for snow and avalanches. It is also recommended that the handbook is made in co-operation with the European Workgroup of Avalanche Warning Services. The hand-

book and the methods should be updated as research on avalanche forecasting advances.

Implementation of specific avalanche forecasting programs should follow the outline below:

- When a site is chosen, a constructed survey of historical avalanches should be made, the weather situations analysed and the recurrence periods estimated. Based on historical data, topography, climate and avalanche models a hazard zone map should be constructed. An evacuation plan should be prepared based on the risk analysis.
- Initial avalanche hazard criteria are worked out for use during the first winters of operation. The criteria should contain threshold values for when the situation should be investigated more closely and a contact be established to the central avalanche institution established.
- A computer program for statistical analysis of weather, snow and avalanche data should be installed.A snow and avalanche observation program should be established and automatic weather stations installed. Snow study plot sites, which should have safe access routes even during bad weather, should be established at representative locations. Computer equipment for performing analyses, storing data and forecasts should be installed. Communication lines for acquiring data and weather forecasts and for distribution of avalanche forecasts should be established, preferably with back-up channels. A work instruction for the observer/forecaster should be prepared.
- Training programs for avalanche observers and avalanche committee members should be established.
- A program for informing and educating the public should be established.
- A project quality plan should be prepared.
- It is recommended that a yearly workshop is organised where the experiences from forecasting operations are exchanged. The workshop should be held nationally or possibly as an Icelandic-Norwegian avalanche forecasting workshop.

Observation Program

Since complete guidelines for observers are not yet available in Icelandic and Norwegian it is referred to international guidelines at this time, notably the *World Meteorological Organisation standards,* the *Observation Guidelines and Recording Standards for Weather, Snowpack and Avalanches*[2] and *the International Classification for Seasonal Snow on the Ground.* The following observation program is suggested:

Hourly measurements (minimum interval) from automatic weather stations:

- precipitation
- wind speed and direction
- new snow
- air temperature
- snow height
- snow temperature

For practicable reasons it is suggested that precipitation is measured at a lowland or valley site while the other measurements are measured at an elevation close to the avalanche starting zones. The data should be available in near real time.

Daily evaluation of:

- weather forecast
- snow drift and accumulation in the starting zones
- avalanche activity

Avalanche activity monitoring and observation of snow distribution in the starting zone(s) is done by visual inspection. This can be aided by using binoculars, possibly infra red for night vision, and continuous video camera surveillance. Permanent snow stakes close to the starting zone make it possible to estimate snow distribution. Ultrasonic snow depth gauges can also be used to monitor snow accumulation continuously regardless of visibility.

Intermittent evaluation of:

- snow stratigraphy
- snowpack stability, rutschblock test

Snow stratigraphy and stability evaluation should be done at least once a week, and more often in avalanche situations.

Forecasting Program

In the case of a forecasting program that has as its main objective to forecast relatively rare or extreme avalanches, and not every avalanche, it is possible to organise the forecasting program using a two step danger evaluation scheme:

Step 1. A daily, short survey of avalanche activity, weather, snow pack and weather forecast. The time necessary for this will be about 1-2 hours per day.

Step 2. Full time monitoring procedure with detailed investigations and continuous evaluation of avalanche danger realted to the evacuation plan. Updated reports are sent as often as required. A two way communication between the observer/forecaster in charge and the central avalanche institute is established.

The criteria for moving from step 1 to step 2 would be:

- When the present avalanche danger degree is developing from **moderate** (2: 'large natural avalanches not likely') to **considerable** (3: 'medium and occasionally large sized avalanche may occur') or higher.
- There are indications from the weather forecast that the avalanche danger degree will increase to **considerable** or higher in the near future.
- There is an alert from the central avalanche institute.

A procedure such as the one outlined above will be advantageous not only because of economic considerations, but also for the morale of the local observers/forecasters who may be working for several winters without seeing any direct use of their work.

Message Format

An avalanche forecast of danger degree three or higher should be reviewed and approved by the central avalanche institute before it is sent. The following outline for the avalanche warning and forecasting message should be used:

- names of author and reviewer
- name of recipient
- number of pages in document
- location, data and time of writing
- location and time span which the message concerns
- main message (flash, one to two lines of text in bold types) and a reference to the European Avalanche Danger Scale
- background weather and snow data
- avalanche danger now
- future avalanche danger
- reference to the hazard zones and evacuation plan
- specification of the confidence level of the evaluation, if appropriate
- time of next evaluation
- request for acknowledgement of reception signatures

The sent forecasts should be stored and a report of the forecasting operation should be written after each season.

Quality assurance

A project quality plan should be prepared for each program. The planning, implementation and operation of the avalanche forecasting program should be in accordance with the international standard ISO 9001.

To identify problems and weak links in the forecasting program, the system should be tested regularly with simulated avalanche situations.

Decision making

The decision making will have to be made differently in Iceland and Norway because of the differences in legislation. In Iceland, guidelines for who is responsible for the decision making in avalanche danger situations are given by law. In Norway, the Police is responsible for the public safety, but the organisation of avalanche committees is not given by law.

Specifically for Norway it is therefore recommended:

- A local avalanche committee with the necessary legal authorisation and political support should be established. The committee, in co-operation with the authorities, should be responsible for the decision making based on the avalanche forecasts. An evacuation and closure plan should be established. The legal and economic responsibility of the commission is determined.
- A plan that determines the specific actions and precautions that are to be taken during the different levels of danger should be worked out. Procedures for how and when such a plan can be circumvented should also be established.

ACKNOWLEDGEMENTS

The authors wish to thank the Division Head Karstein Lied of the NGI, our colleges at the Avalanche Section of the IMO and at the Environment and Avalanche Division of the NGI, and Douglas Fesler of the Alaska Mountain Safety Center for advice and comments. The project was supported financially by the Nordic Ministerial Council.

REFERENCES

Canadian Avalanche Association (1995) Observation Guidelines and Recording Standards for Weather, Snowpack and Avalanches

Føhn, P. M. B., Schweizer, J. (1995) Verification of Avalanche Danger with Respect to Avalanche Forecasting, Actes de Colloque ANENA

International Commission on Snow and Ice of the International Commission of Hydrological Sciences, (1981) Avalanche Atlas

International Commission on Snow and Ice of the International Commission of Hydrological Sciences, (1990). The International Classification for Seasonal Snow on the Ground

Nordisk Ministerråd (1994). Agreement of a Co-operative Snow Avalanche Project Between Iceland and Norway

Stephens, J. et al. (1994). Use of Neural Networks in Avalanche Hazard Forecasting, ISSW Proceedings 1994: 327-340