THE BUILDUP OF THE AVALANCHE SECTION OF THE ICELANDIC METEOROLOGICAL OFFICE.

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ABSTRACT: In this paper I will give a general overview of what we are doing at the Avalanche Section at the IMO. An attempt is being made at evaluating the risk levels for the various "avalanche villages" and base a new generation of risk/hazard maps on those results. We are trying to model snow drift problems in collaboration with French collegues. An investigation into morphological features of fluvial fans and an attempt of identifying avalanche debris is underway with promising results. The avalanche danger monitoring has been organized and evecuation procedures have been set up. The snow observer system has been further strengthened, with better training and equipment. A prototype electronic snow-depth stake is being tested, with very promising results. We are trying to use a laser distometer to measure snow depth profiles up the slopes as well as regular profiles to use in model calculations. In 1996 we installed some avalanche retaining structures to evaluate these structures under Icelandic conditions. We have done several measurements over the past two winters and have had interesting results. In order to evaluate snow accumulation conditions and in some cases in preparation for building avalanche defense structures, we have installed dozens of snow stakes in the starting zones above the various villages. They are regularly measured, using theodolites. A greater effort is being put into the collecting of historical avalanche data and the mapping of past avalanches.

KEYWORDS: Avalanches, avalanche countermeasures, avalanche defense structures, debris flow.

1 INTRODUCTION

This paper can be considered as a continuation of the paper I presented two years ago at the ISSW-96 in Banff. That talk concentrated on the actual monitoring of the avalanche danger. At the end of the talk I mentioned projects we were working on at the IMO. In this talk I will give a more detailed picture of the those and new projects.

2 AVALANCHE DANGER MONITORING

This topic was covered extensively at the ISSW-96 in Banff. The monitoring and evacuation procedures have now been tested through two complete winters and the evacuation procedures have been put into effect several times. The procedures have not changed substantially but have been refined and made more efficient.

I will not cover these procedures any further in this paper but refer to the ISSW-96 proceedings or vol. 16 no.4 of the Avalanche Review.

3 HAZARD ZONING

3.1 Introduction

As became very evident in the avalanches of 1994-1995, the old hazard zoning greatly underestimated the avalanche danger. The old hazard maps were predominately based on the known avalanche history. They could be based on historical records ranging anywhere from five to one hundred years. Since vegetation is very sparse, we have not been able to use the "silent witness" to determine the extent of past avalanches. We are now investigating the possibilities of using metamorphological data to determine maximum runout of individual avalanche paths.

3.2 Risk

A methodology has been developed to estimate a "standard" size of avalanches so as to be able to compare individual avalanche paths.

An investigation into "acceptable risk" was done to try to determine what the general risk is to the inhabitants of Iceland. The aim is to decide upon a criteria for acceptable risk.

The result of this is a proposed governmental regulation that hopefully will be implemented

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soon. The main points are described below.

We want the risk that people in the threatened villages are exposed to due to avalanche danger to be less than the risk due to other accidents, such as traffic accidents, that people are exposed to in the whole of Iceland. Such other risks in Iceland are in many cases, estimated to be of the order of 10^{-4} and thus it is proposed that the involuntary risk due to avalanches should be 0.3×10^{-4} and is referenced to a person living in a "normal" house and is defined to be "at home" 100% of the time.

3.3 Different zones

The formal "hazard" line will be drawn where the calculated risk is 0.3×10^{-4} and the area above it divided into RED, BLUE and YELLOW zones defined as follows:

ZONE	*Calculated risk* $\times 10^{-4}$	
	Lower Limit	*Upper Limit*
YELLOW	0.3	1.0
BLUE	1.0	3.0
RED	3.0	–

Table 1. Limits of acceptable risk of the respective hazard zones.

The uses of the individual zones is prescribed in a proposed governmental regulation as is the required reinforcement of buildings according to their location.

3.4 Zoning projects

Initially, a pilot hazard zoning project was implemented for a village on the East coast of Iceland. Experts from Norway and Austria took part in this project along with staff from the IMO, and the outcome will lay the foundation for the proposed governmental regulation.

Already, a plan prioritising the villages that need hazard zoning, has been drawn up.

This is a long process and thus a simplified procedure has been adapted that enables us to tackle individual requests, such as when someone wants to build a new building or change or modify an existing one. Before the planning authorities can give permission for work to commence, the IMO must evaluate the risk and give its recommendation as to what, if any, restrictions or requirements must be fulfilled before a building permit can be granted. This could be for example, reinforcement of the proposed building or restrictions on its use.

3.5 Rural areas

We still have to define guidelines for the evaluation of the hazard that numerous farms and cottages are exposed to. There is a very strong need for such guidelines but unfortunately we have to prioritise and the villages with the greatest risk have to dealt with first. Thus it will be several years before we can tackle this problem. In the meantime the people living in these places will have to do what they have done in the past, hope that nothing happens, although that is becoming increasingly more more difficult with the recent disasters and the resulting publicity.

4 SNOW DRIFTING

4.1 Introduction

Wind loading in the avalanche starting zones is a major contributor to avalanches in Iceland. All major avalanches on record have been associated with strong winds and thus heavy snow drifts. In an effort to model the effect of wind loading, we have started a joint project between CEMAGREF, CEN (Météo-France) and IMO, named NEVOS(NEpja, Vindur Og Snjór, Neige Et Vent). The project was initiated by the French embassy in Reykjavík in order to enhance exchange of expertise in research of snow.

4.2 Purpose

The purpose of NEVOS is to test and contribute to the evolution of systems developed by CEMAGREF and CEN to numerically simulate buildup and evolution of snow cover. The testing will take place in Iceland where simulated snowdrift and snowcover will be compared with observations.

4.3 The numerical models

- SAFRAN (CEN) estimates the relevant meteorological parameters that are needed for the simulation of the snow cover. The input to SAFRAN comes from atmospheric (NWP) models (ARPEGE).

- CROCUS (CEN) calculates the development of the snow cover during the winter. The input to CROCUS is provided by SAFRAN.
- VENTOSE (CEN) is a statistical model that calculates the wind at ground level from various atmospheric parameters predicted by a NWP model (The ECMWF model).
- PROTEON (CEN) evaluates the ability of the snow to be blown away. The input to PROTEON comes from CROCUS and VENTOSE.
- NEMO (CEMAGREF) calculates the distribution of snow on the ground (location and depth of snowdrifts). The input to NEMO comes from PROTEON and VENTOSE. NEMO is a 2D model but is currently being upgraded to 3D.

4.4 Expected results

Adaptation and validation of the French snow models with respect to real atmospheric conditions in Iceland.

Some results of estimations of local winds in relation to this project, are presented in another paper at this conference, (Gyomarc'h et al., 1998)

5 GEOLOGICAL STUDIES

5.1 Debris flows

5.1.1 Introduction

It is becoming more and more evident that not only do we have to consider the threat of avalanches when we are evaluating the danger that villagers in Iceland are exposed to, the threat of debris flows and rock falls is very evident in many places. In order to evaluate the danger, various projects have been started. This is done in collaboration with both native and foreign experts outside of the IMO.

5.1.2 Collection of historical records

The collection of historical records is done in collaboration with the Icelandic Institute of Natural History. Today the records, from 1925 to 1994 are completed and an ongoing project is collecting data from the year 1000 to 1924. From 1989, a year to year annal have been compiled.

5.1.3 The evaluation of danger.

A pilot project to estimate the threat of debris flows is underway for a community in the eastern part of Iceland in collaboration with the Icelandic Institute of Natural History.

Further work in this field is planned for several communities in Iceland.

5.2 Snow avalanche debris.

5.2.1 Introduction

Studies on avalanche dominated post-glacial systems are underway at several parts of the country. The aim of these studies is to develop a method which can be used to recognize snow avalanche deposits. It is hoped that the results can be used as part of hazard zoning. These studies ar done in collaboration with the Gelogical Survey of Norway where this method has been under developedment during the last few years (Blikra, 1994),

5.2.2 Sediment- and morphological evidence.

In the sedimentalogical aspect of this study, a project is underway in the NW part of Iceland. Several sedimentary sequences have been studied. The stratigraphy in variations in snow avalnche activity and by use of ^{14}C datings these sequences can be dated giving us important paleoclimatic variations.

A prelimenary result has been published (Blikra and Saemundsson, 1998).

In the morphological aspect of this study, another project is underway. This study mainly focuses on mapping the distribution of snow avalanche debris.

6 SNOW OBSERVATIONS

6.1 Introduction

Our network of snow observers has been further strengthened. We have for the most parts finished equipping them. All the main places have now been connected with the Internet and we have established a web page which includes the latest weather forecasts, satellite pictures, radar images and forecast model results, in addition to weather observations.

6.2 Weather observations

We have expanded our network of automatic weather stations and now all the main villages have automatic precipitation gauges.

6.3 Snow measurements

One of our prime goals is to find a method by which we can evaluate the amount of snow in the starting zones.

In a preliminary study that was made at the IMO it was found that no one device can cope with every situation. Thus we aim to install a combination of sensors that will give us reliable results under any conditions. We have thus been investigating various sensors and under what conditions they perform best.

6.3.1 Radars

We tested one of Hansueli Gubler's radars buried under the snowpack. Unfortunately the moist, sometimes wet snow in Iceland is very hard to penetrate with the frequency that the radar is designed to operate on so we had to abandon those test. In the future we might experiment with a radar of a different frequency.

6.3.2 Snow stakes.

We designed an electronic snow stake, with sensors every 10 centimeters, based on the principle that the snow is a good insulator and that fluctuations due to variations in wind and radiation, do not penetrate very far into the snowpack. We are trying various types of sensors but a very important feature is to have the stake coloured black so as to better absorb the radiation. We thus measure how much the temperature fluctuates or more precisely the standard deviation of the measurements. Where the S.D.'s start to fluctuate we conclude that the snow surface is located just below that point.

The problem with this device is that it cannot be made tall enough to last throughout the winter, since snow depth in the starting zones is typically several meters. Since it would be difficult to install and maintain a pole of several meters, we would have to extend it as the snowpack builds up. We intend to develope this idea further.

6.3.3 Acoustic depth sensors.

We have also been using acoustic snow depth sensors to evaluate the snow depth, mainly the SR50 from Campbell Scientific Canada. We have encountered several problems with the sensors, in particular due to the harsh environment we are trying to install them in. The membranes seem to corrode and rupture on a regular basis and the sensors have a tendency to fill with moisture and thus stop working.

We are trying to modify the design so as to give us a more reliable operation and were able to operate one sensor for most of last winter.

6.3.4 Laser distometer.

The possibilities of using a laser distometer to measure snow depth profiles are beeing investigated. The idea is the measure specific paths from a fixed position and always up along an identical profile and thus get an estimate of the now accumulation.

This device is also used to measure regular path profiles for the use in model runout calculations.

6.4 Education

Our training program for the staff based at the main office and the snow observers is well established now. We have a two day training/conferring session each fall and try and go out in the field with the observers as often as possible.

We are compiling "guidelines" that define the various procedures and observations and it is partly based on the CAA "Observation Guidelines" although a lot of the material has to be adapted to Icelandic conditions. We are doing this in collaboration with our Norwegian colleagues at the NGI.

7 AVALANCHE DEFENSE STRUCTURES

7.1 Introduction

When the initial evacuation plans for the threatened villages were published, and publicised, it was stressed that they were only a temporary measure until a more permanent solution could be found.

Thus work was started to get an overall picture as to what was required, in terms of protective measures to bring the risk down to acceptable levels. The government has published an agenda to provide avalanche defenses to the threatened villages. The aim is to bring the risk down to acceptable levels as described above by the year 2010.

The agenda is based upon a report compiled at the IMO (Jóhannesson et al., 1996)

The IMO acts as a consultant to the government in matteres regarding avalanche defense structures. The design and construction of defenses is done by private consulting companies.

7.2 Policies

As can be seen in table 2, the value of property at risk, is far greater than the estimated cost of the defense measures.

Cost of Defences	*Value of Property*
100 Million US$	340 Million US$

Table 2. Summary of the cost of defense structures and the property value of the buildings.

It is the general policy of the authorities to choose the "cheaper" alternative. That is, if the value of the property is greater than the cost of the proposed defenses, the defense structures will be build. If not, the property will be bought and removed from the threatened location, or restrictions put upon its use. For example, a house that is unprotected can only be used during summer. Thus some buildings have been bought by various organizations with the intent of using them as "summer houses".

7.3 Research projects

7.3.1 Avalanche retaining structures

In the summer of 1996, about 200 meters of the various kinds of avalanche retaining structures were installed above the town of Siglufjörður, in northern Iceland. The purpose of this installation was to determine what special "Icelandic requirements" had to be imposed on the design and strength of such structures in Iceland. It is apparent that retaining structures will have to be installad at several locations in Iceland. Since these kinds of structures are very expensive, we wanted to be sure that future installations would be optimized for Iceland.

We installed various measuring devices, among which were automatic tensiometers which measured the snow loading, gliding shoes, pressure plates and a meteorological station. We also did manual measurements of the tension in the various wire ropes. As can be seen in figure 1. the tension reached almost 20 tons in later winter. The main results are as follows:

- The corrosion protection of snow nets needs to be substantially improved for Icelandic conditions.
- Ground plates need to be anchored to the slope in order to withstand wind pressure caused by uphill wind.
- The feasibility of micropile anchoring of snow nets in loose material needs to be evaluated.
- An appropriate mid winter snow density for the design of supporting structures for Icelandic conditions is estimated to be $400 - 450\ kg/m^3$ and the effect of gliding on snow loading appears to be small.
- There are no indications of a variation in density or snow loading with height above sea level and the aspect of the slope.

Apart from this, traditional formulations for snow loading of supporting structures, which are used in Alpine countries, appear to be adequate for Icelandic conditions when proper account is taken of the higher snow densities in Iceland.

These results can mostly be explained by the moist, windy and salty maritime atmosphere in Iceland, the sparse vegitation in the mountains and the fact that starting zones of avalanches in Iceland are usually below 1000 meters above sea level.

7.3.2 Snow depth in starting zones

The most important design parameter, when determining the kind of avalanche support structures to implement, is the snow depth in the starting zone. In order to evaluate snow accumulation conditions and in some cases in preparation for building avalanche defense structures, we have installed dozens of snow stakes in the starting zones above the various villages. They are regularly measured, using theodolites. We hope that within a few years we will be able to determine intelligibly where and how to install supporting structures.

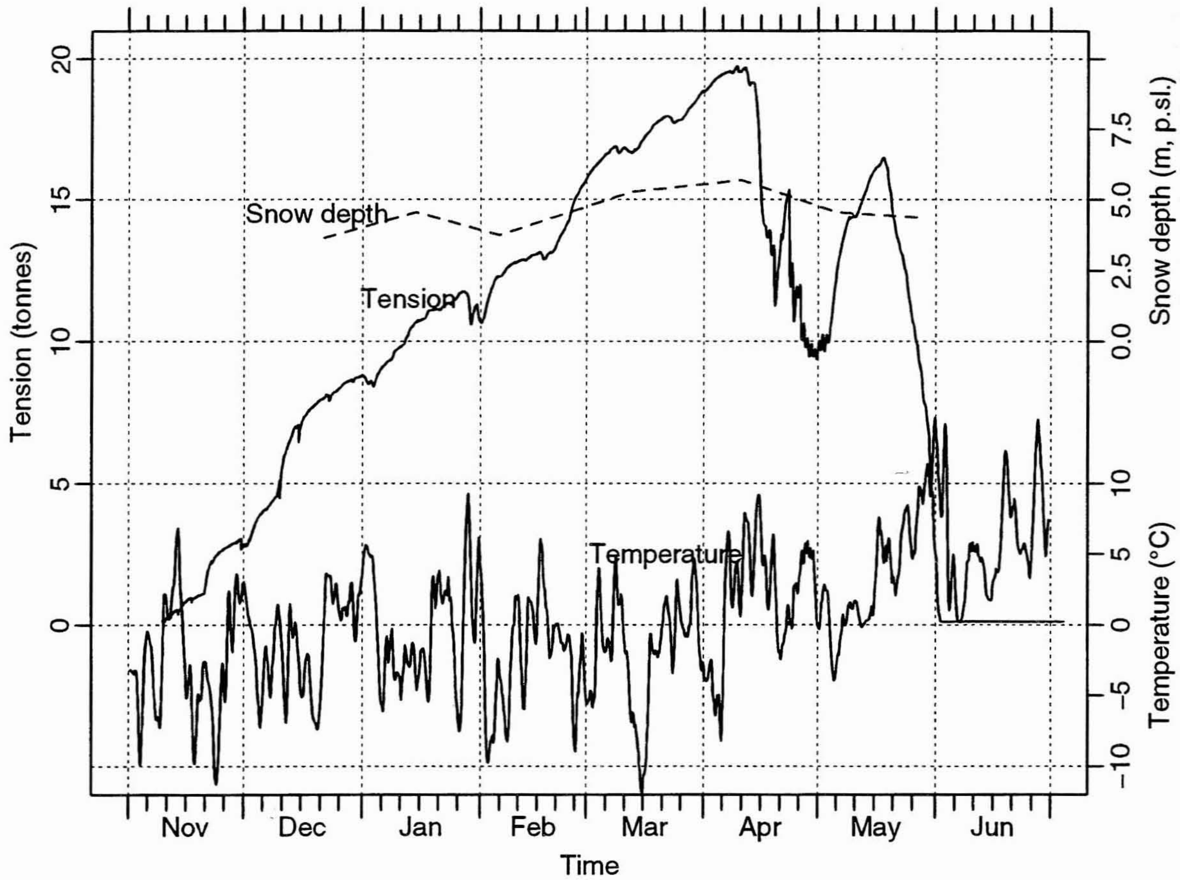

Figure 1: Tension in tthe uphill anchor in one of the nets in Siglufjörður. Also shown are the snow depth perpendicular to the slope in the nets at the location of the tension recording instrument and temperature recorded at a meteorological station at sea level in Siglufjörður

7.4 Avalanche defense projects

At the time of writing, one major avalanche protection project has been completed, two more have been started and several are in the designing phase.

For the town of Flateyri, two large deflecting walls have been completed. They are 20 meters high at the top, decreasing down to 15 meters. The overall length are 650 meters and 600 meters respectively. In addition a 10 meter high and 350 meter long dam was erected immediately above the village so as to catch whatever spills over. The total volume of all the walls is about $600,000m^3$.

In the village of Siglufjörður, in North Iceland, construction has started on the first of a pair of deflecting walls. It is supposed to be completed in the year 1999.

The preliminary design of further defense structures has been completed for three more villages and construction of some of them may start in the year 1999.

In addition to these major projects, there are several smaller ones in which individual buildings are being reinforced and new buildings and additions to existing ones, are being designed to withstand impacts that can be expected at their respective locations.

Thus a lot of money and effort is being put into erecting permanent avalanche defense structures

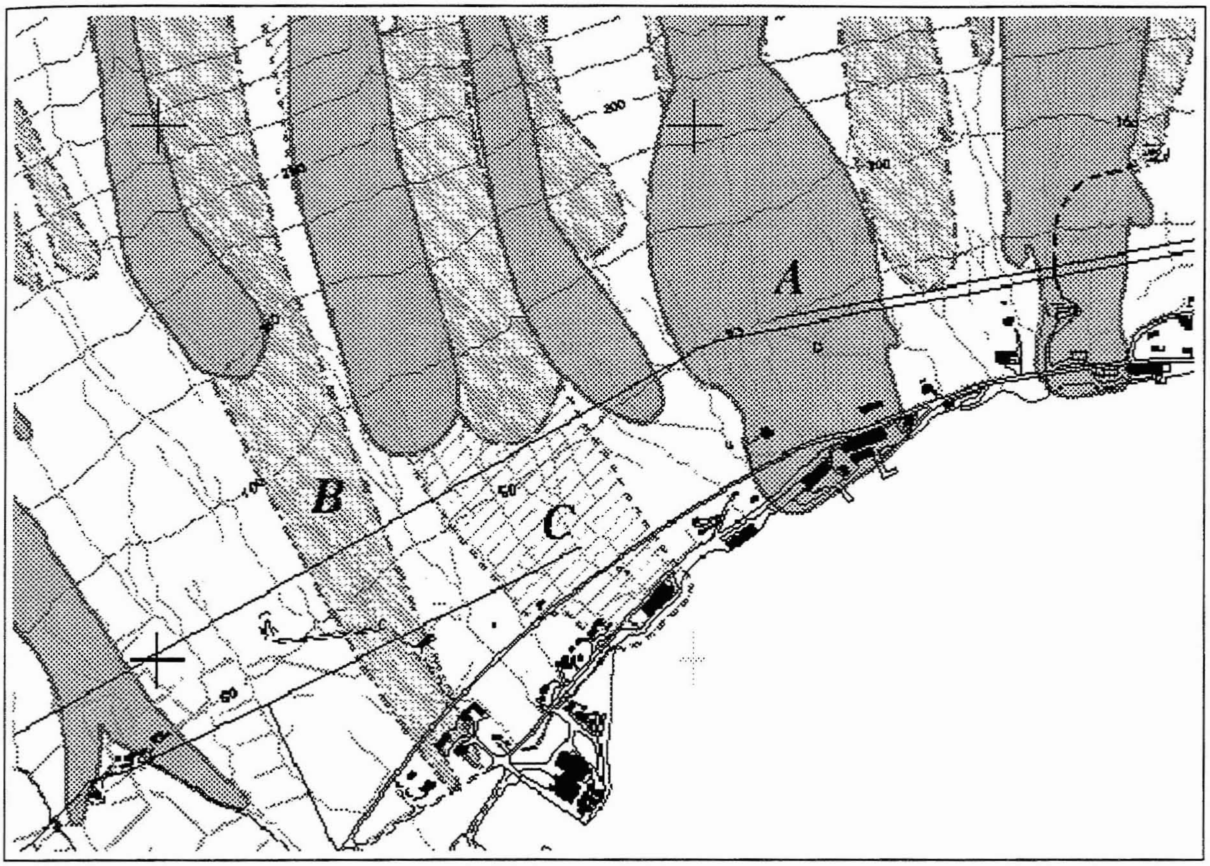

Figure 2: An IMO avalanche map showing the 3 different "certainty" classes. The shading labeled **A** is "certain", shading **B** is "certain-inaccurate" and shading **C** is "uncertain".

in Iceland and thus slowly but surely bringing an unacceptable situation to one, in which the levels of risk are being brought down to acceptable levels.

8 AVALANCHE HISTORY

A large effort is underway to document the avalanche history in Iceland. This is obviously of great importance to all subsequent work on hazard zoning, design of defense structures and future evacuation plans. As this is the topic of the paper (Haraldsdóttir, 1998) presented here at the ISSW-98, I will not discuss that further.

9 AVALANCHE MAPPING

New, more detailed digital maps are being produced. These maps will provide a new foundation for avalanche mapping at the IMO. We are in the process of defining what we want to map and how we want the various records of avalanches to be represented. We have defined three classes of data, depending on how we evaluate their accuracy. Those classes are:

Certain. Outlines of avalanches are mapped with good accuracy by a contemporary.

Certain-Inaccurate. Outlines of avalanches are mapped by a contemporary or according to reliable sources, but the outlines may be inaccurate.

Uncertain. Outlines of avalanches are mapped according to uncertain sources.

An example of this division is shown in fig. 2.

Within the European Uninon project SAME (Snow Avalanche Mapping and Warning in Europe), in which the IMO is participating, several avalanche research institutes have concentrated their effords in order to produce an avalanche mapping system in conjuction with displaying model results.

Within that project the IMO is working on a system that will enable researchers to display the various avalanche areas in Iceland and interactively draw profiles down avalanche slopes for insertion into runout and risk models, and display the result on a computer screen or a map. for insertion into runout or risk models.

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