International Symposium on Mitigative Measures against Snow Avalanches

Egilsstaðir, Iceland
11–14 March 2008

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EDITORIAL COMMITTEE

Tómas Jóhannesson – Icelandic Meteorological Office
Gísli Eiríksson – Icelandic Road Administration
Erik Hestnes – Norwegian Geotechnical Institute
Jakob Gunnarsson – National Planning Agency

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- The Association of Chartered Engineers in Iceland

Co-sponsored by

- Ministry for the Environment, Iceland
- Icelandic Meteorological Office
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- Iceland Road Authority
- International Glaciological Society
- Norwegian Geotechical Institute, Oslo, Norway
- Wildbach und Lawinen Verbauung, Innsbruck, Austria

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(with presenting author underlined if not the first author)

FOREWORD

Mitigative measures against snow avalanches have been built for many decades and even centuries in various places of the world. Improved knowledge and better equipment have, in recent times, made it possible to build considerably larger and more complicated structures than earlier. The aim of the measures is usually to protect human lives or infrastructures, such as roads and communication lines, but they do also affect humans in many other ways. Large structures usually have a significant impact on the environment, either at the starting zone of avalanches or in the run-out zone. In many cases, the run-out zone structures have to be built close to dense settlements; they can be overwhelming and they can even affect the local climate as well as snow accumulation close to the structures.

Relocation of settlements implies many hard decisions when people are forced to evacuate their old homes to move to a new area. A question that needs to be answered in this connection is why to destroy an already built-up area rather than protect it? The value of endangered buildings is also often questioned. How do protective measures affect the daily life of people? Do people believe in the measures and do they feel safe living close to them? What effect do protective measures have on the value of protected buildings and what effect will they have on the future development of the area? Does bad avalanche reputation have an effect on society and future development of the settlement? Travel has increased enormously in the last years and the demand for safe transport has been put at the top of the priority list all over the world. Avalanches pose a serious threat to highways and rail traffic in mountainous areas and many travellers are killed in avalanche accidents every year. Traffic delays and detours also cause large financial losses every year.

Electricity is becoming more and more important in modern society and any disturbance has a large effect on the daily life of people. The end user of a power plant can be an aluminium smelter, which uses an enormous amount of electricity compared with a family home. The effect of an electrical disturbance can be very different for different customers; a disturbance may have unforeseen consequences for the smelter but minor for the small home. Transmission lines are not easily repaired during avalanche cycles!

The symposium addresses three different themes; Snow-engineering, Environment and Society. The goal is to introduce the present state of knowledge and get a glimpse of the future as well as try to broaden the view of participants from each group, make them exchange experience and ideas and find ways to cooperate so that we can improve living in areas threatened by avalanches.

Now, thirteen years after the disastrous avalanches in Súðavík and Flateyri, the avalanche awareness and avalanche knowledge has increased dramatically in Iceland. Protective measures have been built at several locations and intensive monitoring of avalanche danger for villages has been established. In the light of this we thought this would be the right time to share what we have learned but also to listen to what others are doing and learn from it.

Eastern Iceland has several avalanche prone villages, power lines and highways. On December 20th 1974, two avalanches struck Neskaupstaður, the largest village in eastern Iceland, within a short interval. Those two avalanches took 12 lives. In 1982, avalanches hit a fish factory in Seyðisfjörður without any life lost and avalanches affect the road network the area quite frequently. The new power line from the Fljótsdalur power plant to the Alcoa aluminum smelter in Reyðarfjörður is probably one of its kinds in the world with 82 towers especially reinforced to withstand avalanche impacts.

More than 50 researchers from 7 countries have registered and about 40 scientific presentations will be delivered. The workshop is held during 3 days with an intermediate one-day excursion.

The workshop is sponsored by The Association of Chartered Engineers in Iceland and The Icelandic Society of Engineers and co-sponsored by the Ministry for the Environment, the Icelandic Meteorological Office, the National Planning Agency, IceGrid, the Icelandic Road Administration, the International Glaciological Society, the Norwegian Geotechnical Institute, Oslo, Norway, and the Wildbach und Lawinen Verbauung, Innsbruck, Austria.

We are grateful to financial support by the Ministry of the Environment and IceGrid.

Árni Jónsson, chairman of the organising committee

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PROGRAMME
(presenting author underlined)

Monday 10 March

17:00-18:00	Registration at Hótel Hérað
18:00-19:00	Welcome

Tuesday 11 March

08:30–10:00	Registration at Hótel Hérað
10:00–10:05	Opening, Árni Jónsson, Chairman of organising committee
10:05–10:15	Opening, Magnús Jóhannesson, Secretary general of the Ministry for the Environment
10:15–10:40	**Martin Kern, Marc-André Baillifard, Stefan Margreth and Joseba A. Calvo Soto** ON A NEW SET OF RULES FOR AVALANCHE CATCHING DAM DESIGN IN SWITZERLAND
10:40–11:05	**Stefan Margreth and Katharina Platzer** NEW FINDINGS ON THE DESIGN OF SNOW SHEDS
11:05–11:30	**Kristín Martha Hákonardóttir, Gunnar Guðni Tómasson, Hallgrímur Daði Indriðason and Flosi Sigurðsson** THE DESIGN OF AVALANCHE PROTECTION DAMS BASED ON NEW DESIGN CRITERIA: THREE DIFFERENT CASE STUDIES
11:30–11:55	**Manfred Pittracher** DEVELOPMENT, ASSESSMENT AND EFFECT OF A NEW AVALANCHE BRAKING SYSTEM IN THE MÜHLAUER-KLAMM, INNSBRUCK, AUSTRIA

LUNCH BREAK

13:00–13:25	**Magnús Jóhannesson** ROLE OF THE ICELANDIC AVALANCHE AND LANDSLIDE FUND
13:25–13:50	**Matthias Granig** COMPREHENSIVE SNOW NET PROJECT HAFELEKAR/INNSBRUCK
13:50–14:15	**Erik Hestnes and Tore Valstad** LIGHT ROCKFALL PREVENTION MESH USED AS RETENTION STRUCTURE IN SNOWPACKS OF LIMITED HEIGHT
14:15–14:40	**Elisabeth Rainer, Lambert Rammer and Thomas Wiatr** SNOW LOADS ON DEFENSIVE SNOW NET SYSTEMS

Coffee break

15:00–15:25	**Philippe Berthet-Rambaud, Louis Noël, Bruno Farizi, Jean-Marc Neuville, Stéphane Constant and Pascal Roux** DEVELOPMENT OF A NEW HELICOPTER GAS DEVICE FOR AVALANCHE PREVENTIVE RELEASE
15:25–15:50	**Ragnar Jónsson and Egill Thorsteins** TOWERS FOR SNOW AVALANCHES IN 420 kV TRANSMISSION LINES IN ICELAND
15:50–16:15	**Simon Schneiderbauer, Walter Hinterberger, Peter Fischer and Arnold Studeregger** SIMULATION OF SNOW DRIFT AS A TOOL FOR OPERATIONAL AVALANCHE WARNING
16:15–16:40	**Florian Rudolf-Miklau, Wolfgang Schilcher, Johann Kessler and Jürgen Suda** LIFE CYCLE MANAGEMENT FOR TECHNICAL AVALANCHE PROTECTION SYSTEMS
16:40–17:05	**Kristín Martha Hákonardóttir, Stefan Margreth, Gunnar Guðni Tómasson, Hallgrímur Daði Indriðason and Skúli Þórðarson** SNOW DRIFT MEASURES AS PROTECTION AGAINST SNOW AVALANCHES IN ICELAND

Wednesday 12 March

09:00–09:10	Practical information, Árni Jónsson
09:10–09:35	**Árni Jónsson, Steinar Bakkehøi and Sigurjón Hauksson** AVALANCHE RISK ALONG A 420 kV TRANSMISSION LINE IN ICELAND
09:35–10:00	**Hallgrímur Daði Indriðason, Flosi Sigurðsson, Gunnar Guðni Tómasson and Kristín Martha Hákonardóttir** AVALANCHE PROTECTIONS IN ICELAND DESIGNED BY VST CONSULTING ENGINEERS LTD.: EXPERIENCE AND EXAMPLES
10:00–10:25	**Siegfried Sauermoser** AVALANCHE PROTECTION IN AUSTRIA – PRESENT STAGE AND FUTURE DEVELOPMENT

Coffee break

10:45–11:10	**Tómas Jóhannesson and Josef Hopf** LOADING OF SUPPORTING STRUCTURES UNDER ICELANDIC CONDITIONS. THE TYPE OF STRUCTURES AND STRUCTURAL REQUIREMENTS IN FUTURE PROJECTS. RESULTS OF A FIELD EXPERIMENT IN SIGLUFJÖRÐUR
11:10–11:35	**Jón Skúli Indriðason** AVALANCHE PROTECTION – SOME ASPECTS OF DESIGN AND CONSTRUCTION
11:35–12:00	**Eiríkur Gíslason** APPLICATION OF TWO-DIMENSIONAL AVALANCHE MODEL SIMULATIONS AT THE ICELANDIC METEOROLOGICAL OFFICE

LUNCH BREAK

13:10–13:35	**Guðmundur Bjarnason** THE SNOW AVALANCHES IN NESKAUPSTAÐUR IN 1974. THE REACTION AFTER THE ACCIDENT AND THE ORGANISATION AND ADMINISTRATION OF SAFETY MEASURES FOR THE VILLAGE FOR THE MORE THAN 30 YEARS SINCE THE ACCIDENT OCCURRED
13:35–14:00	**Ásgeir Ásgeirsson** INSURING AGAINST THE UNTHINKABLE: A PROFILE OF ICELAND CATASTROPHE INSURANCE
14:00–14:25	**Ólafur Helgi Kjartansson** THE AVALANCHES AT SÚÐAVÍK AND FLATEYRI IN 1995. FIRST ACTIONS ON BEHALF OF THE DISTRICT COMMISSIONER OF ÍSAFJÖRÐUR

Coffee break

14:45–15:10	**Guðrún Jóhannesdóttir and Víðir Reynisson** NON-STRUCTURAL MITIGATION IN AREAS OF HIGH SNOW AVALANCHE FREQUENCIES IN ICELAND
15:20–15:45	**Thorsteinn Thorkelsson** ICELANDIC VOLUNTARY RESCUE TEAMS IN THE SÚÐAVÍK AND FLATEYRI AVALANCHES IN 1995
15:45–16:10	**Árni Jónsson** AN AVALANCHE INDEX FOR ROADS
16:10–17:00	**Poster session**. Presenters will answer questions from the participants.
21:00–	An evening with videos, photos *etc*. at the conference hall.

Thursday 13 March

All day: Field excursion – The bus leaves from the hotel at 8:00 o'clock and expected arrival is around 18:00 (6:00 PM). Participants are urged to be dressed according to weather.

Evening: Gala dinner – Dinner starts at 19:30 (7:30 PM)

Friday 14 March

09:00–09:10	Practical information, Árni Jónsson
09:10–09:35	**Alexander Ploner, Johann Stötter, Thomas Sönser, Peter Sönser and Werner Mauersberg** SUSTAINABLE SAFETY BASED ON ACTIVE RISK MANAGEMENT BY A CONTROLLED USE OF TEMPORARY MEASURES (presented by Daniel Illmer)
09:35–10:00	**Tómas Jóhannesson, Peter Gauer, Karstein Lied, Massimiliano Barbolini, Ulrik Domaas, Thierry Faug, Kristín Martha Hákonardóttir, Carl. B. Harbitz, Dieter Issler, Florence Naaim, Mohamed Naaim and Lambert Rammer** THE DESIGN OF AVALANCHE PROTECTION DAMS. RECENT PRACTICAL AND THEORETICAL DEVELOPMENTS
10:00–10:25	**Leifur Örn Svavarsson** MONITORING AVALANCHE DANGER FOR ICELANDIC VILLAGES

Coffee break

10:45–11:10	**Þorsteinn Sæmundsson, Armelle Decaulne and Helgi Páll Jónsson** SEDIMENT TRANSPORT ASSOCIATED WITH SNOW AVALANCHE ACTIVITY AND ITS IMPLICATION FOR NATURAL HAZARD MANAGEMENT IN ICELAND
11:10–11:35	**Armelle Decaulne, Þorsteinn Sæmundsson and Helgi Páll Jónsson** EXTREME RUNOUT DISTANCE OF SNOW-AVALANCHE TRANSPORTED BOULDERS LINKED TO HAZARD ASSESSMENT; SOME CASE STUDIES IN NW- AND N-ICELAND
11:35–12:00	**Örn Ingólfsson and Harpa Grímsdóttir** THE SM4 SNOWPACK TEMPERATURE AND SNOW DEPTH SENSOR

LUNCH BREAK

13:10–13:35	**Stefán Thors** ENVIRONMENTAL IMPACT ASSESSMENT OF MITIGATIVE MEASURES
13:35–14:00	**Reynir Vilhjálmsson and Ómar Ingþórsson** THE ROLE OF LANDSCAPE ARCHITECTS IN THE DESIGN TEAM. WHY LANDSCAPE ARCHITECTS ARE NEEDED IN THE DESIGN TEAM OF LARGE SCALE PROJECTS!
14:00–14:25	**Tryggvi Hallgrímsson** SOCIAL EFFECTS OF MITIGATIVE MEASURES AGAINST SNOW AVALANCHES IN NESKAUPSTAÐUR
14:25–14:50	**Harpa Grímsdóttir** THE EFFECT OF AVALANCHES ON THE SPATIAL DEVELOPMENT OF SETTLEMENTS IN ICELAND

Coffee break

15:10–16:20	Panel discussion
15:20–16:30	Closing of symposium

Information for presenters:
Each day the presenters of that day are asked to attend a meeting at 8:20 in the morning to prepare for the day. All electroninc files that will be presented that day must be handed over to the session leader/technical expert.

POSTER PRESENTATIONS

Matthias Granig and Stefan Oberndorfer
DEVELOPMENT OF THE DENSE AND POWDER SNOW AVALANCHE MODEL SAMOS-AT

José A. Vergara
HEAVY RAINFALL EVENTS ASSOCIATED WITH AVALANCHES IN THE ANDES MOUNTAINS

Örn Ingólfsson and Harpa Grímsdóttir
THE SM4 SNOWPACK TEMPERATURE AND SNOW DEPTH SENSOR

POSTERS FROM AGENCIES AND INSTITUTES

Ministry for the Environment/Government Construction Contracting Agency
CONSTRUCTION OF AVALANCHE PROTECTION MEASURES IN ICELAND (7 posters)

IceGrid/Línuhönnun
AVALANCHE MAXIMUM PRESSURE MEASUREMENT DEVICES ON 420 kV
OVERHEAD TRANSMISSION LINES FL3 AND FL4 IN EASTERN ICELAND

Icelandic Road Administration
3 posters

IceGrid
1 poster

ORION Consulting
1 poster

POSTER PRESENTATIONS FROM PRODUCERS AND DESIGNERS OF TECHICAL MEASURES FOR AVALANCHE PROTECTION

Geobrugg AG
GEOBRUGG PROTECTION MEASURES FOR PEOPLE AND INFRASTRUCTURES

Eggert Ólafsson
RETARDING MEASURES FOR AVALANCHES

The role of the Icelandic Avalanche and Landslide Fund

Magnús Jóhannesson

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ABSTRACT

In the wake of two catastrophic avalanches in two small towns in the north-west of Iceland in the year 1995, the Icelandic Government decided to reorganise its support and at the same time increase public funding to local communities for dealing with threat from avalanches and landslides. Apart from designating the Icelandic Meteorological Office as the expert advisory body, the Government established an Avalanche and Landslide Fund to provide funding for local communities to implement the necessary measures. The Avalanche and Landslide Fund has played a central role in establishing the safety criteria for avalanche and landslide protection measures as well as providing for over 90% of the real cost of such measures undertaken in local communities in Iceland since 1995.

1. INTRODUCTION

Catastrophic avalanches in the small towns of Súðavík and Flateyri in 1995 caused 34 fatalities and extensive economic damage. These tragic events changed the public and political opinion on avalanche safety in Iceland, in part because the avalanches fell in areas considered to be outside avalanche hazard zones. These events demonstrated clearly that a complete review was needed of all aspects of risk assessment, hazard evaluation and protective measures against avalanches and landslides. Furthermore, the administration in this field needed to be strengthened. Hazard evaluation which had been carried out for several communities with known avalanche hazard at the time was deemed to be of limited value in light of the tragic events. The time had come to use a scientific approach for hazard zoning of populated areas in the various small towns around the country.

The prime minister established a committee in the fall of 1995 to review the legal framework from 1985 in the field of protection from avalanches and landslides. The administration of these matters at the federal level was at the time considered complex and the responsibilities were unclear. The task of the committee was to redefine the role of the government in the field of avalanche and landslides and give authority and overall responsibility to a single body in the administration. Financial support by the government to the municipalities subjected to avalanche hazard was to be increased to facilitate the construction of protective structures by the local authorities. In addition, the committee was to make proposals to increase the safety of people in case of avalanche risk.

The committee proposed the following four actions:

(1) Strengthening of requirements for municipalities to secure protection from avalanches and landslides.

(2) The administration in the field of avalanches and landslides to be transferred from the Ministry of Social Affairs to the Ministry for the Environment.

(3) Research and advice on preventive measures to be given to the Icelandic Meteorological Office (IMO), an institute under the Ministry for the Environment. Responsibility for hazard zoning and regular snow observations would also be transferred to IMO.

(4) A new Avalanche and Landslide Committee to be established under the Ministry for the Environment.

This was a complete and radical change in the administration and involvement of the government in the field of avalanches and landslides protection.

2. THE AVALANCHE AND LANDSLIDE COMMITTEE

A new act on protective measures against avalanches and landslides was approved by the parliament (Althing) in 1996 and reviewed again in 1997 (49/1997). The Ministry for the Environment organized public meetings in all communities where avalanche hazard was known to introduce the new measures in the field of avalanche protection and to raise public awareness of the problem. Furthermore, it was explained at these public meetings that the implementation of permanent protection structures would take several years. However, in the meantime comprehensive plans on monitoring and evacuation schemes would be developed as a matter of priority for all the communities in question.

The main thrust of the legislation on protective measures against avalanches and landslides was to aim for permanent structures unless cost and benefit analysis showed that it would be considerably less costly to purchase the buildings in a particular hazard zone. The new act established a national fund, the Avalanche and Landslide Fund. The main income of the fund derives from an annual fee levied on all property insured against fire, 0.3‰ of the insured value. The main role of the fund was to assist municipalities to deal with protective measures for existing populated areas within towns and villages.

The new act established also an Avalanche and Landslide Committee. The role of the committee is to decide on proposals from municipalities on protection measures and to allocate funding from the Avalanche and Landslide Fund. Assets of the fund can be used to pay the cost of protection against avalanches and landslides and other relevant measures in accordance with the following:

a. total cost of hazard zoning of populated areas considered to be at avalanche risk,
b. total cost of measuring equipment for research and surveillance of areas considered to be at avalanche risk,
c. up to 90% of the cost of preparation, design and construction of protection structures,
d. up to 60% of the cost of maintenance of protection structures,
e. up to 90% of the cost of buying houses and apartments and transportation of property to areas outside hazard zones.

3. PROBLEM ASSESSMENT AND CAPACITY-BUILDING

The reorganisation of the management of avalanche problems in Iceland was carried out in collaboration with several international avalanche research institutes and experts, particularly the Norwegian Geotechnical Institute (NGI) in Oslo, Norway, and the Eidgenössisches Institut für Schnee- und Lawinenforschung (SLF) in Davos, Switzerland. French and Austrian scientists from Cemagref in France and the Austrian Service in Torrent and Avalanche Control in Austria also participated in research projects and consulting activities together with

Icelandic scientists and engineers from the IMO, the University of Iceland and private engineering companies. The first collaboration of this kind was consultation of experts from NGI regarding strengthening and reorganisation of avalanche preparedness in Iceland immediately after the avalanche in Súðavík in January 1995. This was followed by a collaborative research project organised by Karstein Lied from NGI and funded by the Nordic Council of Minsters. It involved studies and capacity building in several fields, including avalanche warnings, standardisation of work procedures for Icelandic snow observers, hazard zoning and modelling of Icelandic avalanches. This first project was followed by several bilateral collaborative projects supported by the Icelandic Avalanche and Landslide Fund, both research projects and a practical consultation work, where protection measures, hazard zoning and avalanche warnings were investigated. Several international research projects supported by the European Commission, in particular SAME, CADZIE and SATSIE, have also been important in the build-up of expertise in avalanche science in Iceland.

The Avalanche and Landslide Committee decided in 1996 in consultation with municipalities in avalanche areas to undertake a comprehensive study and preliminary assessment on the needs for avalanche protection structures in Iceland. The study was performed by national and international experts. The objective was to assess the needs for protection structures in Iceland and estimate the cost of preparation, design and construction. This would help to plan and schedule the work ahead. The study was concluded in October 1996 and showed the probable extent and cost of necessary actions to insure the safety of people in their residential dwellings in densely populated areas. The cost at the time was estimated to be of the order of 7 to 14 billion ISK at 1996 price levels and the construction time would be several years, realistically at least 10 to 15 years. Extensive cooperation was with expert institutes in Norway, France, Switzerland and Austria during the study.

A pilot experiment on supporting structures in Icelandic conditions was also carried out in Siglufjörður at early stage of the preparations. This was primarily to study the resilience of supporting structures in typical Icelandic weather conditions. Important lessons were learned from this experiment, such as regarding snow load, wind load, corrosion and erection of the structures. Furthermore, the experience gained was written into an Icelandic annex to be used together with a Swiss standard when designing supporting structures for Icelandic circumstances.

Due to the extensive task at hand and the different circumstances in the various municipalities it was necessary to prioritize. An implementation plan was drawn up by the Avalanche and Landslide Committee in consultation with the municipalities. According to this original plan the most urgent tasks were to be finished before 2010. The prioritization took into consideration the wishes of the municipalities, different circumstances, financial capabilities of the Avalanche and Landslide Fund each year and the various actions needed. The framework plan was adopted by the Government in 1996 and revised in 1997. Construction has not been fully according to the framework plan. However, it has proved to be an important tool for organizing the various tasks and prioritizing between the various municipalities.

4. ACCEPTABLE RISK AND HAZARD ZONING

One of the very first decisions to be taken before permanent protective structures could be designed for the areas in question was to define an acceptable risk from avalanches and landslides for living quarters in towns and villages. This proved to be a daunting task which involved a number of experts and eventually a political decision.

The regulation on hazard zoning due to avalanches and landslides, classification and utilization of hazard zones, and preparation of provisional hazard zoning which was signed by the Minister for the Environment on July 6, 2000 defines acceptable risk.

> “Local risk to humans in residential dwellings, schools, day-care centers, hospitals, community centers and similar locations is considered acceptable if it is less than 0.3 x 10^{-4} annually. For commercial buildings where there is steady activity, the risk is acceptable if local risk is less than 1 x 10^{-4} annually. For recreational homes, risk is acceptable if local risk is less than 5 x 10^{-4} annually. In determination of these limits an exposure of 75% is assumed for residential dwellings, 40% for commercial buildings and 5% for recreational homes. In addition, it is assumed that children do not generally occupy commercial buildings, with the exception of schools and day-care centers.”

Based on the above definitions a hazard map on the scale 1:5000 shall show a hazard line, *i.e.* on one side an area of acceptable risk and on the other upslope areas marked with A, B or C with increasing local risk according to the following table:

	Lower limit	Upper limit
Hazard zone A	0.3 x 10^{-4}	1.0 x 10^{-4}
Hazard zone B	1.0 x 10^{-4}	3.0 x 10^{-4}
Hazard zone C	3.0 x 10^{-4}	-

The term “local risk” is defined as the “annual probability of death as a result of snow- or landslides for an individual, dwelling continuously in a non-reinforced single family building”, *i.e.* it is essentially individual risk of accidental death but without regard to the so-called “exposure”, which is the probability of being in hazard zone when a snow- or landslide falls.

In areas protected by permanent structures, risk with and without the structures shall be shown. Furthermore, the map shall especially identify structures and landscape features which reduce risk and hence may not be altered for safety reasons.

No residential, recreational or commercial activities may be planned unless it has been established that the risk due to avalanches and landslides is acceptable. An existing detail and/or master plan which are not in accordance with the hazard map must be revised. Disputes regarding revised plans can be referred to the Ruling Committee for Planning and Construction.

Since 1996 hazard zoning has been completed for the following towns and villages:

- Ólafsvík
- Patreksfjörður
- Bíldudalur
- Þingeyri
- Flateyri
- Suðureyri
- Bolungarvík
- Ísafjörður
- Hnífsdalur
- Súðavík
- Siglufjörður
- Ólafsfjörður
- Seyðisfjörður
- Neskaupstaður
- Eskifjörður
- Fáskrúðsfjörður

Hazard zoning is in preparation for the following towns:

- Tálknafjörður
- Drangsnes
- Akureyri
- Kirkjubæjarklaustur
- Vík
- Mosfellsbær
- Reykjavík

It should be mentioned that when the new legislation was passed and the present efforts to improve safety due to avalanches and landslides were initiated, it was generally considered that only 8–10 local communities were threatened by avalanches or landslides in Iceland.

5. PROTECTIVE MEASURES

According to the *regulation on hazard zoning due to avalanches and landslides, classification and utilization of hazard zones and preparation of provisional hazard zoning*, protection structures are only to be built to ensure safety of people in already populated areas. Within six months from the completion of hazard zoning, the municipality has to make an action plan to ensure safety of people in buildings. In hazard zone C, security shall be ensured with permanent protection structures or the purchasing of residential housing. For hazard zones A and B, safety of people can be ensured through monitoring and evacuation.

One of the first tasks supported by the Avalanche and Landslide Fund after revision of the legal framework was the relocation of the small town of Súðavík. The task was approved in the fall of 1995 and mostly completed in the spring of 1997. A total of 55 residential units were built and a few houses were relocated in the process.

6. CONSTRUCTION OF PROTECTION STRUCTURES

The first permanent structures were built in Flateyri and completed in 1998. The Avalanche and Landslide Fund has supported the construction of several protection structures in various municipalities. Furthermore, several of those have been hit by avalanches and hence already proved their value.

Protection structures have been constructed or houses purchased in the following towns and villages:

- Súðavík – relocation project completed in 1997.
- Flateyri – construction of a dam was completed in 1998.
- Ísafjörður – construction of dams for a part of the town was completed in 2004.
- Hnífsdalur – purchase of houses and demolition completed in 2007.
- Siglufjörður – construction of dams for a part of the town was completed in 1999; construction of supporting structures for a part of the town was completed in 2004.
- Seyðisfjörður – construction of a dam was completed in 2005.
- Neskaupstaður – construction of dams and supporting structures for a part of the town was completed in 2001.

Protection structures are under construction in the following towns:

- Ólafsvík – construction of a small dam, landscaping and supporting structures started last year and will be completed this summer.
- Siglufjörður – construction of several additional dams will be completed this summer.

Protection structures are under preparation in the following towns and villages:

- Bíldudalur – construction of a dam will start this spring and be completed in the fall.
- Bolungarvík – construction of dams will start this spring and be completed in 2010.
- Ólafsfjörður – construction of a dam is planned in 2008.
- Eyjafjarðarsveit – construction of a small dam at the farm Grænahlíð in 2008.
- Neskaupstaður – design of dams and supporting structures for the Tröllagil area will start this year.

Current plans aim at the conclusion of construction of protection structures in the various municipalities in the period 2013–2015, which is about 5 years later than was initially scheduled. This is partly due to the fact that more towns and villages are threatened by avalances or landslides than were initially thought and partly because the government decided to slow down constuctions in the years 2004 to 2007 due to general economic expansion. The estimated cost of the total effort set out in 1996 now appears to be in the range of 16 to 20 billion ISK. This is within the original estimate when inflation rate is accounted for.

7. CONCLUSIONS

Radical improvements have taken place in safety against avalanches and landslides for most communities that were thought to be threatened by avalanches and landslides in Iceland, since the two tragic events ocurred in Súðavík and Flateyri in 1995. Considerable knowledge on hazard zoning, design of permanent protection structures and construction of the same has been gathered, awareness has been raised at the municipal level and with the public at large. Permanent protection structures have already been established in a number of communities and some have already proven their value. The decision to establish a special fund by the government to deal with this problem of the past has proved to be very useful and enabled the small communities to deal with these issues, which they had surely not been able to do without the support of the fund.

Comprehensive snow net project Hafelekar/Innsbruck

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ABSTRACT

This paper gives information about the snow net project at the Hafelekar at 2250m a.s.l. above Innsbruck/Austria performed by the Forest Technical Service for Avalanche and Torrent Control (WLV) in cooperation with the Federal Forest Research Center (BFW) in Innsbruck. For snow pack stabilisation in the avalanche starting zones principally two systems are applied: snow bridges and snow nets. The construction of snow bridges is well established in Austria. In contrast, snow net systems are used less extensively, because there are still some uncertainties in the construction and the foundation of nets. Therefore, a test site at the Hafelekar above Innsbruck was installed to analyse the different systems. Especially the difference between the triangle net types and the rectangular net types was one of the major points of interests. The WLV/BFW carried out extensive measurements of the forces in the installed snow nets, in order to obtain information of the forces in the different net systems. Additionally, tests with anchors and the analysis of materials in terms of corrosion protection are ongoing and will help to estimate the durability of the different systems. These findings from the test site at the Hafelekar should help to define an Austrian guideline for snow nets.

Keywords: avalanche protection, snow net, snow bridges

1. INTRODUCTION

The Forest Technical Service for Avalanche and Torrent Control (WLV) has been constructing a large number of avalanche protection works in the avalanche starting zones for more than fifty years. In Austria, snow bridges are the standard type to prevent the release of avalanches in Alpine regions. Flexible snow net systems are installed only to a certain extent.

As steel prices are continuously rising, the price difference between the two systems is getting smaller and smaller. There is a paradigm shift of the population in their perception of efficient protection works to fit well into the landscape. In consequence, a variety of approved systems allow a broad spectrum of applicable protection works to be installed.

In 2006, the WLV launched a comprehensive project for detailed investigation on snow nets. The goal of the project is to combine empirical experience and scientific data in order to avoid a long period of trial and error with this system and to provide a scientifically based decision-making aid for engineers within 2–3 years. An intensive survey to gain experience on snow nets is necessary to ensure the correct application of the system, in places where it is possible, and the construction of snow bridges, where the need to provide maximum security for settlements necessitates this.

The project is divided into three major work packages, which are executed by different institutions and partners. The Forest Technical Service for Avalanche and Torrent Control is responsible for the carrying out the project, for system analysis, summary and analysis of damages in the field and the research on the anchorage. The Federal Forest Research Center has the task to measure the forces in the snow nets, to analyse the static calculations and to monitor the snow cover throughout the winter season. The University of Innsbruck is in charge of the material tests and provides scientific data on the life cycle of the systems.

Many experiences have already been made in other countries such as France, Italy, Slovenia or Switzerland with similar avalanche hazards. In the beginning of the snow net project, all existing experiences and results were collected and analysed. Haefeli (1954) has first described static calculations for snow nets. These findings are still in use for the dimensioning of snow nets. SLF in Davos has intensively investigated this matter in the nineties. Margreth (1995) describes their measurements of the forces in the upper anchors, lower anchors and in the poles on triangular nets. In France, measurements on the upper anchors of the triangular net systems and calculations on the snow loads were done by Nicot (1999, 2000, 2004). Rudolf-Miklau and others (2004) summarized all information and experiences in this field from Austria. From this basis the project was designed to gain additional data.

The construction of a large snow net field on the Breitlehner avalanche path is in progress to protect the town Telfs/Tyrol. The construction plan comprises 8km of snow nets in high altitude at 2600m in very rough terrain. The exposure to the Inn valley was the decisive criteria to use snow nets. The responsible ministry prescribed scientific monitoring of this enormous construction in the administrative procedure. An own test site in comparable setting was installed on Hafelekar above Innsbruck to study the behaviour and reliability of the rectangular and triangular snow net types during winter over the duration of 10 years.

Figure 1 Overview test site Hafelekar/Innsbruck in Tyrol.

This paper gives an overview of the comprehensive snow net project of WLV, which combines different results to obtain an integral guideline on the topic. The test site Hafelekar, the experiments on the anchorage at Erzberg in Styria and the present big construction site Breitlehner/Telfs permit an exchange of practical experiences and scientific knowledge for engineers as well as scientists.

2. METHODS

The project test site was installed in autumn 2006 and is situated at Hafelekar near Innsbruck/Tyrol at 2250m a.s.l. The site has high amounts of snow to ensure maximum snow loads in the snow nets. The records of the ski station in this area indicate an average snow height of about 3m and maxima up to 6m. Around the year access is assured by cable car directly from Innsbruck, which is important for monitoring. The slope is facing south with a slope of 38°. A webcam allows easy checking of current snow conditions on the test site.

Three different types of snow nets (D_k=3,5; N=2,5; f_c=1,1) are built to study the advantages and disadvantages of each system. One of the main focuses is to analyse the difference between rectangular type nets and triangular nets.

Figure 2 Rectangular snow net system in the front and triangular snow net system in the back.

The two systems are equipped with measurement devices to survey the forces (Figure 2). Additionally, the attached inclinometers on the poles and the nets themselves give information on the change of geometry during the winter. This is important to recalculate static forces. The data are saved by data loggers and transferred via GSM for further analysis.

For a long life cycle of the protection work, it is crucial to provide a solid connection between superstructure and the anchorage in the ground. Experiments with the anchors were done at the test site Erzberg/Styria in three batches from 2005–2007 to investigate the strength and reliability in loose soil material. At this site, the worst case of soil properties are experienced. The loose excavated material from the mining operation is similar to areas, which are heavily influenced by rock fall. Tension forces were studied using a 100 ton mining bulldozer and heavy-duty measurement equipment. After force measurements the anchors were pulled out entirely to examine the whole anchor. This is usually not possible on the construction site. Scientific analysis was done by the University of Mining in Leoben/Styria.

Table 1 Overview of the results of the anchor tests 2005.

Anchor No.	Position	Length [Tension [m]]	Length [Pressure [m]]	Maximum Tension [kN]	Calc. load at rupture [kN]
1	1	5	3	208,0	442
2	2	5	3	168,6	442
3	3	5	3	128,8	442
4	4	5	3	59,8	442
5	9	4	3	172,3	270
6	8	4	3	168,2	270
7	16	2,95	-	133,5	?
8	7	4	3	291,2	270
9	6	5	3	179,3	442
10	5	5	3	379,1	442
11	10	4	-	352,8	700
12	11	4	-	292,8	700
13	12	4	-	348,3	700
14	13	4	-	262,2	470
15	14	4	-	243,5	470
16	15	4	-	117,7	470

The University of Innsbruck analyses the durability of materials. Usually protection works are designed to last for more than 50–60 years. The tests should indicate the resistance for corrosion of snow nets and their galvanized layers.

3. DISCUSSION AND RESULTS

The measurements on Hafelekar represent comprehensive data on snow net systems over two winters. So far results are within the expected range. Static calculations proved the safe dimensioning of the rectangular and the triangular snow nets. Comparing the field tests, no indication of a possible failure was found. There are major differences between different types in terms of applicability in certain kinds of terrain. Some systems are very easy to install in smooth terrain, but cause major problems in rough terrain. On steep and rugged slopes it is necessary to have enough range to adjust the nets properly. Not every type has this necessary flexibility. In Austria, in most cases, systems are constructed with the support of helicopters. Therefore, an optimised helicopter construction method is preferred. The experiences on the site at Breitlehner/Telfs showed that each row of snow nets should not exceed more than 22-25m, because of lateral spreading of forces. The systems can be loaded unequally and this can lead to sideward movements of poles. The spherical joint on the bottom of the poles avoids damages to the system, because it allows flexible movement in all directions within a given range. Although a collapse of a cornice into the snow nets was located, no damages of the protection works were observed there.

A crucial point is the anchorage. For a long life cycle this very time-consuming part of the construction has to be set up carefully. The tests at Erzberg/Styria showed a very inhomogeneous range of necessary forces to damage the anchors between 60–600kN. The strength of the anchorage strongly depends on soil type, anchor, mortar, drilling system, and workers' experience. The construction site manager has to ensure a good balance between these factors to provide the optimum strength.

Material tests showed that the minimum and maximum requirements of the galvanising layer have to be defined by the customer to provide an optimum range. The analysis of fifty year old snow nets indicated that in Alpine regions, life cycles exceeding 50 years are conceivable with today's improved materials. Long-term experiences in Switzerland, *i.e.* at the Pilatus/Wallis confirm this assessment.

The Forest Technical Service for Avalanche and Torrent Control is working on a guideline for avalanche protection. The project findings should be implemented in this work to assist engineers in their planning process on avalanche protection works.

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Life cycle management for technical avalanche protection systems

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ABSTRACT

Large areas in the alpine regions of Austria are endangered by avalanches. In order to protect inhabited areas and publicc roads technical protection works (*e.g.* snow bridges, deflecting dams) have been built in large numbers where the effects of protective forests are not sufficient for adequate safety. Avalanche defence works are subject to extraordinary loads and extreme environmental impact which frequently cause damages and shorten the life time of the constructions. Regular inspection and maintenance are expensive but also essential in order to preserve the functionality of the protection works. The type of construction is substantial for the maintenance costs later on. The approach of life cycle cost is suitable in order to plan protection measures economically. The article gives an overview of the most important uncertainties of stability and usability of technical avalanche protection works and of the most common types of damages. Furthermore it gives an insight into the well established system of life cycle management (maintenance) in Austria and presents the legal and technical standards that are under development.

1. INTRODUCTION

Technical avalanche protection in Austria is foremost equivalent to defence works in the starting zone (Fig. 1). Approximately 95 % of the investments for avalanche protection were used for snowpack-stabilizing works within the last 50 years. In the Alps, modern avalanche defence works have been carried out since the 1950s. This development was triggered by the avalanche disaster of 1954, which caused the death of 109 people only in the district of Bludenz (Vorarlberg).

Figure 1 Avalanche defence work in the starting zone in the Grappes-Lawine (Vorarlberg).

The first systematic avalanche defense works in Austria were built for the protection of the Arlberg railway at the turn of the 19th to 20th century. In the 1950s the Swiss Institute for Snow- and Avalanche Research (Davos) issued the first technical guideline for defence works in the starting zone. Based on this standard, the Austrian Service for Torrent and Avalanche Control developed its own system of technical avalanche protection supported by the practical experiences of engineering. Only in the province of Vorarlberg, about 100 km of defence works have been built according to the principles of this system since that time. Today, technical avalanche protection is a task of paramount importance for the safety in the Alpine valleys and guarantees the sustainability of the basic functions of living (live, traffic, health, work, supply, mobility).

After their completion, avalanche protection works are subject to extreme environmental conditions and loads, consequently the ageing and wear rate is high and the life time of the constructions is limited. Extraordinary snowpacks and the impact of avalanches, which were not taken into account in the planning process, may as well cause severe damages. While defence works in the starting zone are particularly endangered by dynamic loads, the risk by avalanche impact on the stability of retarding and deflection works (*e.g.* dams and concrete barriers) is low. In order to reach the "optimal" life time, avalanche defence works have to be maintained regularly. The maintenance of a building is the "combination of all technical and administrative measures and management tasks during the life time in order to preserve or restore the effectiveness of the construction so that the demanded function durability exists" (Schröder, 2005). In the course of planning, the durability of the protection works is improved by the selection of a construction (design) adapted to the function of the building, the use of resistible building material and the dimensioning including a safety factor. The standards of quality for avalanche defence works in the starting zone are as a rule lower than in general civil engineering. The tolerance for ageing and wear is generally higher as the protection works may still fulfil their function even after extreme events. This tolerance is compensated by a careful assumption of loads.

Due to the constantly raising demands for safety concerning natural hazards and the large stock of avalanche defence works in Austria it seems to be urgent to develop a general technical standard at the state of the art for this branch taking also into account the supervision and maintenance of the constructions.

2. UNCERTAINTY CONCERNING STABILITY AND USABILITY, TYPES OF DAMAGES FOR TECHNICAL AVALANCHE PROTECTION WORKS

A "damage" is an alteration of a building, of its foundation or surroundings caused by external or internal influences, that lead to a reduction of the stability, usability or durability of the supporting construction. Damage occurs if a certain limit value of the "stock of wear and tear" (according to DIN 31051) is not reached any more and a critical state or the usability arises. Regular maintenance counteracts this critical state and extends the life time of the defence work. A defence work may fail when the limit value of stability, usability or durability is exceeded. A failure or destruction can be preceded by damages in the construction but also occur suddenly due to overload. In general, the failure of a building is assumed if a defined limit state is exceeded. This limit state is reached if the building (including its foundation and subsoil) or parts of it do not meet the requirements of design any more. As a rule, local failure of single snow bridges does not inevitably lead to a failure of the whole protection system, nevertheless an expansion of the damage may cause a serial failure. In this case, avalanche release is also possible from protected areas in the starting zone. The most important cause of damages to the stability of defence works in the starting zone are presented in Table 1.

Table 1 Causes of damages to avalanche defence works in the starting zone and average costs of repair.

Causes for damage		Impact on the defence work	Average costs for repair since 1996 for 100 km of snow bridges [€/year]
a)	Overload caused by snow pressure	Deformation and breaking of components of the snow bridges	1.000 €
b)	Overload caused by avalanches	Deformation and breaking of components of the snow bridges	8.000 €
c)	Insufficient slope stability	Slip of the foundation	13.500 €
d)	Rock fall	Damage or destruction of parts (components) of the snow bridge.	3.500 €
e)	Unsatisfactory building quality	Destruction of anchorage or slip of foundation	2.500 €
f)	corrosion	Loss of stability by wear.	0 €

Figure 2a Damages (failure) of snow bridges (protection work in the staring zone) due to overload caused by snow pressure (left), overload due to avalanches (middle) and insufficient slope stability (right).

Damages due to overload primarily occur in lee zones due to excessive accumulation of snow drift. Mainly the upper most beams are deformed. Due to this deformation, the beam looses its power of resistance and may fail. Damages caused by avalanches occur in areas where unprotected parts in the starting zone still exist. The costs for repair may be especially high in areas where slope movements occur due to insufficient slope stability. Especially shallow seated movements turn out to be problematic as the foundation slips away while deep reaching anchorage stays stable. Rock fall may fill up storage room of snow bridges and cause overload of the supporting construction. Extreme rock fall events may trigger the failure and destruction of avalanche defence works. Unsatisfactory building quality is often due to insufficient length and stability of anchorage. If the foundation of the supporting pole is dug too shallow it may easily slip away.

Figure 2b Damages (failure) of snow bridges (protection work in the staring zone) due to rock fall (left), slip of foundation (middle) or destruction of anchorage (right).

Figure 2c Damages (failure) of wooden snow bridges (protection work in the staring zone) due to collapse of the supporting construction (left); destruction of concrete retarding barriers due to extreme avalanche pressure (right).

3. LIFE CYCLE MANAGEMENT (MAINTENANCE) SYSTEM IN AVALANCHE PROTECTION

3.1 Life cycle management in avalanche protection

The prerequisite for a sustainable preservation of the protection function of technical avalanche control measures requires a long-term planning of financial resources for maintenance. In competition with other investment tasks of public households, it is necessary to take into consideration a partial or total renunciation of supervision and maintenance measures. This scenario will most probably lead to a significant reduction of durability and an early decline of the security level as well as an increase of damage potential. These effects have to be visualized in the hazard maps.

In addition to the economic aspects of maintenance management also legal, organisational and technical standards are required for the fulfilment of this important task. The supervision of avalanche protection works involves a wide range of public and private institutions (municipalities, beneficiaries, authorities, land owner), for this reason a lot of interfaces exist which require intensive coordination. The maintenance of avalanche protection works is a legal obligation of the person or corporation which has got the permission from the authority to build the avalanche protection works. The coordination of supervision and maintenance measures is due to the Forest Act a task of Austrian Service for Torrent and Avalanche Control.

The following instruments are basic requirements for an integral maintenance management system:

- Legal regulation of supervision of protection measures
- Cadastre of protection works (data base)
- Organisational model for the recurring supervision and inspection of protection works (monitoring)
- Specification of the optimal maintenance strategy

3.2 Legal basis for maintenance

The legal basis for the financing of avalanche protection works in Austria is the Hydraulic Engineering Assistance Act. Subsidies come from the federal Disaster Relief Fund. Thereby municipalities have easy access to the necessary financial resources for maintenance measures. Technical avalanche protection measures are by legal definition “water protection works” according to Art 41 Water Act and require a permission by the authorities, which includes the obligation of maintenance. Nevertheless, protection works are due to Art 297 Civil Code part of the real estate and thus property of the land owner. For this reason, in most cases the obligation of maintenance is separated from ownership apart from the case that the land owner is identical with the protected person. According to the legal regulations, maintenance includes the task of the current supervision, the servicing, the regular inspection by an expert and the repair of damages. Due to Art 102 Forest Act, the inspection of the biological and forestry measures is task of the Austrian Service for Torrent and Avalanche control as well as the supervision of the avalanche catchment areas. However, a public obligation for maintenance of protection measures is not derivable from the legal regulations.

3.3 Maintenance service

Avalanche protection works are most often planned in combination with reafforestation. Afforestation measure in high altitude areas require regular care for decades, consequently the supervision of technical measures can be realized without additional costs. During winters of abundant snow, the supervision of avalanche protection works is carried out by aerial observation (helicopter). Great parts of the damages can already be detected from the air. The regular inspection of technical protection measures guarantees the execution of urgent maintenance measures in time.

3.4 Financing of maintenance measures

Avalanche protection projects require long time for realization, thus damages that occur during the first decades can be repaired by means of the project funds. Minor repair measures (limit: € 15.000) are regularly financed in the framework of the so called “maintenance service” of the Austrian Service for Torrent and Avalanche Control. These funds are available unbureaucratically and do not require a specific approval by the authorities in charge. In case of severe damages, it is necessary to apply for the financing of a separate maintenance project, which is supported by public subsidies and contributions of the beneficiaries.

3.5 Standardization of monitoring and maintenance in the ONR 24807

In order to achieve constant quality of monitoring and maintenance of avalanche defence works, an Austrian Standard Rule (ONR 24807) is under development. The monitoring concept, based on the Austrian standard mentioned above, is divided in two parts, the inspection and the measurement or intervention part (Fig. 3). The main target of the inspection part (first part) is to assess the condition in a comprehensive manner. The aim of the inspection is to classify the structure in one of three condition levels. Level 1 - buildings are new or as good as new, level 3 -building are completely destroyed.

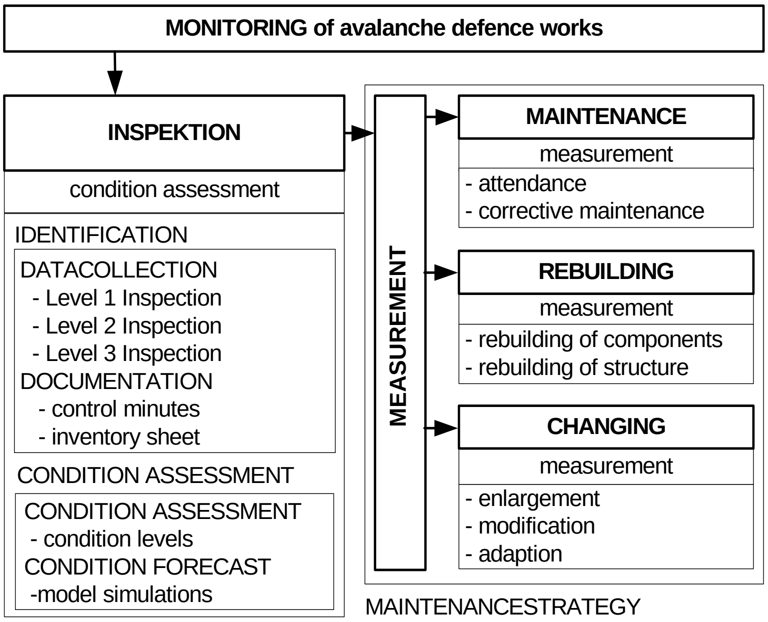

Figure 3 Configuration of the maintenance concept for avalanche defence works

The measurement part (second part) contains precise structural and organisational procedures. Depending on the condition levels in the ONR 24807 minimum standards for structural measurements and periods for their realization are defined. These minimum standards are stricter for “key structures”. The measurements can be divided into the maintenance, the rebuilding and the changing of a structure.

A permanent technical protection system against avalanches contains a lot of single structures (snow bridges, avalanche retarding structures) which are in permanent interaction. Taking into account this interaction, the whole system contains structures with higher and lower negative effects on the safety of the whole protection system and the protected areas, if they fail. Depending on the weightiness of these negative effects the structures can be divided into “standard” and “key structures”. This classification (referring to *Austrian Standard Rule EN 1990*) of protection measures has to be defined at the beginning of every monitoring process.

In order to assess the safety of a structure, data about the past, the actual and the expected prospective condition are needed. Thus, a fundamental task for the condition assessment is the periodic inspection of these structures. To consider economic limits, three control levels have been developed. In level 1 (L1) all structures will be periodically inspected *e.g.* by lumbermen during the annual inspection. If a damage of a structure is identified, a competent expert will do a level 2 inspection (L2). If there is no chance of assessing the actual condition of a structure, a level 3 inspection (L3) will be held. Level 1 and 2 are done with visual inspection methods. For a level 3 inspection, more complex engineering methods are used.

Table 2 Types of inspection according to ONR 24807.

Types of Inspection	**L1**	**L2**	**SL2**	**L3**
	Level 1 Inspection	**Level 2 Inspection**	**Special Level 2 Inspection**	**Level 3 Inspection**
Periods	Key structure: annually Standard structure: at least every 5 years	all structures: before end of guarantee Key structure: every 5 years	Key structure: after extreme events	all structures: in vase of need
Methods	visual	visual		advanced methods
Executed by	Lumbermen	Experts		Experts (interdisciplinary)
Result	Level 1 minutes	Level 2 minutes		Level 3 minutes

3.6 Sustainable planning and maintenance strategy of avalanche protection measures based on a Life Cycle Costing (LCC) approach

The concept of life cycle costing (LCC) integrates all costs (planning, building, maintenance, and removal) which occur during the life time of a protection measure. The goal is to optimize costs for the whole life cycle of the single protection work as well the whole protection system. A farsighted maintenance of protection measures requires as a rule a combination of preventive (*e.g.* condition monitoring) and corrective measures (*e.g.* repair). Concerning the controllability of life cycle costs, it turns out that the best chances exist in the planning and construction phase: Maintenance cost can be optimized by means of design, selection of the type of measure, durability of selected building material und serviceability of the construction. During the operation phase, regular supervision and recurring inspection of the protection measures is a guarantee for sustainable usability.

4. CONCLUSIONS

Technical avalanche protection works are subject to extreme environmental conditions and forces (snowpack, avalanches, rock fall, unstable slopes, corrosion), which may cause severe damages and lead to a failure of the construction. Regular supervision and recurring inspection (condition monitoring) help to detect damages in an early state. Adequate maintenance of avalanche protection works requires convertible legal regulations and operational tools at the state of the art, the technical standards and procedures for this task will be set up in the new Austrian Standard Rule ON 24807 (edition expected: 2008). Maintenance measures, obligation of the regional commissioner are carried out within the framework of the Austrian Service for Torrent and Avalanche Control, the financing supported by public subsidies from the Federal Disaster Relief Fund. An economical use of these funds requires a maintenance strategy based on the principles of life cycle costing (LCC). It is the goal of sustainable maintenance to preserve a sustainable function of avalanche protection measures.

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New findings on the design of snow sheds

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ABSTRACT

Snow shed design is based in practice on simple hydrodynamic equations. The dynamic forces exerted by an avalanche are a function of flow velocities, flow height and slope deviation angle. Between 2002 and 2006, scale experiments using granular material on a laboratory chute as well as large chute experiments with snow on the Weissfluhjoch (Davos) were used to determine the relevant dynamic parameters of avalanches flowing over an inclined plane with a deviation. The performed experiments result in an improved approach to calculate the dynamic forces due to a deviation and in more detailed data on the coefficient of friction depending on the snow type. The new findings were implemented in the revision of design guidelines for snow sheds. The guidelines describe the design concept, typical load cases and formulas to calculate the avalanche actions. Finally practical results from an application of the guidelines are presented.

1. INTRODUCTION

Snow sheds are among the most important structures to protect traffic lines from avalanche actions. They are roof-like structures, which guide the sliding snow across e.g. a highway and prevent deep snow deposits on the roadway. Snow sheds are among the oldest structural avalanche protection measures in the European Alps (Fig. 1 and 2). The dynamic forces exerted by an avalanche on a snow shed are a function of flow velocities, flow height and slope deviation angle. In the 1960s, force measurements were performed on five different snow sheds in Switzerland to develop a first design approach (Salm and Sommerhalder, 1964). However, only the maximal forces of all avalanches occurring during one winter period could be measured. Vertical loads varying between 19 and 60 kN/m^2 were applied. The horizontal loads were calculated with coefficients of friction μ of 0.4 and 0.5. In 1994, the Swiss Federal Roads Office and the Swiss Federal Railways jointly published guidelines on snow shed design based on simple hydrodynamic formulas (ASTRA/SBB, 1994). Design engineers often observed discrepancies when they had to check the structural safety for the maintenance of old snow sheds. In spite of degrees of compliance of only 70% compared to the avalanche design loads, no structural damages were observed on 40 year old snow sheds. Therefore, the question was raised whether the design loads were too high, especially the horizontal loads according to the guidelines. In 1999, full-scale measurements were completed at the experimental avalanche test site Vallée de la Sionne to check the validity of the guidelines. Unfortunately, large avalanche deposits on the experimental set-up prevented good measurements (Platzer and Margreth 2007). A new project, whose concepts and results are described within this paper, was therefore elaborated in 2001.

Figure 1 312m long stone-arched snow shed built at Splügenpass in 1843. The snow shed was in operation until 1950.

Figure 2 130 m long snow shed built at Val Raschitsch in 2002 as a monolithic jointless concrete structure.

2. EXPERIMENTAL INVESTIGATION OF AVALANCHE FORCES

Between 2002 and 2006, scale experiments using granular material on a laboratory chute as well as large chute experiments with snow on the Weissfluhjoch (Davos) were used to determine the relevant dynamic parameters of flowing avalanches (Platzer and Margreth 2007). In the laboratory approximately 100 experiments were performed on a wooden chute of 7 m length and 0.5 m width (Platzer and others 2004). On the Weissfluhjoch snow chute, which is 30 m long and 2.5 m wide, more than 50 experiments with 8 to 15 m^3 snow for each experiment were performed. Within both experimental setups a series of optical velocity sensors, ultrasonic flow height sensors and force plates – measuring the normal- and shear component of an avalanche over time – are used in combination to determine the characteristics of flowing avalanches when moving over a deflecting structure. The main findings of the experiments result in an improved approach to calculate the dynamic forces due to a deviation and in more detailed data on the coefficient of friction depending on the snow type (Fig. 3). Near the deviation point, meaning up to a distance of 1.5 times the flow height of an avalanche, the so far applied formula underestimates the applied dynamic forces, whereas after a distance of more than 6 times the flow height of an avalanche, the dynamic forces due to a deviation have vanished. The mean coefficient of friction μ is for dry snow avalanches 0.3 and for wet snow avalanches 0.5 (Platzer and others 2007). The measured coefficient of friction is reduced by about 30% when the avalanche flows over a deposited snow cover.

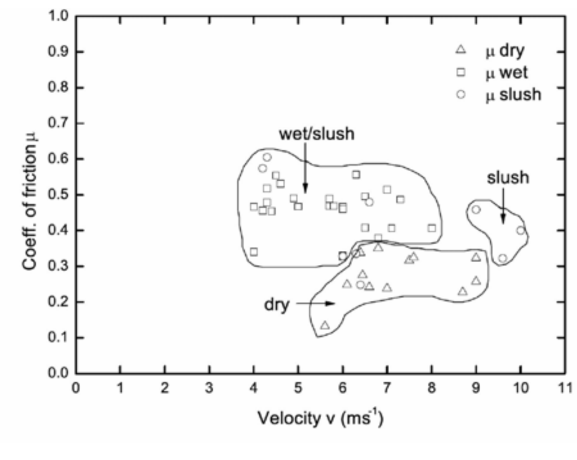

Figure 3 Coefficient of friction μ as a function of the measured flow velocity on the snow chute.

3. SNOW SHED GUIDELINES OF 2007

3.1 Overview

The goal of the guidelines is to define a procedure to determine avalanche actions on snow sheds and to set up uniform basics for the structural design. The loading of a snow shed depends strongly on its geometry (Fig. 4). Because the geometry is often optimized during the design process the guidelines propose that the avalanche expert determines the flow height d_L and velocity of the design avalanche v_L at an interface position, which is located at a distance of at most 100 m upside of the structure (Fig. 5). The design engineer calculates the determining avalanche actions in relation of the deviation angle α and the inclination β of the snow shed roof . At the location of the snow shed the avalanche expert defines the height of the natural snow cover d_S, the height of avalanche deposits d_A and the flow width of the avalanche. These parameters are determined by a hazard analysis including information from the avalanche history, terrain analysis, climatic conditions and avalanche dynamics calculations. Based on the results of the experimental investigations the guidelines from 1994 were revised by a working group under the lead of the Swiss Federal Roads Office (ASTRA/SBB, 2007).

3.2 Basics

It is fundamental that a snow shed has to cover the full width of an avalanche path. Insufficient lengths are the most common reasons for failures. Sometimes it is possible to reduce the width of an avalanche by constructing lateral dams or walls. According to the guidelines the geometry of the shed should be chosen so that the deviation of the avalanche flow is as small as possible. If this is not possible the deviation point of slope inclination should be positioned at a distance of more than 6 times the flow height uphill of the shed. The outside wall should be closed if the terrain below the snow shed is not much inclined so that avalanche snow might flow into the snow shed.

3.3 Load cases

In the guidelines (ASTRA/SBB, 2007) eight different load cases are distinguished (Tab. 1). For the verification of the structural safety avalanches with a return period of 30 years are regarded as variable actions and with a return period of 300 years as accidental actions.

Table 1 Load cases to determine the actions induced by snow and avalanches

Case 1: Avalanche slides on snow shed without snow deposit	The actions consist of the moving avalanche and the deflection. The deflection and friction force are maximal.
Case 2: Avalanche slides on snow shed covered with snow	Similar to case 1 however the weight of the natural snow cover has to be added.
Case 3: Avalanche slides on snow shed covered with avalanche deposits	Similar to case 1 however the weight of the avalanche deposit has to be added. Because of the deposit the deviation angle is reduced.
Case 4: Avalanche deposit on snow shed	At locations with huge deposits often the determining load case.
Case 5: Static snow pressure on the outside wall of snow shed	If a snow shed is completely covered by avalanche deposits the static snow pressure can load the outside wall.
Case 6: Dynamic avalanche pressure on the outside wall of snow shed	Avalanches from the opposite valley side can impact the outside wall of the shed.
Case 7: Snow pressure on the roof	If snow shed is situated below a steep slope.
Case 8: Avalanche impact on the roof of the snow shed	If the avalanche jumps on the roof or if the deviation angle α is bigger than 60°

All actions from avalanches like friction, normal loads and deviation loads are combined as? either leading action or accompanying action. The actions from avalanche deposits and sliding avalanches cannot be combined as? leading actions?. If snow sheds are loaded by avalanches and rockfall the two actions must not be combined.

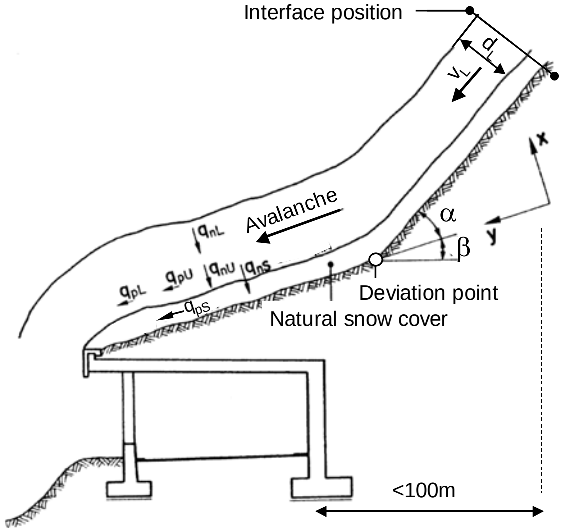

Figure 4 Load case 2.

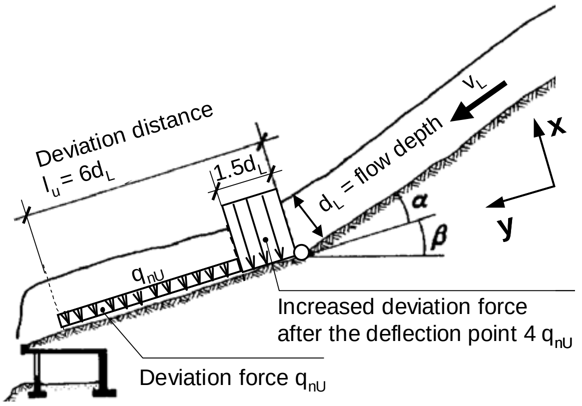

Figure 5 Distribution of deviation force.

3.4 Determination of avalanche actions

In Table 2 recommended values for the specific weight γ and friction coefficients μ for sliding avalanches are listed. The specific weight γ varies according to the snow type. The coefficient of friction μ was newly defined for dry and wet snow avalanches. If a snow shed is situated at high elevations the coefficient of friction μ for dry snow avalanches can normally be applied.

Table 2 Specific weights and coefficients of friction for different types of snow and sliding surfaces (ASTRA/SBB, 2007)

Snow type	Specific weight (kN/m^3)	
Sliding dry snow avalanche	$\gamma_L = 3.0$	
Sliding wet snow avalanche	$\gamma_L = 4.5$	
Natural snow cover	$\gamma_S = 4.0$	
Avalanche deposit	$\gamma_A = 5.0$	
Sliding surface	Coefficient of friction μ	
	Dry snow avalanche	Wet snow avalanche
Snow cover	0.20	0.35
Smooth surface (e.g. concrete, grass)	0.25	0.45
Rough surface (e.g. scree)	0.35	0.55

The formula to calculate the actions of the load cases 1 to 4 on a snow shed with a surface inclination β are given in Table 3. The actions are calculated normal (q_n) and parallel (q_p) to the ground. The actions consist of the static load of the deposited snow (q_S resp. q_A) and the dynamic forces of the sliding avalanche (q_L) comprising the friction force and the deviation force (q_U). The friction force (q_{pL} and q_{pU}) is calculated with the Coulomb's friction model. The formula of the deviation force normal to the ground q_{nU} is based on the principle of linear momentum and the assumption of a stationary flow (Salm and Sommerhalder 1964). In the revised guideline the distribution of the deviation force was optimized (Fig. 5). The deviation force q_{nU} acts maximally over a distance of 6 times the flow height of an avalanche. Close to the deviation point, meaning up to a distance of 1.5 times the flow height of an avalanche, the deviation force becomes 4 times bigger.

Table 3 Formulas to calculate the actions on a snow shed (ASTRA/SBB. 2007)

Action	Normal to the ground surface	Parallel to the ground surface	
Natural snow cover	$q_{nS} = \gamma \cdot d_S \cdot \cos\beta$	$q_{pS} = q_{nS} \cdot \tan\beta$	(kN/m^2)
Avalanche deposit	$q_{nA} = \gamma \cdot d_A \cdot \cos\beta$	$q_{pA} = q_{nA} \cdot \tan\beta$	(kN/m^2)
Sliding avalanche	$q_{nL} = \gamma \cdot d_L \cdot \cos\beta$	$q_{pL} = \mu \cdot q_{nL}$	(kN/m^2)
Deviation force (Fig. 4)	$q_{nU} = \frac{\gamma \cdot d_L \cdot v_L^2 \cdot \sin\alpha}{6 \cdot d_L \cdot g}$; $g = 9.81\ m/s^2$	$q_{pU} = \mu \cdot q_{nU}$	(kN/m^2)

3.5 Practical experience

The guidelines, which were applied since 1994, are considered by the practitioners to be very useful. Especially the concept of the interface position allows a clear separation between the competence of an avalanche expert and a design engineer. The more detailed specification of the friction value μ and the adapted formula for the deviation force in the new guidelines enable to calculate the actions more accurately. The experience shows that in a lot of locations avalanche deposits are the determining loads. However the assessment of the height of avalanche deposit is difficult because it is hardly possible to calculate it. Typical results for design loads on snow sheds from real cases are compiled in Table 4.

Table 4 Typical loads on snow sheds (total loads due to avalanches and snow deposit). Results from SLF consulting reports.

Location	Site characteristics, observations	Load case	Variable action (30 y.)		Accidental action (300 y.)	
			Normal q_n	Parallel q_p	Normal q_n	Parallel q_p
Val Chasté, Tschlin	Large avalanche, gully, return period 2 y., deposit height 7 m, no deflection.	3	43 kN/m^2	7 kN/m^2	73 kN/m^2	12 kN/m^2
		4	50 kN/m^2	7 kN/m^2	74 kN/m^2	11 kN/m^2
Taverna, Davos	Multiple avalanche events from both valley sides, no deflection.	3	38 kN/m^2	9 kN/m^2	60 kN/m^2	15 kN/m^2
		4	54 kN/m^2	12 kN/m^2	88 kN/m^2	20 kN/m^2
Camp, Vals	No multiple avalanche events, unconfined flow, 15° deflection.	2	11 kN/m^2	2 kN/m^2	23 kN/m^2	6 kN/m^2
		4	10 kN/m^2	2 kN/m^2	15 kN/m^2	3 kN/m^2
Seehorn, Davos	No multiple avalanche events, unconfined flow, no deflection.	2	11 kN/m^2	2 kN/m^2	15 kN/m^2	3 kN/m^2
		4	20 kN/m^2	4 kN/m^2	27 kN/m^2	5 kN/m^2
Val Ota, Susch	Small avalanche, steep track, deflection 20°, small avalanche deposit.	2	24 kN/m^2	5 kN/m^2	36 kN/m^2	8 kN/m^2
		4	15 kN/m^2	4 kN/m^2	24 kN/m^2	7 kN/m^2
Cozz, Mesocco	Small avalanche, deflection 20°, return period 10 y.	2	25 kN/m^2	3 kN/m^2	36 kN/m^2	5 kN/m^2
		4	30 kN/m^2	3 kN/m^2	40 kN/m^2	4 kN/m^2
Lant, Mesocco	Large avalanche, multiple avalanche events, canalized flow.	2	51 kN/m^2	7 kN/m^2	74 kN/m^2	9 kN/m^2
		4	50 kN/m^2	4 kN/m^2	80 kN/m^2	7 kN/m^2

The accidental actions with a return period of 300 years are approximately by a factor of 1.6 larger compared to the variable action with a return period of 30 years. The data of Table 4 demonstrate clearly that it is not advisable to work with standard loads because the loads depend very much on the site characteristics.

4. CONCLUSIONS

With the performed experiments on the laboratory chute as well as on the Weissfluhjoch chute, it was possible to improve the calculation formula of the guidelines. Especially new findings on the snow densities, the coefficients of friction and the formula to calculate the deviation force could be introduced. The realisation of the experiments on the snow chute was more demanding than previously assumed, especially the repeatability was not perfect because of the varying types of snow. An important point that should be studied in more details in the future, is the influence of a snow cover or of avalanche deposits on the damping of the dynamic avalanche loads. In addition, the distribution of the force could be measured with a higher resolution using more and smaller load plates after the deviation point. The new findings proposed in this paper are mainly based on scaled experiments. It would be desirable to verify the results with full-scale experiments on real snow sheds. However, such experiments are quite costly because an extensive instrumentation with load plates, snow depth gauges and velocity measurements is necessary. Further, the avalanche frequency should be high to have a complete data set – and it should be taken into account that avalanche deposits on the load plates can prevent good measurements as we have learned from the Valleé de la Sionne avalanche test site.

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Heavy rainfall events associated with avalanches in the Andes Mountains

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ABSTRACT

Intense rainfall events trigger avalanches (rain-on-snow) and landslides of different magnitudes depending on the snowpack and soil properties, air temperatures and rain intensities. Winter storms in the Chilean Andes Mountain Range typically have rain/snow levels between 1000 and 2200 m. above sea level, but warm storms with higher rain/snow level of to 3000 m above sea level. occur in extreme winters and have the potential to generate rain on snow floods and wet-snow avalanches. For example, the floods of June 29 of 2000 occurred after one of the wettest June months of the last 40 years when snowfall reached 991 cm in the Aconcagua Valley. Storm activity generated a huge snowfall and rainfall over the Andes Mountains in June of 2000 (1525 mm in El Maule Valley). At the end of the unusually wet period, the floods were triggered by rising temperatures in the mountains and heavy rain fall (199 mm in 24 hours) on the fresh snow on the morning of June 29. Flood waves developed and moved down along all rivers in the central part of Chile, the flood peak was 2970 m^3/s in the El Maule basin on the morning of June 29. This poster describes the characteristics of warm storms and their potential to generate wet-snow avalanches in the Chilean Andes Mountains.

On a new set of rules for avalanche catching dam design in Switzerland

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ABSTRACT

A new dam design procedure has been developed in Switzerland which takes into account different energy dissipation mechanisms during the avalanche–dam impact. The new design procedure represents a more objective approach to dam design as it does not require a subjective estimate of the energy dissipation implied in the traditional „Salm rule of thumb“. From scaled laboratory experiments, we empirically found hat the energy dissipation may be governed by gravitational or momentum driven effects, depending on whether a so-called granular bore develops or not. The degree to which a granular bore develops decisively determines the dam height necessary to stop a given avalanche. The necessary dam height then depends on the avalanche Froude number and on the dam geometry given by the mountain-side dam inclination and on the length and inclination of the dam apron. We demonstrate how the theoretical description of the avalanche–dam interaction was derived and then empirically justified in scaled experiments with chute flows of dry cohesionless material and snow. We present some evidence for the applicability of the theoretical framework on the real-scale from observations at the full-scale field site in Vallée de la Sionne. Furthermore, we discuss the validity of the theory in the light of similarity considerations. The theoretical description has been condensed into a set of rules for practitioners in charge of dam design. We test this set of rules in a series of case studies reviewing project documentations of several avalanche catching dams that currently are in the project phase in Switzerland.

Snow loads on defensive snow net systems

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ABSTRACT

Net systems are safety devices which stabilize the snow cover in avalanche starting zones. The system snow load and snow net is complex and is influenced by several factors. In the test site “Hafelekar” at 2.254 m a. s. l., close to Innsbruck (Tyrol, Austria), two different types of snow net systems have been equipped with gauges to measure the load on different components of the net. In addition to the pressure forces on the posts and the tension forces in the anchors, the base perimeter wires and the up- and downstream wires, the continuous change of the net geometry during winter was recorded. This paper presents the data measured on the two net systems, especially the snow load variation over the course of the winter. The temporal variation of snow depth was recorded with a terrestrial laser ranging system. Two automatic weather stations are providing continuous measurements of wind, snow height and air temperature. Finally a summary of the statics calculated according to Haefeli (1954) and the Swiss Guidelines (BUWAL/WSL, 1990) as well as a comparison between the calculated and the measured forces on the snow nets is given. From the results you can depict that both registered pressure forces on the posts and tension forces in the anchors and up- and downstream wires are smaller than those calculated according to Haefeli and the Swiss Guidelines.

1. INTRODUCTION

Snow nets are flexible supporting structures built in the starting zone of avalanches in order to prevent the failure of the snow cover. Over the past decades these structures have become more commonly used. Because of their linear and modular shape snow nets can be adapted to specific topographic conditions. In contrast to rigid structures such as snow bridges or snow rakes, snow net systems have not yet been extensively tested in the field and the knowledge regarding their effectiveness is still limited. The development of snow nets was basically empirical and up to now only a few approaches have been made to improve the design of the snow net system (*e.g.* Nicot and others (2002), Boutillier and others (2004)). In 1954 Haefeli proposed a simple method for the design of snow nets which is still the most recognized basis for calculating these flexible structures. Margreth (1995) worked on the validation of Haefeli’s proposal by field measurements.

A flexible supporting surface consisting of wire ropes, pivoted posts, wirings and anchors are the essential components of each snow net system. The swivel support allows the posts to move freely in all directions. The downward movement of the snow cover, composed of a gliding motion parallel to the ground and a creeping motion, causes forces on the structure. According to Newton’s third axiom “actio = reactio”, an equal reaction force is applied to the snowpack. The effect of this force is the designated stabilization of the snowpack.

Based on the above mentioned fundamental configuration, different types of snow nets have been launched. The objective of this study is a comparison of different types of snow nets in regard to their effectiveness under variable snow loads. Therefore the forces and stresses on the snow net components were measured and subsequently the design method of Haefeli was verified.

2. METHODS

The selected test site is located in the central alpine region of Tyrol at 2.254 m a. s. l., close to Innsbruck. The south facing slope has an average inclination of 38 °.

2.1 Experimental set-up

Two snow net systems were equipped with force gauges. One type consists of singular triangularly shaped wire rope nets (Geobrugg, left picture of Figure 1) which are connected to a trapezium. The second investigated snow net system (Trumer company, right picture of Figure 1) consists of a unique continuous rectangular shaped net which is connected to triangular nets on both edges. Both systems have an effective height of 3.5 m.

Figure 1 Detail of a Geobrugg snow net (photo on the left) and a Trumer snow net (right side), (photo: BFW).

Different types of sensors are measuring the forces acting on selected points of the snow net systems. Moreover the changing geometry of the supporting nets and the poles are continuously recorded. For the assessment and the interpretation of the effectiveness of the snow net systems exposed to different snow loads, it is essential to determine the temporal and spatial variation of the snow depth in the test site. In this case the monitoring of the snow cover is realized with a terrestrial laser ranging system. In order to evaluate the scan results the snow height was additionally measured with a probe in a defined grid, north of the instrumented snow nets. During the winter 2006/07, the distribution of the snow cover was investigated six times with the terrestrial laser scanner. The probing of the snow heights was carried out at six different days, too. Additionally an average density of the snow cover behind the snow nets was calculated from the field tests.

Figure 2 shows the positions of the two equipped snow net systems Trumer and Geobrugg and the position of the laser scanner.

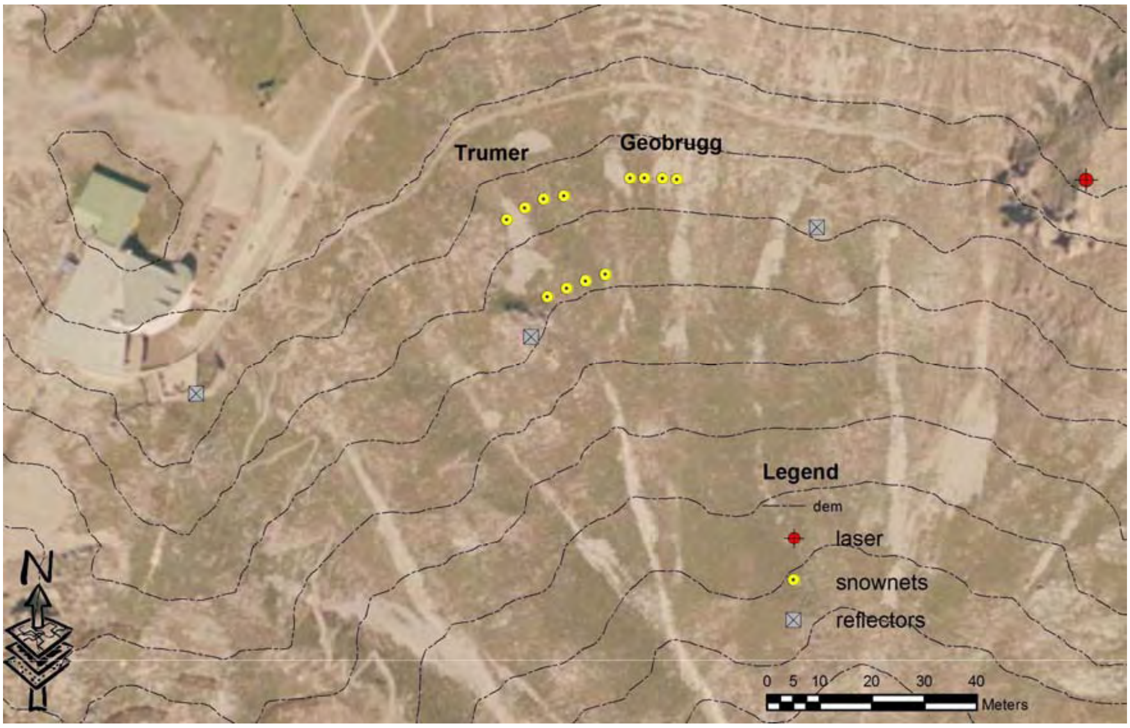

Figure 2 Overview of the snow net test site “Hafelekar”.

2.1.1 Measurements on the snow nets

Figure 3 shows the measuring equipment installed on the snow nets. Measuring instruments were only installed on one half of each net type. The axial and transverse forces in the base point of the posts are measured with a load measuring pin of the type Magtrol LB236. For the measurement of the tension forces in the anchors and all wire ropes, a special sensor containing HBM KMR200 or KMR300 has been designed at the BFW. The inclination of the supporting net and the posts is recorded by a biaxial inclinosensor HLPlanar NS-25/E2. The data is recorded every thirty minutes with Campbell data loggers that are fixed on the posts. Every four hours the measured values are directly transferred to an internet platform and automatically edited in a graphical way.

2.1.2 Measurements on the snow cover

During field visits the snow distribution, snow depth and snow density were measured. Besides the manual observation the temporal variation of snow depth was documented with a terrestrial laser scanner (Riegl company, LPM-i2k). Laser ranging is based on measuring the time-of-flight of a short laser signal from the instruments’ transmitter to the target and back to the receiver. A detailed description of the laser scanner is given by Wiatr (2007). In order to position the laser scanner five reflectors (tiepoints) have been installed within the test site. Due to the high reflectivity this points appear as bright spots in the laser scan image, so the exact coordinates of the laser scanner can be determined. The laser output is an irregular scatter-plot, therefore data is transformed to a regular grid with the Nearest Neighbour interpolation. To verify the results of the laser measurements, which means the difference between summer and winter DEM (digital elevation model), snow depth was measured with probing at several positions within the test site.

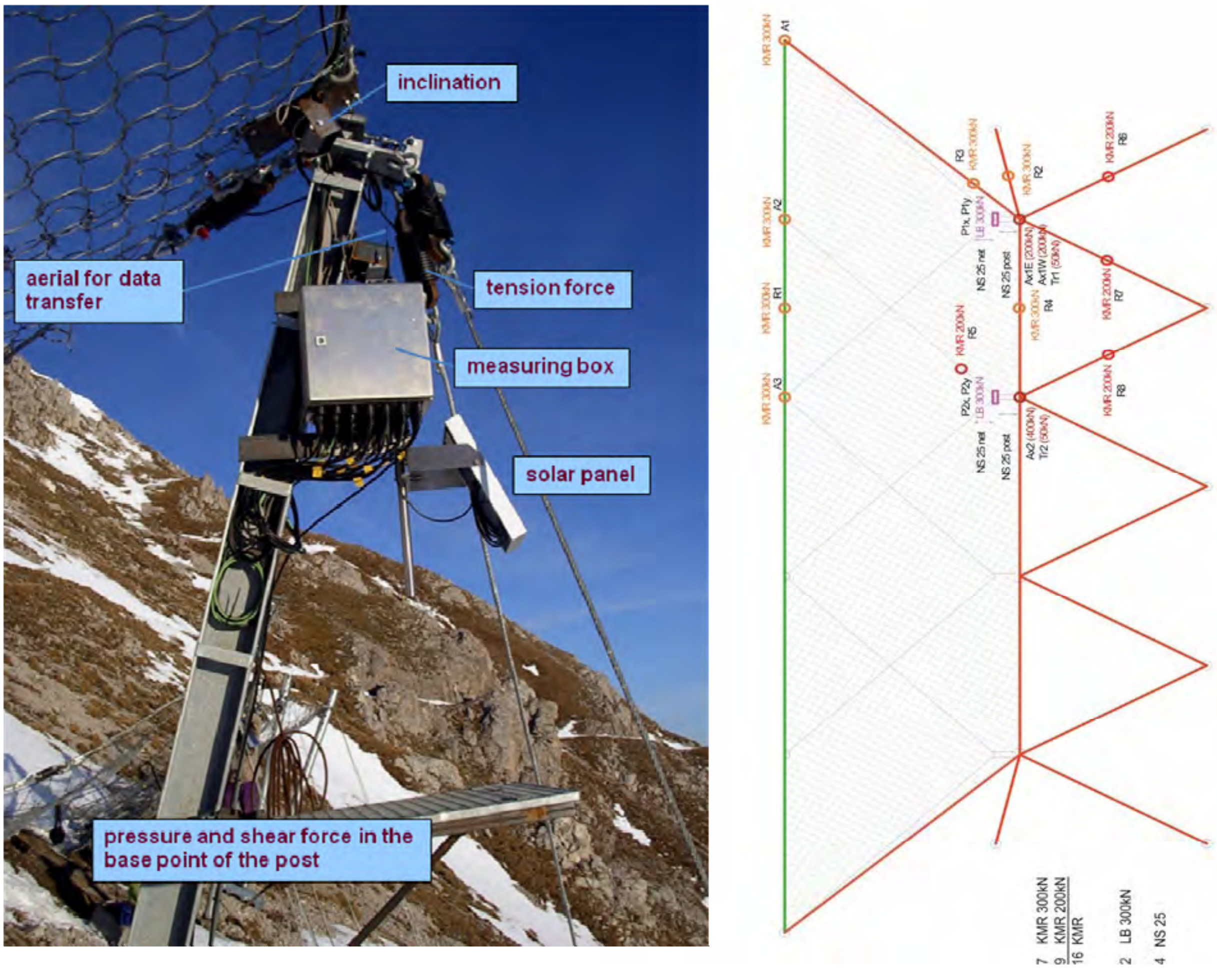

Figure 3 Instrumentation of the Trumer snow nets, as example (photo: BFW).

2.2 Design of snow nets

With the measured data on the snow cover in the test site (snow heights, snow density), the corresponding snow loads and forces applied to the different components of the snow nets can be calculated. According to the Swiss guidelines the components of the snow pressure on a net in the middle of a line are:

- Snow pressure parallel to the slope S_N: $S_N = f_S \cdot H_K^2 \cdot N \cdot f_C \qquad [kN/m]$

f_S factor considering the reduction of the snow pressure on a flexible supporting structure [-]

H_K extreme snow height at the side of the structure [m]

N gliding factor [-]

f_C altitude factor [-]

- Weight of the snow prism, formed by the supporting plane of the net and an imaginary plane perpendicular to the slope starting at the base of the net.

According to the guidelines the component of the snow pressure perpendicular to the slope can be disregarded. The resultant snow pressure is considered to be uniformly distributed over the height of the net. For the calculation of the snow pressure, averaged values of both the snow heights (scanned and probed values) and the measured snow density behind the nets are used. The knowledge of the spatial and temporal variable snow depth in the test site enables also the calculation of the spatially distributed snow pressure on the snow nets.

3. RESULTS

3.1 Experimental results

The following graphs visualize the main data that has been measured in the components of the Trumer snow net during the winter 2006/07 (for the matching of the used variables check Figure 3 and Figure 6). The forces applied to the components of the Geobrugg net during the same winter were much smaller. This difference is caused by a heterogeneous snow depth distribution due to the unequal wind and geomorphological conditions within the test site. The mean deviation of the scanned snow heights behind the two net systems represents 32 cm.

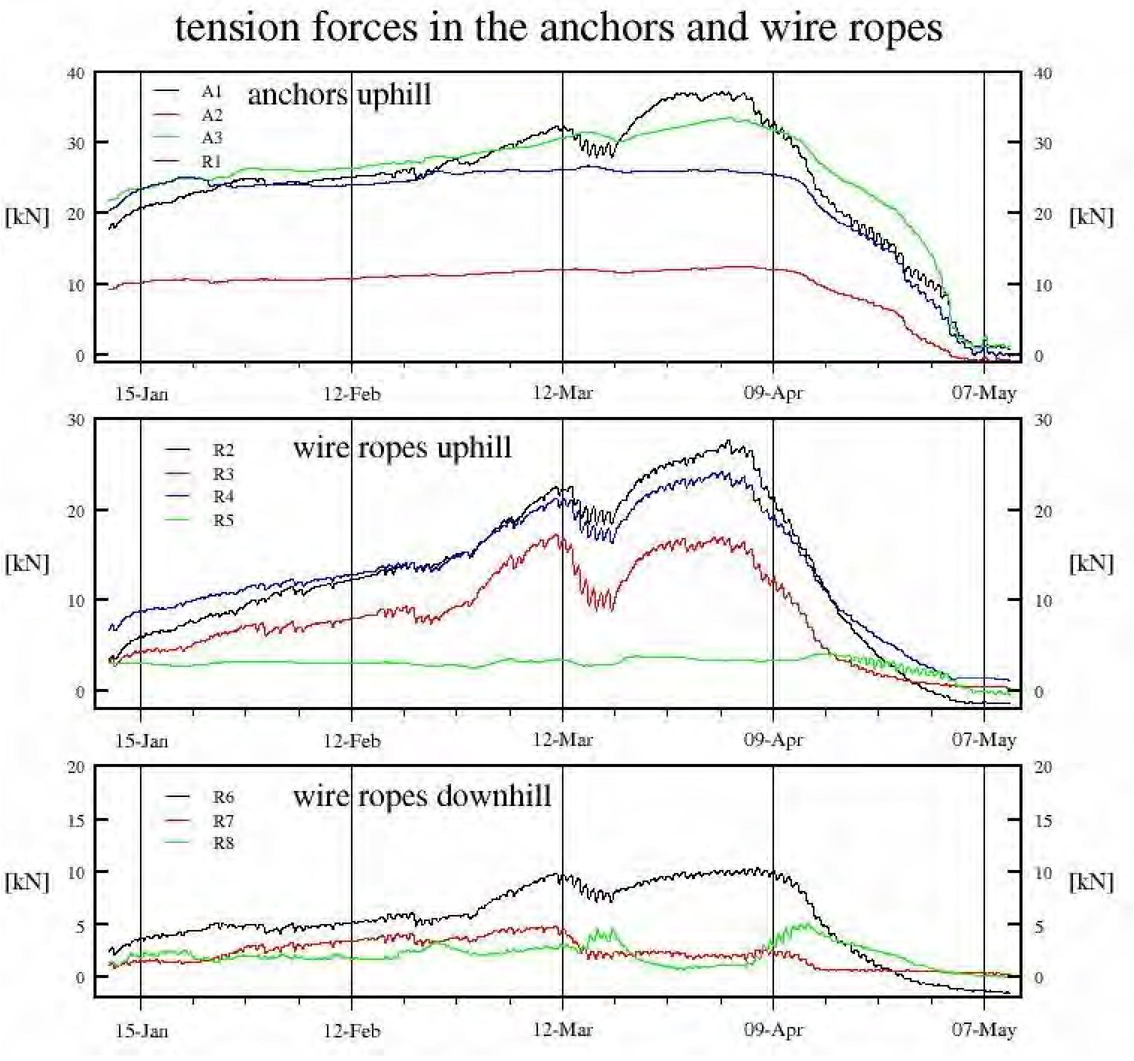

Figure 4 Tension forces in the anchors and wire ropes of the Trumer net, winter 2006/07.

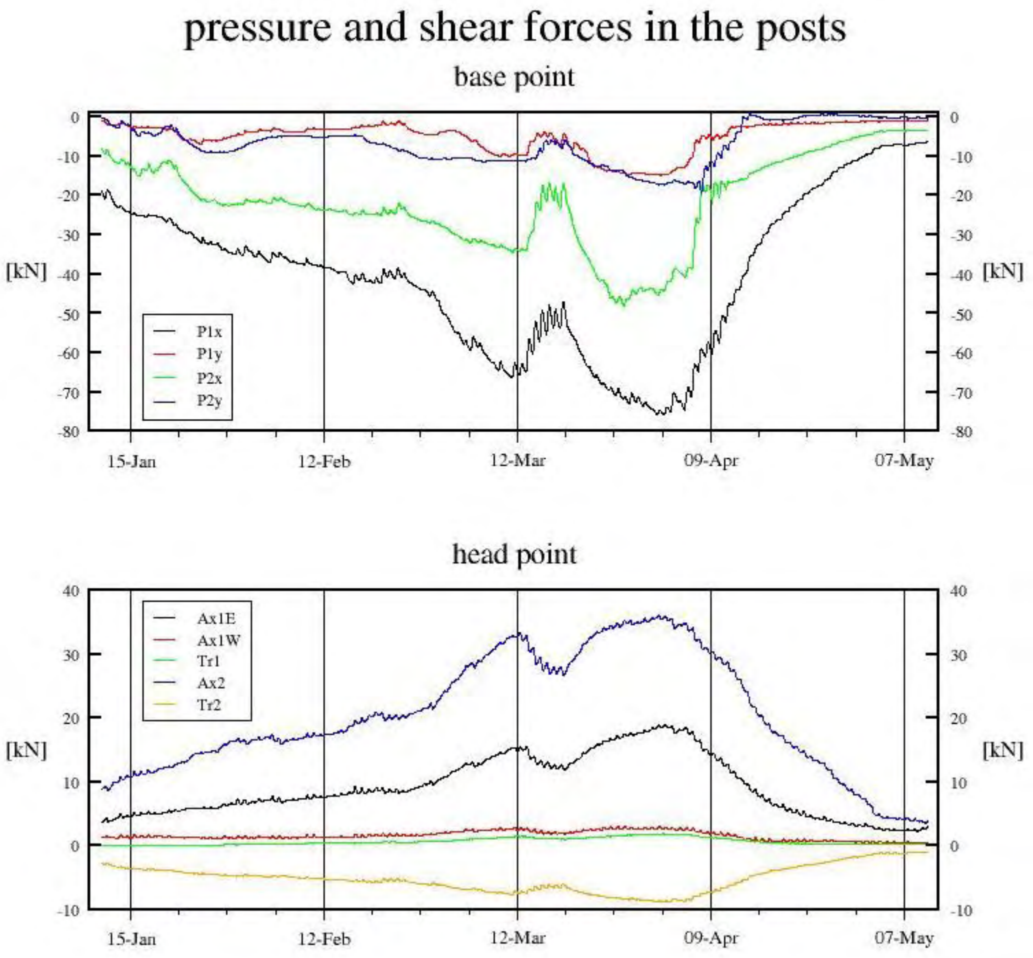

Figure 5 Pressure and shear forces in the posts of the Trumer net, winter 2006/07.

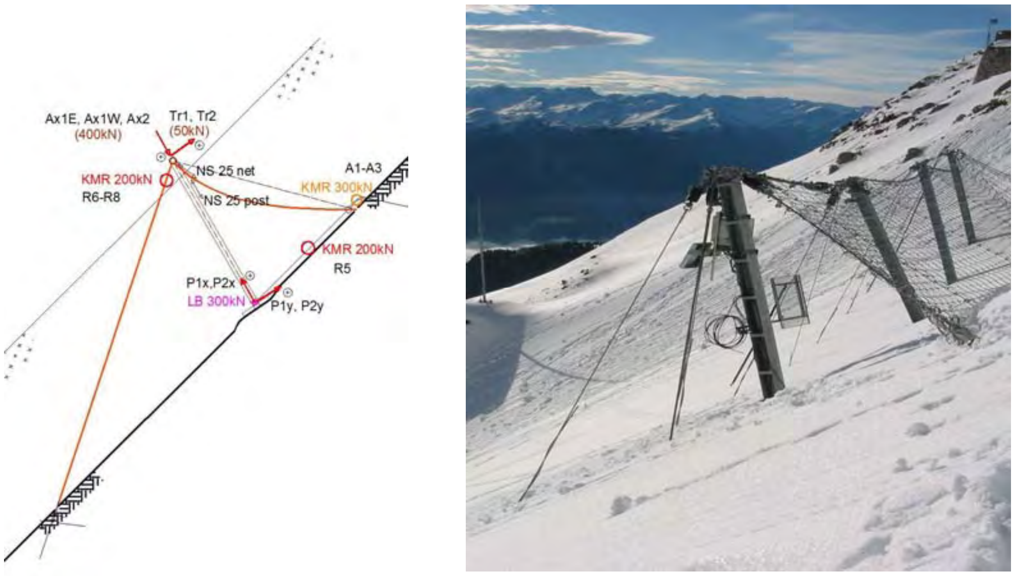

Figure 6 Crosssection of a Trumer snow net (photo: BFW).

The maximum anchor tension forces during the winter 2006/07 have been recorded at the upper anchor A3 and amount to 34 kN. The maximal measured tension forces in the uphill wire ropes R2 and R3 range between 17 kN (R3) and 28 kN (R2), the maximal tension force R4 in the wire rope that connects the head points of the posts is 24 kN. The forces in the downhill wire ropes R6, R7 and R8 vary from 1 kN to 10 kN. The maximal pressure force of 48 kN was recorded on the outermost post.

3.2 **Numerical results**

The following Table 1 depicts the forces in the Trumer net calculated according to the Swiss guidelines and the method of Haefeli. On the stated days, the snow heights behind the nets were measured with the terrestrial laser scanner. R4 represents the tension force in the wire rope connecting the head points of the posts, R8 the tension force in the downhill guy, A3 the tension force in the uphill anchor and P2x the pressure force in the post (see Figure 6). The values in parenthesis are the corresponding measured forces.

Table 1 Calculated forces in the Trumer snow net on selected days during the winter 2006/07.

Date	H [m]	ρ [kg/m³]	R4 [kN]	R8 [kN]	A3 [kN]	P2x [kN]
05.02.07	1.37	376	25.0 (12.1)	25.4 (4.4)	29.8 (26.1)	50.0 (21.5)
20.02.07	1.59	361	29.4 (14.3)	29.9 (5.6)	36.5 (27.3)	58.9 (25.1)
05.03.07	2.54	351	54.8 (18.9)	55.8 (5.8)	76.3 (29.4)	109.7 (32.2)
15.03.07	2.02	387	42.3 (19.1)	43.1 (8.4)	54.7 (31.7)	84.8 (24.3)
28.03.07	2.00	435	45.1 (23.5)	46.0 (2.4)	56.7 (32.6)	90.4 (46.4)

The calculated tension force in the wire rope R4 varies from 25.0 kN to 54.8 kN, the tension force in the guy R8 from 25.4 kN to 55.8 kN and the tension force in the uphill anchor A3 from minimal 29.8 kN to maximal 76.3 kN. The results for the pressure forces P2x of the interior post range from 50.0 kN to 109.7 kN. The minimum determined values correspond to a snow height of 1.37 m, measured on 05.02.2007, the maximal calculated forces to a snow height of 2.54 m on 05.03.2007.

The comparison of the calculated and measured forces depicts that the values determined with the theoretical approach of Haefeli are consistently higher than the recorded field data. The major difference between measured and calculated values results for the tension force R8 in the downhill wire rope. The measured tension force R8 only amounts to about 20 % of the calculated force. The calculated tension forces R4 and pressure forces P2x are almost twice the amount of the corresponding measured values. The best accordance between calculated and measured forces exists for the anchor tension force A3.

CONCLUSIONS AND OUTLOOK

From the measurements of the forces applied to the snow nets and the determination of the temporal and spatial variable snow cover in the test field “Hafelekar” several interesting conclusions can be drawn:

- The major part of the snow load is applied to the posts.
- During the observation winter 2006/07 both the tension forces in the anchors and wire ropes and the pressure forces in the posts, determined according to the theory of Haefeli, are overestimated.
- The terrestrial laser scanner is a very useful instrument to detect the snow depth distribution with a high spatial resolution, however the time needed for image acquiring is rather long; the best results can be obtained under an overcast sky, at dawn or at night.

So far field data was required in a relatively snowless winter 2006/07. Additionally, the snow cover distribution in the test field was very heterogeneous. Thus, a comparison between the effectiveness of the two equipped snow net systems is not yet possible, but will be one of the future project goals.

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Development of the dense and powder snow avalanche model SamosAT

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ABSTRACT

Developments in snow sciences, calculation technologies and the demand for more detailed and comprehensible hazard mapping have led to a further step in the development of the 3D powder snow avalanche model Samos. As a result, a new model – SamosAT – was initiated in 2004 by the Forest Technical Service for Avalanche and Torrent Control/ Austria and released in October 2007. The 2D and 3D model provides simulation tools for dense and for powder flow avalanches. The previous Samos simulation platform has been completely redesigned in order to provide improved results and an easier software handling. In regard of these enhanced technologies, the name Samos has been extended by the affix AT for Advanced Technology. The calibration of the model was done with 22 well documented reference avalanches by the Centre for Snow and Avalanches (WLV). In a systematic study, all internal parameters were analysed and adjusted to the reference data. By creating matrices with the decisive model parameters and the reference avalanches the suitable calibration values for the dense- and powder flow model were determined.

Keywords: Avalanche simulation, SamosAT, model calibration

1. INTRODUCTION

An enormous increase in required space in terms of valuable building land in the Alps leads to a high pressure on the Alpine environment. Parallel with this development, the demand for safety is constantly growing. Thus, enhancements in risk management are needed to maintain a high level of safety for the exposed society. Avalanche simulation models are one possible component in hazard analysis in connection with a comprehensible and objective estimation of avalanche runout. In Austria, the Forest Technical Service for Avalanche and Torrent Control has applied different avalanche models for practical use for many years. In the beginning of 1999 the first 3D avalanche simulation model called Samos (Snow Avalanche Modelling and Simulation) was released by the authorities (BMLFUW) in cooperation with the company AVL List GmbH in Graz. The program enabled both, a dense flow and a powder snow avalanche simulation in 2D and 3D.

New technologies, developments in snow sciences and the demand for a more detailed and comprehensible hazard mapping led to a further step in the development of the 3D powder snow avalanche model Samos. As a result, a new model – SamosAT – was initiated in 2004 and released in October 2007. The advanced model provides simulation tools for dense and for powder flow avalanches, depending on the respective settings. The previous Samos simulation platform has been totally altered in order to provide improved results and an easier software handling. In regard of these enhanced technologies the appellation Samos has been adapted by the affix AT for the Advanced Technology.

2. OBJECTIVES

The Samos model (release 1999) significantly overestimated the total avalanche runout distances. Especially the simulation of the dense flow part resulted in nonsatisfying outcomes mainly due to the friction model. The powder model, which is coupled with the dense flow part, overrated the runout particularly in the pressure zone between 1–5 kPa. Therefore, the main emphasis in the development of SamosAT was the proper modelling of the dense flow part and the improvement of the runout behaviour for the powder part.

3. METHODS

Major changes have been made in the calculation of the dense flow part, in the alteration of the simulation environment of the powder part and finally in optimising the resuspension layer, which is responsible for the transition of the dense snow into the powder layer.

Extensive tests with various friction laws were necessary to find a suitable setup for properly modelling the dense flow avalanche.

$$\tau^{(b)} = \tau_0 + \tan\delta \cdot \left(1 + \frac{R_s{}^0}{R_s{}^0 + R_s}\right) \cdot \sigma^{(b)} + \frac{\bar{\rho}\bar{u}^2}{\left(\frac{1}{\kappa}\ln\frac{\bar{h}}{R} + B\right)^2} \qquad [1]$$

The SamosAT friction law [1] in the actual setting provides suitable runout behaviour. The bed friction angle tanδ still plays the decisive role in the calculation of the maximum avalanche runout. The term (R_S^0, *Rs*) increases the bed friction angle at lower avalanche velocities in order to stop smaller avalanches more realistically and to prevent lateral spreading of avalanches at very low flow heights (under 0,5 m depending on the setting). R_S^0 is an empirically determined constant to reduce the spreading of avalanches at very low velocities.

Another step was the alteration of the irregular Delauny triangulation to a constant Eulerian grid. This improves the calculation time, increases the stability and reduces random outliers.

The flexible user interface provides extended possibilities in avalanche simulations especially in the data in- and output.

The calculation of the powder snow avalanche in the newly released model is performed on an AVL-Swift V8 platform. The basic formulas have been adapted to the SamosAT model. Additionally, a real two phase calculation model of ice particles and air has been integrated to obtain a more realistic simulation of the aerosol. Besides the gain of mass particles, this method allows for a supplementary loss of snow particles along the avalanche path.

Consequently, snow particles can rise and drop within the aerosol especially at strong surface bends.

4. RESULTS AND CONCLUSIONS

The Forest Technical Service for Avalanche and Torrent Control has collected extensive data from catastrophic avalanches in the last decades. For the model validation, 22 well documented avalanche events have been chosen to calibrate the various internal parameters. The reference avalanche data pool contains mapped avalanche runout zones, information on measured snow heights, approximated avalanche pressures at damaged buildings and/or recalculated avalanche velocities. This rather punctual information is, in addition to the surveyed avalanche outlines, taken into account in the calibration of the dense and powder flow models.

The comparison of simulations and reference data showed satisfying results for the recalculation of the dense part. The lateral spreading in the runout zone can be minimised by increasing the bed friction angle at low avalanche velocities. Hence the SamosAT dense flow model reacts sensitively to the surface topography.

The simulations of the powder avalanche showed a significant decrease of the spreading in the runout zone in comparison to the reference data. The modelling with the proposed parameter setting for the powder part led to more realistic avalanche speed and pressure by SamosAT. The calculation of mass balances were in general agreement with the release mass of the avalanche events and the runout behaviour.

The backcalculations with 22 reference avalanche events pointed out the applicability of the SamosAT model for operational use. The model simulates dense flow avalanches as well as powder snow avalanches in a suitable way. Nevertheless, the investigations showed once more that more detailed information on avalanche mass balances are required to optimise the simulation tools. Further investigations with additional reference data, especially with simulating avalanche dams, are the next steps in the permanent development process.

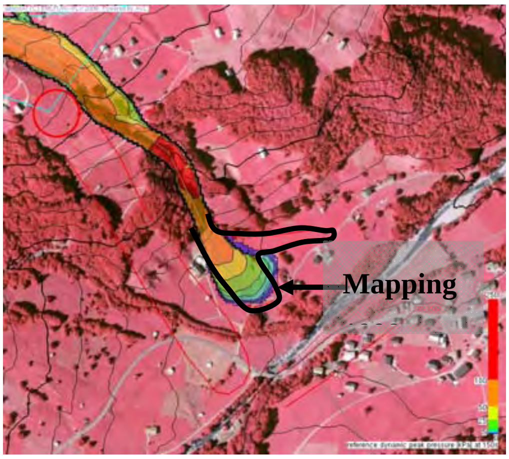

Figure 1 Mapping of avalanche runout in 1999 in comparison with the simulation result.

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Light rockfall prevention mesh used as retention structure in snowpacks of limited height

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ABSTRACT

A concept for application of light rockfall prevention mesh as retention structures has been developed. The structure is flexible and easily adjustable to undulating terrain. It is easy to construct as well as repair, if needed. The retention mesh is designed for snow height limited to two metres measured normal to the ground within a predefined return period. The cost per metre was one fifth of an ordinary retaining structure of comparable height.

1. INTRODUCTION

Conventional supporting structures like snow bridges and snow nets are expensive and barely feasible on slopes where the snow height is limited and primarily controlled by the precipitation and not by snow drift. Typical examples can be steep meadows, open patches in wooded areas and potential starting zones of limited size in rocky hillsides.

A concept for application of light run-proof prevention mesh as retention structure has been introduced as mitigative measures above a new tourist resort in Sirdal in Southern Norway. The retention structure has been designed for a lifetime of 25 years. Meanwhile vegetation is meant to be established where conditions are favourable. Beyond that the structure will be maintained when needed (Fig. 1).

Figure 1 Tourist resort protected by light retention meshes and conventional snow bridges. Six locations of meshes can be identified by grey posts in the hillside.

The structure is light weight and easy to transport and install under difficult topographical circumstances. With firm rock at the surface the foundation work is limited to bolts grouted into boreholes. Under such conditions the cost per metre is approximately one fifth of a conventional supporting structure or snow net of comparable height. The transparent design of the structure makes them virtually invisible in both summer and winter. This is particularly suitable in tourist and recreational areas. The growth of plants is not restricted by shadows cast by conventional supporting structures (Figs. 1–2).

Figure 2 a) Light retention mesh. b) Strut (tread bar) coupled to rock anchor and post. Mesh with ground clearance clipped to wire going through the adjusting eye bolts.

2. DESIGN

The maximum snow height recorded in the area has only once been above 2 metres in 30 years. Within a return period of 25 years it is assumed that the critical snow height on the south-facing hillside would not exceed two metres measured normal to the ground, corresponding to approximately 2.3–3.0 metres measured vertical on slopes of 30–45 degree. In some locations, a maximum depth of two metres is expected.

Accordingly, the vertical height of posts and strength of structure was designed for 2.0, 2.5 and 3.0 metres of low density snow (200 kg/m^3), respectively and 1.3, 1.7 and 2.3 metres of high density snow (400 kg/m^3). The design snow loads were calculated in accordance with the Swiss guidelines with some adjustments to account for verified creep and glide conditions of Norwegian snow.

The design of the retention structure was based on the forces acting on posts, tendons and mesh from the calculated loads. An example of estimated section forces between post and tendon is shown in Figure 3.

The ideal location for the fix point between tendon and strut as well as dimensions of posts, are shown in Table 1.

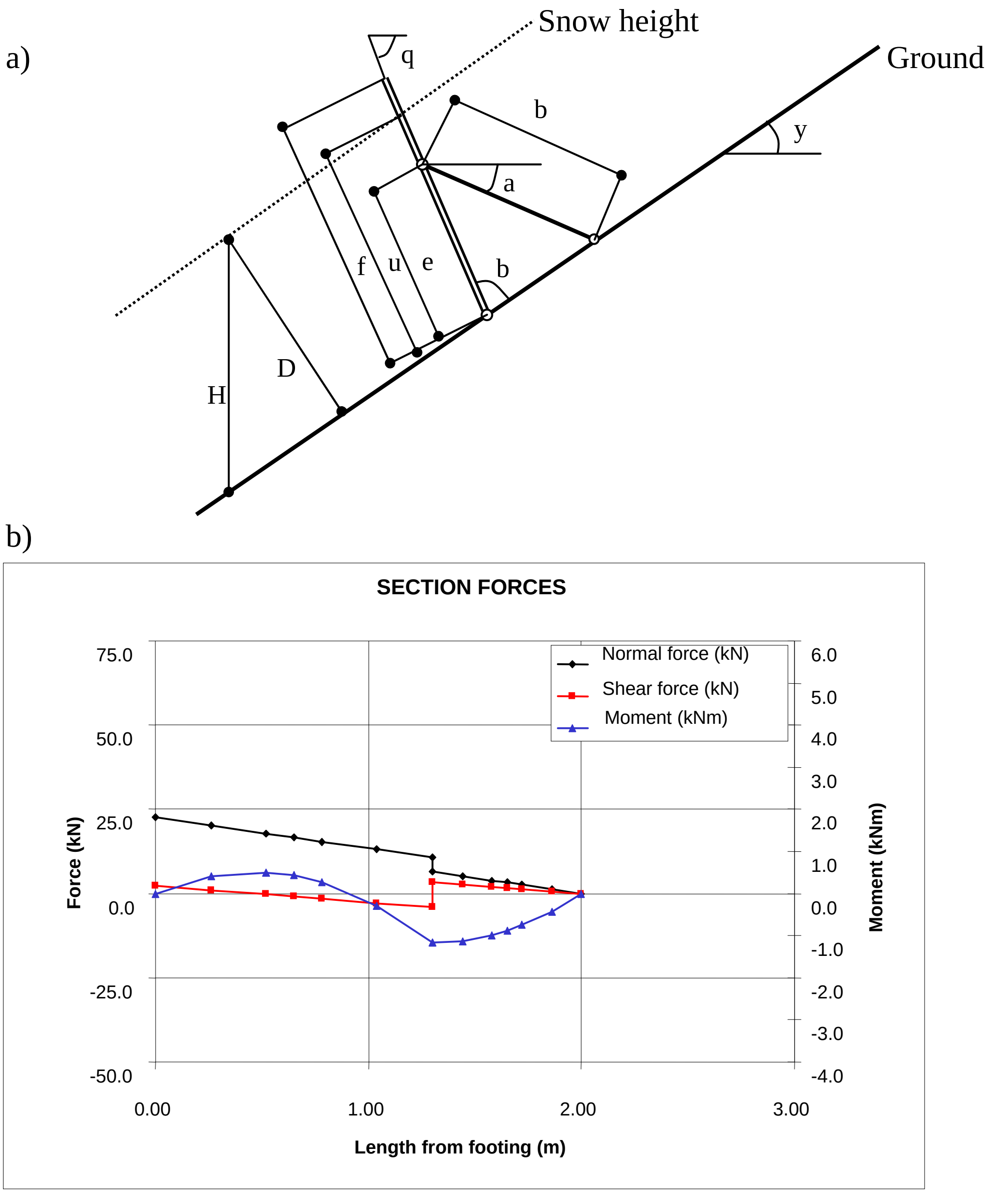


Figure 3 a) Input parameters for design of posts and struts.
b) Estimated section forces between post and tendon indicate the ideal fix point.

Table 1 The posts - Square steel hollow sections

Length of post	Fix point location	Dimensions	Material
m	m	mm	no.
2.0	1.3	50x50x4	St. 52
2.5	1.6	60x60x4	St. 52
3.0	2.0	70x70x4	St. 52

3. PRINCIPLE DESIGN

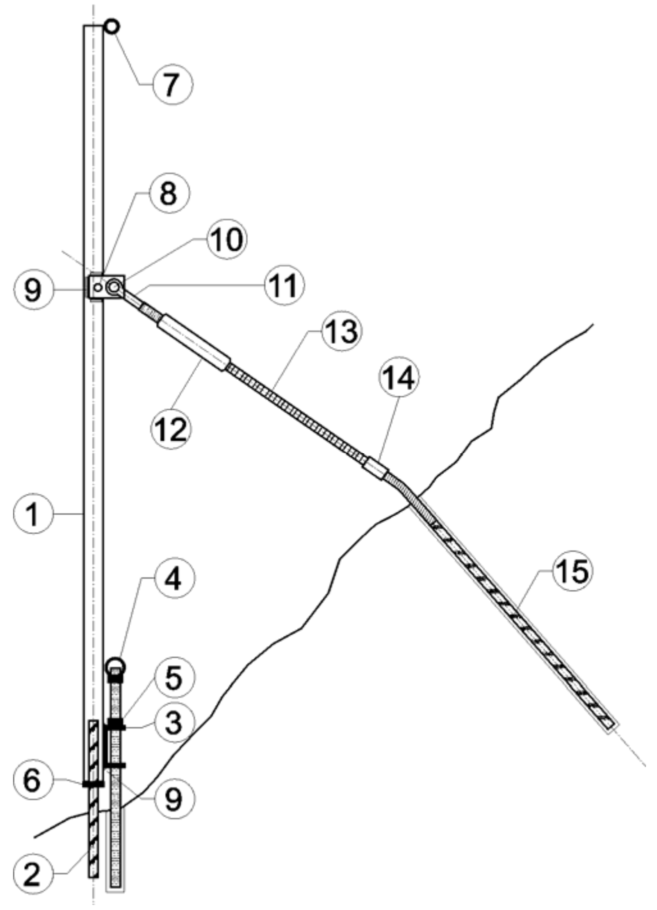
3.1 The Posts

The principle design and foundation of the square steel hollow posts are shown in Figure 4. Some adjustments of the tabulated accessories are acceptable on the assumption that the structure retains its strength properties.

The bracket at the foot of the post made of a channel section (3) and the eye and fork connection (8), are both flare welded to the posts. All end poles have additional eye and fork connection and struts (13) in the line of the mesh (Fig. 5).

The eye bolts (4) and channel section (3) on the posts were originally dimensioned to take the shear forces and keep the posts to the ground. However, the dowel (2) and pipe clamp (6) made it much easier to even the top line of the posts across uneven terrain. The selected solution requires a heavy clamp for supporting the post.

The adequate dimension of struts (rolled thread bar) and connecting accessories are OD16 mm, while the rebar bolt should be minimum OD20 mm. However, the whole system may as well be done in OD20 mm. The inclination of the strut may vary between 45^{o} – 60^{o}.



Accessories

no	Type	Dimension (mm)
1	Post	50x50x4, L=2000 60x60x4, L=2500 70x70x4, L=3000
2	Dowel, rebar	OD20
3	Channel section	INF100, L=50
4	Tread bar with eye nut	OD20 OD20
5	Nut	OD20
6	Pipe clamp	
7	Cable eye	
8	Eye and fork connection	ear: min. 8 mm
9	Flare welded	
10	Bolt and nuts	min. OD16
11	Turn fork or eye nut/eye bolt	OD20
12	Turnbuckle	OD20
13	Strut, rolled thread bar	OD20
14	Coupler	OD20
15	Rock anchor, rebar	OD20, L=800

Figure 4 Principle design and anchoring of the square steel hollow posts. The accessories were made in galvanized steel and dimension OD20.

3.2 The mesh

The light mesh (21) is mounted to the vertical posts and reinforced by wires (24) along the four rims. The principle securing of the mesh is shown in Figure 6. The wires goes through the cable eyes (7) on the top of the posts, down through the eye and fork connection (8) of the end posts and through the eyes of the adjusting bolts (4) at the foot of the posts. The wires are secured with wire clamps (25). The top wire was fixed in both ends to the rebar bolt of the end, either directly or via a strut with eye nuts fixed in the cable eye of the end posts (Figs. 2 & 6).

Figure 5 The bearing top wire of the mesh goes through a cable eye to the rock anchor.
Figure 6 Details of tendons anchored by turnbuckle and fork, and wires to eye nut and bolt.

The mesh is fixed to the wires with clips (26) with defined strength. The mesh may normally have a ground clearance depending on the potential hazard of shallow snowpacks at the actual locations of the retention structures. In the protection area a ground clearance varying from 20–100 cm was recommended. There was in fact no need for special adjustments due to uneven terrain. The height of the actual meshes where 1.5 m and 2 m respectively (Table 2).

Table 2 Mesh and wire - Accessories

no	Type	Dimension (mm)
21	Mesh	1x1500 / 2x1000
22	Mesh size	80x100 / 50x70
23	Mesh gauge	3.0 / 2.2
24	Wire gauge	10-12
25	Wire clamp	10-12
26	Wire rope clip	

3.3 Corrosion protection

Avalanche protection measures are exposed to varying corrosive environments. The corrosion protection of the individual elements can be adapted to the prevailing situation in order to achieve an adequate life expectancy of the structure. Standard galvanized products were selected for the planned life expectancy of the actual measures.

4. COST AND CONTROL

All together were nine light retention meshes varying in length from 5 to 18 metres, installed above the new tourist resort in Sirdal. Total length 84 metres. All foundations were in rock. The average cost per metre was 3000 and 3400 NOK, respectively for 2 m and 3 m high meshes (2005). This included the time the contractor needed to establish rational methods for production of posts as well as practical techniques for anchoring and installation of the structures. Even so the cost was approximately one fifth of a conventional supporting structure of comparable height.

The light run-proof mesh and simple construction of the foundation and posts, makes it easy to maintain the structure when necessary. The Norwegian Geotechnical Institute will carry out routine control of the constructions for some years to monitor the performance and functionality of the new measure.

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Development, assessment and effect of a new avalanche braking system in the Mühlauer-Klamm, Innsbruck, Austria

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ABSTRACT

North of Innsbruck the Mühlauer-Klamm–avalanche endangers Mühlau, a part of Innsbruck the capital of Tyrol. The starting zone spreads over an area of 2.6 km² and leads to a gorge-styled avalanche track. The average inclination of the track is 15°. The run out close to the lower end of the gorge is densely settled. Six buildings are in the red zone and 7 buildings in the yellow zone of the hazard-map of Innsbruck. This situation was not accepted by the authorities. So, a special protection-system was developed, which consists of 2 braking – structures to enhance the retarding effort of the gorge.

The environmental conditions of the catchment and the selection-procedure of the protection measures with regard to economical, ecological and technical conditions, are described. Finally, the influence of the avalanche braking – system on land-use planning is presented.

Since this protection-measure is unique, no experience about its effects exists. Therefore, in cooperation between the federal service of avalanche and torrent control (WLV) and the federal forest research centre (BFW), a study was carried out to verify the expected effect of the system. A numerical investigation was conducted with SAMOS and ELBA avalanche simulation models. In addition, model tests in a water-tank will be performed.

The decision procedure of the project and results of the numerical analysis are presented.

1. INTRODUCTION

The population have increased considerably in the Alps since 1950 especially in Innsbruck. The number of inhabitants has increased from 95.000 in the year 1950 to 150.000 in 2007 (Grieser, 2007). The city of Innsbruck covers an area of 105 km², but only 35 % or 36 km² of this area is suitable for permanent settlement. Innsbruck have a population density of 3.830 persons per km². More than half of the available area for settlement is already planned for construction. In this situation the price range of housing space lies between EUR 3.000 and EUR 4.000 per m². Because of the continuous increasing population these prices are expected to grow further.

During the last 50 years, the settlements have expanded into areas which are endangered by natural hazards like the Mühlauer-Klamm-avalanche. This avalanche endangers 41 people (Nolf, 2007) and therefore causes the biggest risk in Innsbruck. The resettlement of these persons to safe parts of the city is not a political option. No politician could stand the public storm caused by a drastic measure like that. So in the past, Innsbruck decided to evacuate the affected persons in hazardous periods. These evacuations are also extremely unpopular and have not always been accepted by some of the inhabitants. Therefore the municipal government finally decided to reduce avalanche risk in the endangered area of Innsbruck by the name of Mühlau. As a by-product, new development areas of 9.000 m² will become available. This would be equal to a value of EUR 6.800.000.

Due to these facts, the municipal government applied to the Austrian Service for Torrent and Avalanche Control in Innsbruck to develop a master plan for safety measures and determined this planning as most important for Innsbruck. In this project, the challenge was to take into account all ecological, economical und social aspects. Limiting factors were the natural scenery, the water supply of Innsbruck, the recreational area and the missing space for mitigation measures in the run out. Considering these limitations we decided to brake the avalanche in its path. The avalanche dynamic models FIRE and SAMOS AT were used to estimate the general effect of the planned measures. In addition to these calculations, water tank simulations were carried out by the BFW to study the detailed effects of the braking system.

The suggested braking system therefore is a special solution for the Mühlauer-Klamm-avalanche and cannot be used generally, only in very similar cases.

2. DESCRIPTION OF THE AVALANCHE CATCHMENTS

2.1 Starting zone of the avalanche

The starting zone of the Mühlauer-Klamm-avalanche (Fig. 1) situated on the southern slope of the Nordkette north of Innsbruck covers an area of 2.64 km² and reaches up to an altitude of 2.250 m. Due to the geological and erosive conditions, the upper part is divided into numerous sub-catchments. Because of this distinct morphology a unique avalanche release including the entire starting zone is not realistic for further consideration. So the size of the expected avalanche release areas is in the range of 0.17 km² - 0.7 km². These sub-catchments are inclined between 35° up to more than 50° and they join at the beginning of the avalanche path at station km 2.6 called “Ursprung” at the altitude of 1.100 m a.s.l.

2.2 Avalanche path

The 1.5 km long path starting below a cliff follows a 100 m deep narrow gorge down to the level of the valley at 720 m. The gorge has an inclination of 16° in average. The steepest part (20° – 29°) is situated directly above the settled area. In the middle of the path the inclination drops down to 14°. The gorge in its upper part is 15 m to 20 m wide, in the lower part 5 m – 10 m. The avalanche has to pass two punctual constrictions in station 2.2 km and 1.9 km, which contract the gorge to 4 m – 10 m. Beside this configuration of the path there are no other terrain features which interfere with the avalanche dynamic.

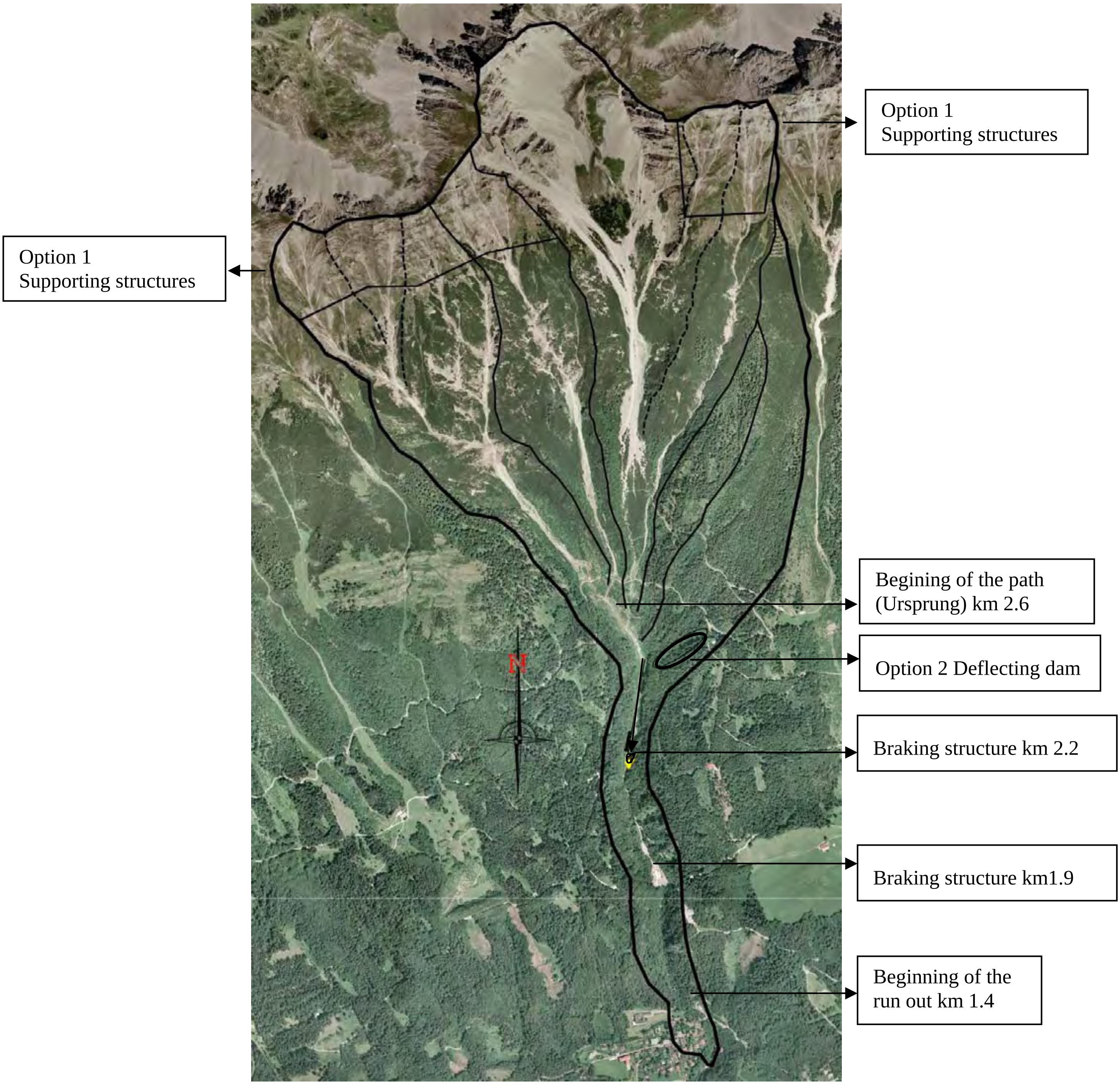

Figure 1 Overview of the entire and sub-catchments of the Mühlauer-Klamm-avalanche (Photo plan Amt d.Tir. Ldreg., WLV 2008).

2.3 Run out zone

The run out starts 150 m above the settlement at station 1.4 km. Basically, this area is dominated by a 10 m deep channel with an inclination of 9°. At the beginning the channel bends sharply to the left so an out-break into the settled area is to be supposed. After a distance of 180 m the channel gets slightly steeper (11°).

2.4 Meteorological conditions

The snow cover in the Mühlauer-Klamm-avalanche is influenced by North-West-weather conditions combined with hard winds. Every year winds build up 10 m high cornices on the ridge in the western part of the starting zone. The eastern sub-catchments are not so much affected by northwest winds, but here as well as in the western half of the Mühlauer – Klamm avalanche, west winds blowing along the Nordkette are important for loading the deeper parts of the starting zones with considerable snow mass. The meteorological station (1.900 m a.s.l.) at the Seegrube (ZAMG) near the avalanche catchment have the following return period of the recurrent design event in Austrian risk mapping:

Table 1: Extrapolated values for snow depth. (Statistical database: Gabl, 1996)

Sum	**Return period**	**Snow depth**
1 day new - snow	150 years	1.6 m
3 day new - snow	150 years	3.0 m
Largest	150 years	5.4 m

3. HISTORICAL EVENTS

The chronicle comprises events since 1855: They can be split up into 4 categories:

1) - Avalanche reaching station km 2.6 (the beginning of the path) every year.
2) - Avalanche reaching to the path section between km 2.0 – km 2.3 with a return period of about 30 years.
3) - Avalanches reaching the lower part of the path below km 1.8 till km 1.6 with a return period of 50 – 100 years.
4) - Avalanches reaching the settlement with a return period of 100 years and more.

These big avalanches occurred twice in the last 150 years. The one in 1951 is well documented (Heuberger, 1952). It reached to station km 1.2. An avalanche mass of 600.000 m^3 was deposited in the gorge and the run out zone. This event could be assigned to a precipitation return period of 90 years (Gabl, 1996). Heuberger reports that the 1951 - avalanche has been not a single event but has been the effect of a series of avalanches, which filled the upper part of the gorge before the catastrophic event occurred.

4. CHARACTERISTICS OF THE MÜHLAUER-KLAMM-AVALANCHE

The sub-catchments in the western part of the entire avalanche area are extremely steep and slippery. In addition to these morphological conditions, extraordinary snow height caused by winds is the reason of small but frequent avalanches. This prevents big catastrophic avalanches, which affect the settlement, but fills up the uppermost part of the path around station 2.6, where all sub-catchments join. So not only the cliff above the beginning of the gorge is levelled out, but due to the snow deposition, friction within the gorge is substantially reduced and so the subsequent avalanches flow further and further. The big avalanches are then able to reach the lower parts of the path. This scenario is documented very often by the chronicle. Especially Heuberger reports about this situation during the event of 1951. In addition the filling of the Ursprung is one of the criteria for the avalanche commission to act (Nolf, 2008).

5. ENDANGERED VALUES

Six residential buildings are situated in the red zone, where substantial destruction of buildings is expected. Seven non-enforced buildings are in the yellow zone, where damages are supposed. The affected settlement has been built after 1950 and before the hazard zones were determined. This means that currently 18 persons live in the red and 23 persons in the yellow zone. Because of the weak structure of all houses, nobody in these two groups is safe within their houses. So the avalanche commission has to evacuate the people on behalf of the mayor of Innsbruck in case of avalanche hazard. This happens once in a decade on average (Nolf, 2008). Furthermore, the avalanche endangers 450 m of roads and building sites of 9.000 m².

6. OPTIONS FOR MEASUREMENT

To reduce the risk for the settlement the Federal service of torrent and avalanche control evaluated 3 security concepts:

6.1 Supporting structures in the starting zone

To reduce the avalanche mass in a considerable amount, the building of supporting structures on 40 ha release area would be necessary (Fig. 1). Theses measures cause an expense of about 450.000 EUR/ha. An investment of about EUR 18.000.000 in total, is not justified by the value endangered by the avalanche. The construction site is situated within the centre of the ground water protection zone. These springs cover 80 % of the water supply of Innsbruck. According to this we had to expect either a rejection by the authorities or the building costs would become too high. The third heavy argument against this option is the influence on the natural scenery north of Innsbruck by such a big expansion of the defences to stabilize the snow cover. Environmentalists might have activated a public opinion against the project so that there would be no political chance for acceptance.

6.2 Deflection dam above station km 2.6

The purpose of this deflection dam is to divert avalanches towards the western canyon side in the upper quarter of the path (Fig. 1). The volume to be moved to build the embankment would have an amount of 100.000 m³ – 150.000 m³, so that costs would come to EUR 2.200.000. The effect for the settlement would be completely insufficient. The dam would not stabilize the main part of the catchments especially in the western part and it would cause considerable damage on the forests on the right - hand side of the gorge without considerable effect in regard of risk reduction in the settlement. In addition, a part of the excavation area would take place within the ground water protection zone. The influence would have been heavy during the construction phase but situated beneath the timber line these damages would vanish after a decade.

6.3 Braking system in the middle of the canyon

A third scenario is to increase friction within the long gorge and to stop the avalanche before reaching the settlement (Fig. 1). In the centre part of the path between station km 2.3 and station km 1.7, the longitudinal section has its lowest inclination (14°), as well as two constrictions at km 2.2 and km 1.90. In this part of the canyon it would be most successful to build 2 braking dams to increase the braking efficiency of the path. The cost of them comes to EUR 5.340.000. This scenario would not affect the groundwater protection zone of Innsbruck, because the construction sites would be situated far beneath the wells. The environmental aspect is taken into account because the dam can only be seen from special locations in Innsbruck and the size of the affected area is limited. The simulation with FIRE (Schaffhauser, 1997) and SAMOS AT (Herbert and others, 2007) confirm the expected significant influence of both constructions on the impact of the avalanche in the settled area.

7. ASSESSMENT OF THE SCENARIOS

Table 2: Ranking of protection measures (Assessment scheme Vogl WLV/Innsbruck, 2007).

Comparison of versions Mühlauer-Klamm - avalanche			**Szenarios**			
			0 Variant no measurements	**Variant 1** supporting structures	**Variant 2** Deflecting dam	**Variant 3** Breaking system.
Categories with weighting	**Remaining risk**	**2**	10 (5)	4 (2)	10 (5)	4 (2)
	Costs	**1**	1	5	2	3
	Follow-up costs	**1**	5	2	5	3
	Ecologie	**1**	2	4	3	2
Asssessment			**18**	**15**	**20**	**12**
Rank			**3**	**2**	**4**	**1**

Assessment	**positive**				**negative**
	1	**2**	**3**	**4**	**5**

Due to the assessment scenario 3, the braking system, came into consideration. This measure is nearly as effective as defence structures to stabilize the snow cover, but is less expensive, has no influence on the groundwater protection zone and hardly a consequence seen from the environmental aspect.

8. DESCRIPTION OF THE BRAKING SYSTEM MÜHLAUER-KLAMM-AVALANCHE

The braking effect of the gorge in the middle section will be enforced by the building of two dams at its beginning and end. The upper dam (Fig. 3) should prevent the filling of the braking section below by smaller avalanches and reduce the speed of the bigger ones. The lower dam (Fig. 2) has to catch as much avalanche mass as possible, so that the dense layer is separated from the suspension layer. Avalanches, which nevertheless go further down the gorge, should stop in the lower part of the canyon or should remain within the gully in the settled area around station km 1.4.

On the one hand, the powder part of the avalanche should be separated from the dense layer (Issler, 1999) to retard the current, on the other hand, the suspension layer is expected to decelerate by turbulences when passing the dams.

The most effective construction suggested is a dam, which is permeable in its middle part so that the clearance keeps open as long as possible. Both dams are 20 m high and have an inclination on the upper side of 60°. The construction in the centre of the dams consists of 5 walls made of reinforced concrete which divide the section into 4 gaps each 4 m wide. On both flanks, earth dams close the cross section of the gorge. In the original concept both dams are of the same type.

Figure 2 Braking dam at station km 1.7 (photo: Gwercher/WLV Innsbruck 2007).

This complex structure of the braking dams should cause different effects on the avalanche. Due to the gaps the centre of the avalanche should be prevented running up the upstream dam slope. During passing the 4 gaps the dense layer should become slower because of higher friction by splitting up into 4 parts (Kern and others, 2004). Both lateral earth dams should stop the dense layer at the flanks and cause a run up. Such different flow behaviour should increase the internal friction of the avalanche.

The different permeability of the cross section is expected to create higher turbulence in the lower part of the suspension layer. Due to the effects on the dense layer, the separation of the two layers is supposed. Both higher turbulence and loss of the matrix should weaken the suspension before it reaches the settlement (Isssler, 1999).

In the end, we expect that the impact of the jet stream below the dams cause considerable energy dissipation. Heuberger (1952) also describes that downstream the constriction at station km 1.9 no powder avalanche effect could be observed. Another evidence that our theory is working, is reported by Skolaut (1997) from the WLV in Salzburg where a torrent braking measure of similar construction stopped a powder snow avalanche. Now our district bureau in Innsbruck tries to confirm the theory in cooperation with the BFW in Innsbruck by water tank experiments at the University of Innsbruck. The simulations with FIRE (Schaffhauser, 1997) and SAMOS AT (Herbert and others, 2007) support the expected effects of the concept. Based on the work of Kristín Martha Hákonardóttir and others (2001) we changed the shape of the avalanche braking structure in km 2.2.

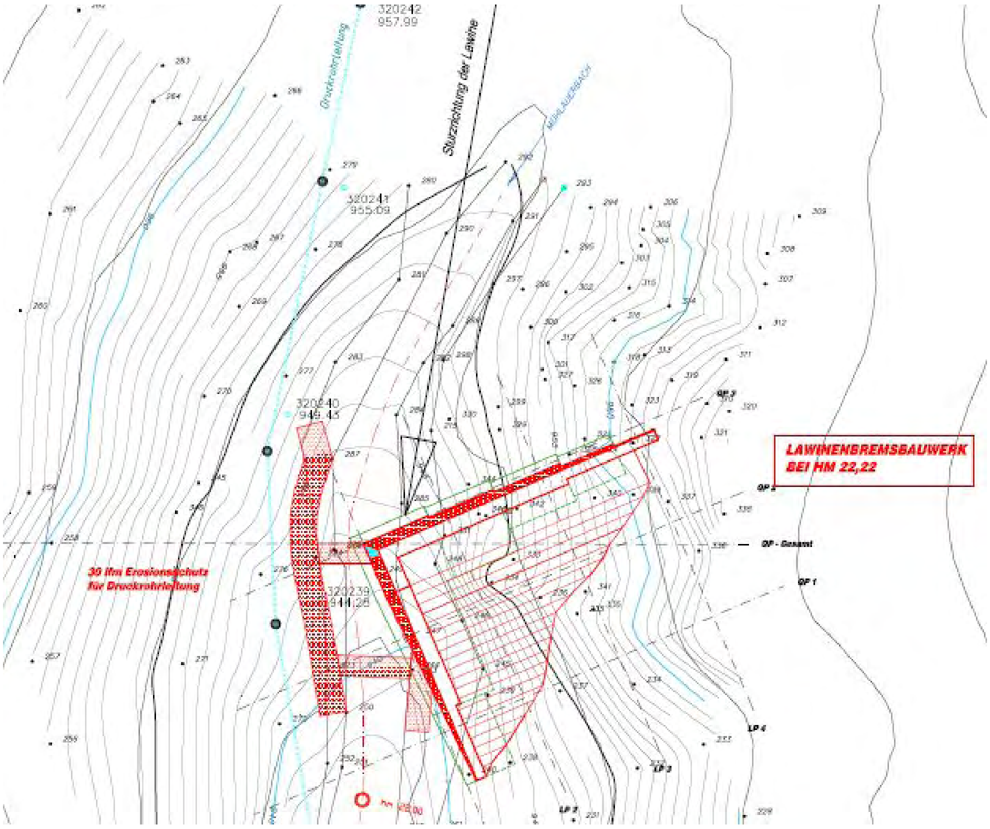

Figure 3 Plan view of the braking structure at station km 2.2 (Pittracher/WLV. 2007).

According to the proven effect of mounds in the run out of avalanches (Hákonardóttir and others, 2003) we decided to build a construction which closes 50 % of the cross section of the canyon at station km 2.2. Built of concrete a 20 m high wall propped up by an earth dam at the downstream side closes the left side of the gorge completely. Based on the result of 3 numerical simulations with 3 avalanche of different size by SAMOS AT (Herbert and others, 2007) we decided to apply to the authorities for the approval to build the upper braking construction as a mound. All three avalanche scenarios show that the mound in km 2.2 reduces the speed of the avalanche significantly.

9. CONSEQUENCE ON RISK PLANNING IN MÜHLAU/INNSBRUCK

The calculation with FIRE und SAMOS AT shows an influence of the braking system on the velocity of all three scenarios. These scenarios consider avalanches from separate starting zones with masses of 120.000 m³, 130.000 m³ and 250.000 m³ (Schellander, 2004). In the model, the braking dam at station km 2,2 reduces the velocity of the flowing avalanche depending on the mass. The braking effect also grows with rising mass upstream of the dam in km 1,7. The model shows that both dams cause a reduction of speed at the peripheral parts of the settlement from 20 – 30 m/s without measures to 0 – 5 m/s with measures. The behaviour of the powder avalanches is influenced in a quite similar way.

In consideration of these results and the experience of 1951 the red hazard zone, can be reduced to the valley within the settled are. The yellow hazard zone affects only the peripheral zone of the settlement. The residential area will be expected to be secure regarding the avalanche with a return period of 150 years. Of course, a remaining risk will continue to exist in case of big avalanches with a return period of more than 150 years or the pre-filling of the braking dams. In this case, the avalanche commission would still have to evacuate people, but the return period of these evacuations is so long that this measure will be acceptable for the inhabitants.

Braking measures should occasionally be preferred to supporting structures in the starting zones because of their big advantage with regard to sustainability. Unfortunately, they can only be erected depending on the suitable shape of path and run-out.

10. CONCLUSION

Though the provided simulation tools are a big advance to understand the effects of protection measures in general, they only can show tendencies of the influence since the grid for the calculation is too large meshed and the database is to rough. According to these facts, during the planning of the braking systems several questions emerged:

- How is the flowing behaviour of dense layer and suspensions layer influenced in detail by catch dams and braking systems with different permeability?
- Is there a change of the snow quality after the avalanche passing protection measures and would this have an effect on the suspension layer?
- Is there an influence of the surrounding terrain on the effect of the mitigation measures?

In addition, it would be necessary to unveil what happens to the suspension layer when it is separated from its matrix, the dense layer. Theses studies should be extended to describe the behaviour of avalanches amid a heavily built up settlement.

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Avalanche risk along a 420 kV transmission line in Iceland

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ABSTRACT

Two transmission lines between Fljótsdalur and Reyðarfjörður in northeast Iceland have been investigated concerning snow avalanche hazard. As a basis for the calculations of the return periods of the avalanches, weather and snow analyses are performed for the surrounding weather observational stations. A model analysis is performed for some weather situations with a high avalanche risk in order to calculate the snow drift in the mountainous areas around the transmission lines.

Run out distances for avalanche profiles passing the masts are performed using GIS systems and different avalanche runout programs. Level of probability of simultaneous failure for both the lines is specified less than approximately 6.5×10^{-4} per year. For each mast, the risk level must be considerable lower than for the transmission lines as a whole, and this question has been treated statistically in this paper. To attain the specified safety goal a total sum of 82 masts have to be designed to withstand loads from avalanches. In addition, some other masts might be influenced by avalanches passing under the lines between masts.

For the 82 exposed masts, the avalanche impact forces are calculated due to the accepted risk level for the transmission lines and the forces are also calculated for the cables exposed to avalanches. A discussion of possible different types of avalanche masts and other means of protective measures are discussed related to protective solutions in Iceland and Norway.

1. INTRODUCTION

IceGrid, the owner of these transmission lines, has requested, due to the risk of snow avalanches at several places, that the hazard might be investigated, making it possible to design the lines in accordance with an acceptable risk.

IceGrid made very high demands for the security of these lines to minimize the probability that snow avalanches will interrupt transmission through both lines. These lines are the only lines with high enough capacity to run the aluminum smelter in Reyðarfjörður. The terrain where the transmission lines were planned had therefore to be closely investigated and mapped according to avalanches. In addition, the snow conditions and the weather conditions had to be analyzed.

2. CALCULATION OF RISK AND DESIGN LOAD

The risk and design load are depending on the weather, climate and snow conditions along the line in addition to the run out distance for an extreme avalanche. The lines are passing through different valleys in a mountainous area, see Fig. 1.

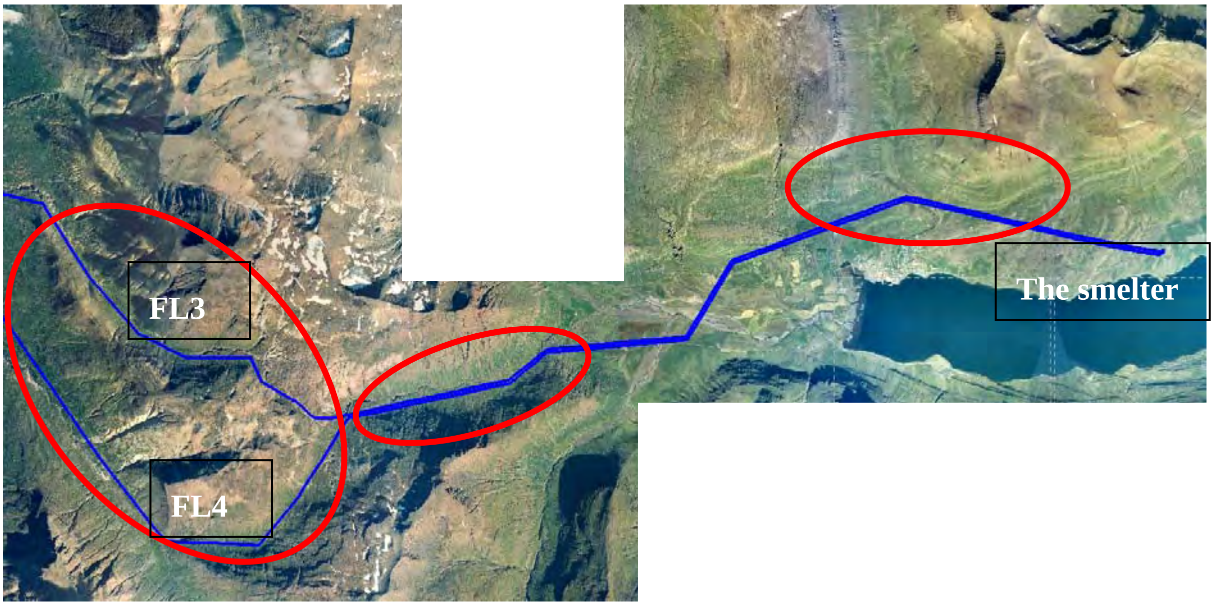


Figure 1. Aerial photo of the power line routes (blue lines). Red ellipses show three of four observation sites.

2.1 Climate and snow conditions

Historically, a 66-kV transmission line passing the NE side of Hallsteinsdalur was hit by an avalanche in 1982 and a few masts were damaged. This resulted in relocation to the SW side of the valley where the masts have stood since without damage. The intended location of the new line on the south side of Áreyjadalur, however, seems advantageous compared to the north side of the valley when the prevailing frequency of precipitation accompanying winds from NE directions is regarded, as Figure 2 shows. Such conditions are optimal for avalanches.

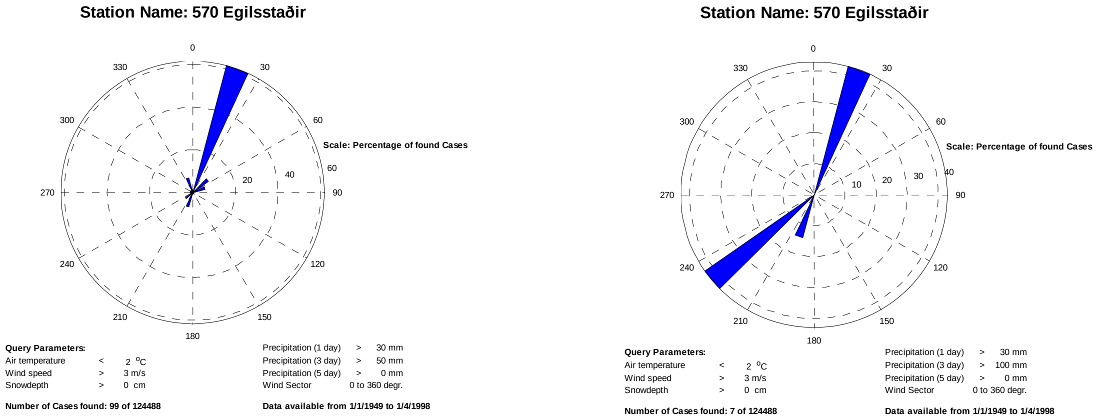
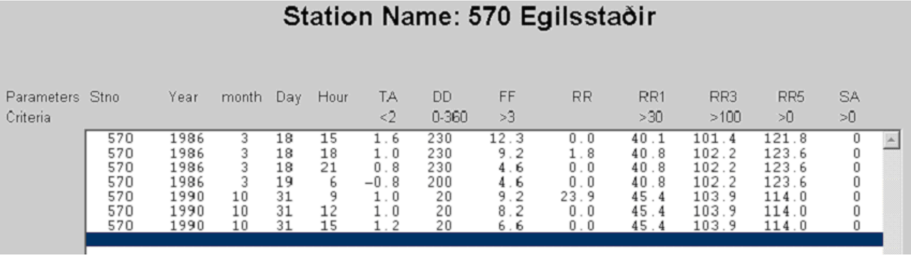


Figure 2. Left drawing gives wind dominating directions during snowfall in the mountains, right drawing gives wind directions with extreme snowfall in the mountains; meteorological statistics for Egilsstaðir during the period 1949–1998, data from the Icelandic Meteorological Office (IMO).

The left drawing in Figure 2 shows that the dominating wind direction accompanied by intense snow precipitation is from NNE, and the transmission lines in Áreyjadalur will be located at the side that presents less probability of snow avalanches.

The right drawing in Fig. 2 shows examples of conditions with high snowfall in the mountains concomitant to winds. Only seven incidences are found in nearly 125,000 records over a 50-year period. When these records are examined more closely, it is seen that there are only two separate events in question, the first is from 1986 and the second from 1990. These two situations took place from opposite wind directions; see further in Figure 3. Both of these two incidences are further analyzed in a weather report, see Ólafsson (2004).



Station Name: 570 Egilsstaðir

Parameters	Stno	Year	month	Day	Hour	TA	DD	FF	RR	RR1	RR3	RR5	SA
Criteria						<2	0-360	>3		>30	>100	>0	>0
	570	1986	3	18	15	1.6	230	12.3	0.0	40.1	101.4	121.8	0
	570	1986	3	18	18	1.0	230	9.2	1.8	40.8	102.2	123.6	0
	570	1986	3	18	21	0.8	230	4.6	0.0	40.8	102.2	123.6	0
	570	1986	3	19	6	-0.8	200	4.6	0.0	40.8	102.2	123.6	0
	570	1990	10	31	9	1.0	20	9.2	23.9	45.4	103.9	114.0	0
	570	1990	10	31	12	1.0	20	8.2	0.0	45.4	103.9	114.0	0
	570	1990	10	31	15	1.2	20	6.6	0.0	45.4	103.9	114.0	0

Figure 3. Data on conditions presenting a high probability of major avalanches. FF is wind speed in m/s, RR1, RR3 and RR5 is precipitation in mm in a period of one day, three days and five days.

The climate in this area is similar to that at Stryn on the west coast of Norway, where the Norwegian Geotechnical Institute (NGI) has an avalanche research station. On the other hand, the mountains around the transmission line corridor are considerably lower (~1.100 m) than the mountains in Stryn (~1.600 m), which means that the proportion of wet avalanches by Fljótsdalslínur 3 and 4 will be higher than in Stryn. In Stryn (Ryggfonn avalanche), NGI has recorded avalanche pressures and impact on a mast for many years in cooperation with Statnett (the Norwegian owner of most electrical power lines), and results from these measurements are used as input in the calculations.

Haraldur Ólafsson (2004) did a research on available weather data which spans the last 50 years. Extreme weather conditions, which normally would accumulate snow in starting zones in the observation area, were studied and ten of them were simulated in MM5 computer simulation software. The simulation was carried out on a 300 m to 900 m grid. The result of the simulations confirmed our research about snow accumulation and precipitation in the area.

ORION Consulting (2004) performed more detailed study of the wind conditions in the starting zones and along the transmission lines. Their studies are based on several of the weather situations that Ólafsson presented. Drifting snow and snow accumulation can be interpreted from the gradient in the wind. The result gave good indication on how the conditions would be along the line and in the starting zones.

2.2 Calculation of runout distances and velocity

An Icelandic topographical runout-distance model (alfa/beta-model) (Jóhannesson, 1998), build on an Icelandic data set, was used as well as PCM (Perla and others, 1980) and NIS (Norem and others 1987) which is built on results from Ryggfonn in Norway. Due to differences in those two dynamical models calculated velocity did vary between them in many avalanche paths. The higher velocity was always chosen due to the high safety requirements.

The Icelandic alfa/beta-model provides an approximation for runout distances with annual probabilities of about 1x10^{-2} .

2.3 Security for the transmission lines

The two transmission lines pass four different avalanche areas from the power plant to the aluminum smelter and the transmission towers in the avalanche areas will be designed to tolerate avalanches with given return periods and given dimensions. Three of them, where the lines run parallel; near the power plant in Fljótsdalur, in Áreyjadalur and above Reyðarfjörður village, are assumed to have the same acceptable probability of damage of an individual tower 0.5x10^{-4} pr. year. The fourth area, between Skriðdalur and Áreyjadalur in Þórudalur and Hallsteinsdalur, is assumed to have the probability of 1.0 x10^{-4} pr. year.

The term damaged is defined as tower hit by an avalanche which acts with higher load than the design load. It was found that the probability that both of the lines were damaged at the same time: 0.75x10^{-4} for the first area, 2.5 x10^{-4} for the second area and 2.25 x10^{-4} for the third area. The fourth area, were the lines run in two different valleys, the probability is calculated to 1.0 x10^{-4}. In this case it is not considered that the two lines are entirely independent as the highest risk is connected with the same extreme event which leads to a probability of simultaneous damage to both the lines is higher than the product of the probabilities.

When these results are added together the conclusion is that the probability that both lines are damaged in the same event is less than 6.5 x10^{-4}.

2.4 Determination of design load

Snow avalanches

Design load from the snow avalanche was calculated for the towers and the conductors. Some of the research data from Ryggfonn, Norway, was taken into account in this work. Force from an avalanche on an obstacle is calculated from:

$$F = C \times p \times A$$

where:

> *F:* force (N), *A:* projected frontal area of an obstacle (m²), *C:* unitless drag coefficient, *p:* dynamic pressure of free stream flow (N/m² or Pa),

Dynamic pressure of free stream flow (DPOFSF) is calculated according to following equation; it applies over the thickness of dense cores in an avalanche.

$$p_1 = \frac{\rho_1 \times v_1^2}{2}$$

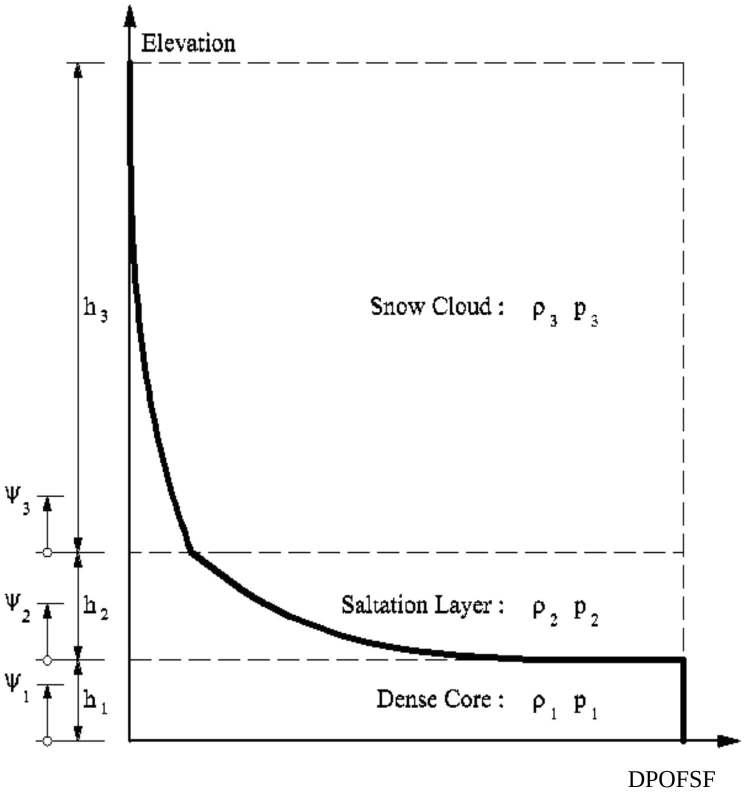


Figure 4. Schematic diagram of the DPOFSF distribution in a snow avalanche.

2.4.1 Drag coefficient and point load

The authors have chosen C=2.0 for rectangular form and C=1.5 for circular form for dense core. For the powder- and saltation layers, wind standards should be applied.

It is well known that avalanches often bring with them a lot of other material than snow. The authors found it reasonable to calculate the load due to stones at least 50 cm in diameter. It was also assumed that the design velocity of such stones or boulders is somewhat lower than the velocity of the avalanche (*i.e.* speed of the tongue) and therefore probably traveling in the rear section or the tail of the avalanche.

2.4.2 Snow thickness on ground

The authors estimated the snow cover to be in the range of 2.0 to 3.0 m at tower location. In addition to this snow cover height of debris from old avalanches was taken into account. Here it was assumed to be in the range 1.0 to 2.0 m. It was also assumed that the height of an avalanche is in the range of 2.0 to 3.0 m. When adding all these heights the height of snow cover and dense core of an avalanche can be in the range from 5.0 to 8.0 m.

The foundation building started in 2005 and was continued in 2006. Erection of the avalanche towers began the fall 2006 and the lines are now in use.

3. CONCLUSIONS

Altogether 82 masts had to be supported to withstand avalanche pressure, and due to calculated avalanche forces for each mast one had to decide what type of mast and foundation was needed. Different solutions might be possible like deflecting walls, breaking mounds, dams or different types of “avalanche” masts. Different types of “avalanche” masts are presented in Fig. 4, and the “Y” shaped Canadian type of mast was chosen. This type has been used at the research field at Strynefjell, Norway, and has only been broken down with higher pressures than calculated for the lines passing the mountains west of Reyðarfjörður.

Figure 4. Different types of “avalanche” masts, to the left the French type used in Western Norway, in the middle a local type used in Western Norway and to the right the erection of one of the avalanche towers in Áreyjadalur (photo: Línuhönnun 2006).

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Simulation of snow drift as a tool for operational avalanche warning

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ABSTRACT

A new numerical approach is introduced as a tool for avalanche warning. Avalanches are mostly triggered by a critical rate of snow loading. The snow drift pattern on mount Grimming was computed. By examining the snow distribution, the potential avalanche fracture areas were identified. The results show the applicability of the new simulation method for operational avalanche warning.

1. INTRODUCTION

Up to now, the evaluation of avalanche danger depends on the knowledge of the properties of the snow cover, the available meteorological data and the interpretation of meteorological weather models. Following this approach it is possible to identify regional levels of avalanche danger, but the outcome is not sufficient for assessing the avalanche danger on small scales.

The determination of snow drift occurrences at critical local failure scars is limited by these common methods. Due to low visibility during snow storms it is not possible to evaluate the layering of the snow cover by visual monitoring. In fact, the avalanche professionals are aware of the existence of a critical snow layer, but it is very difficult to examine the amount of accumulated snow at potential avalanche fracture areas from the valley. The decision of avalanche commissions whether roads or ski trails should be closed because of avalanche danger is based on experience and the available data mentioned above.

In contrast to the current way of determine the critical snow load on slopes and potential fracture lines we introduce a new approach: Potential avalanches threatening roads, rail traffic or ski trails are determined by a new simulation tool.

Avalanches are mostly triggered by a critical snow load during storms. The numerical simulation of snow drift occurrences and precipitation provides an area-wide and time-dependent distribution of snow depth. Hence, potential avalanche fracture areas can be identified, supporting the local avalanche commissions and, respectively, the local avalanche warning services in decision making.

The numerical approach includes time-dependent geometries of the snow cover, time dependent weather data and complex particle transport phenomena. Additionally, the erosion and accumulation of snow particles leading to a deformation of the snow cover is determined by wall shear stress criteria. These deformations of the shape of the snow pack couple to the wind field and thus the flow is changed by the new geometry.

2. PHYSICAL CONCEPT OF SNOW DRIFT

Snow transport can be described as follows. If the wind shear exceeds a certain threshold grains will be entrained and set in motion. The so called fluid threshold (for reference see Bagnold, 1941) is given by

$$\tau_{c_e} = (A_e)^2 (\rho_P - \rho_a) g d_P .$$

ρ_P and ρ_a are the densities of the snow particles and air. Furthermore g denotes the standard acceleration due to gravity, d_P the snow particle diameter and A_e a dimensionless empirical parameter, which is a function of the particle shape and particle cohesion. The exact underlying mechanism which is responsible for the initiation of the snow drift process is not completely known. Following Bagnold, Anderson and Haff (Anderson and Haff, 1991) estimated that the number of entrained grains per unit time and unit area depends linearly on the excess shear stress

$$\frac{\partial N_e}{\partial t} = \xi\left(\tau_a - \tau_{c_e}\right),$$

where τ_a denotes the air induced shear stress. ξ is an empirical constant with the dimensions of (force x time)$^{-1}$. The entrained particles are easily accelerated by the wind because of their small mass and diameter. Already entrained grains contribute to the wind shear, *i.e.* they reduce the threshold. In addition, the wind influences the heights of the transport modes, *e.g.* the saltation layer height increases with increasing wind speed (for reference see Owen, 1964). Therefore, a higher amount of snow can be transported and more grains are entrained per unit of time. Due to the interaction between grains and wind the wind field is modified. However, if the wind shear is below a second threshold, the impact threshold, snow will be accumulated

$$\tau_{c_i} = (A_i)^2 (\rho_P - \rho_a) g d_P ,$$

where A_i is again a dimensionless empirical parameter. Grains whose motion is directed towards the snow pack are deposited. The mass flux to the snow pack can be obtained by the change of volume fraction of the snow in an arbitrary control volume. The change of mass inside the control volume has to be equal to the mass flux through the faces of the control volume by the principle of mass conservation.

Finally, it should be mentioned that only a certain amount of grains can be transported by the wind. This leads to deposition where the volume fraction exceeds a third threshold, the saturation volume fraction. In all cases, gravity acts as a body force. Due to the slope angle of the snow pack the snow grains are affected by a downhill-slope force. Since the shear stress thresholds mentioned above are only valid for flat plains a modification, which additionally incorporates the slope angle, is applied.

The transport processes discussed above change the shape of the snow pack. In deposition zones, the snow cover grows and thus the new shape influences the local velocity field. In addition, in erosion zones a reversed process takes place. Hence, due to the modification of the wind field, the zones change with time and depend on the shape of the snow pack.

3. A MIXTURE MODEL APPROACH

The mixture model approach is based on the balance equations of a mixture for interpenetrating phases, where the phases are allowed to move with different velocities (Schneiderbauer, 2006). In the model we consider three different phases:

- Air
- Drifting snow
- Precipitation.

Air acts as carrier phase and is observed as a wind field or primary phase. The transported grains are modelled by the secondary phases, which are observed as drifting snow. The saltation and the suspension layers are not separated as in Gauer (1999), but they are given by the behavior of the snow phase due to the flow field of air and due to the influence of gravity. This snow drift model is fundamentally based on Bagnold’s impact and erosion criteria (Bagnold, 1941), which distinguish between zones of erosion and zones of deposition. Additional empirical relationships, which are obtained from several measurements (for reference see, *e.g.*, Naaim-Bouvet *et al*., 2001), such as the height of the saltation layer, which influences the saturation volume fractions in the finite control volumes, are of vital importance for computational calculations.

Precipitation is included by an additional secondary phase to incorporate the different physical properties of precipitating snow and drifting snow. In especially different grain sizes, densities and particle shapes are placed in the snow drift simulation.

As mentioned above, in our mixture model approach, the saltation and suspension layer are not treated separately in different calculation domains. The saltation layer is rather modelled by volume fractions of the snow phase in the volume cells adjacent to the snow cover. The mass fluxes are obtained from the flow field of the snow phase. Bagnold's “stick-slip” criteria are used to distinguish between zones of deposition and aerodynamic entrainment. To avoid unphysical effects in the flow field we introduced a saturation volume fraction. The deformations of the snow cover are predefined by the mass fluxes and the unit surface normals. A dynamic mesh model will remesh the domain if yield criteria are exceeded.

4. RESULTS

Snow drift distributions of fracture zones are very important for operational avalanche warning. In practice, the assessment of those zones is a major problem for the present avalanche warning systems.

The boundary conditions for the wind field computation are provided by the local weather model Inca (Haiden *et al*., 2007).

In Figure 1 the resulting snow drift pattern is shown. White areas correspond to additional snow loads. The dashed circle indicates a chute, where a road is threatened by avalanches. The results show a high amount of accumulated snow in that area, which is in agreement with observations in reality. The avalanche alert service of Styria, Austria, observes the mountain channel from Figure 1 using radar measurements which is often pretty tricky during adverse weather periods.

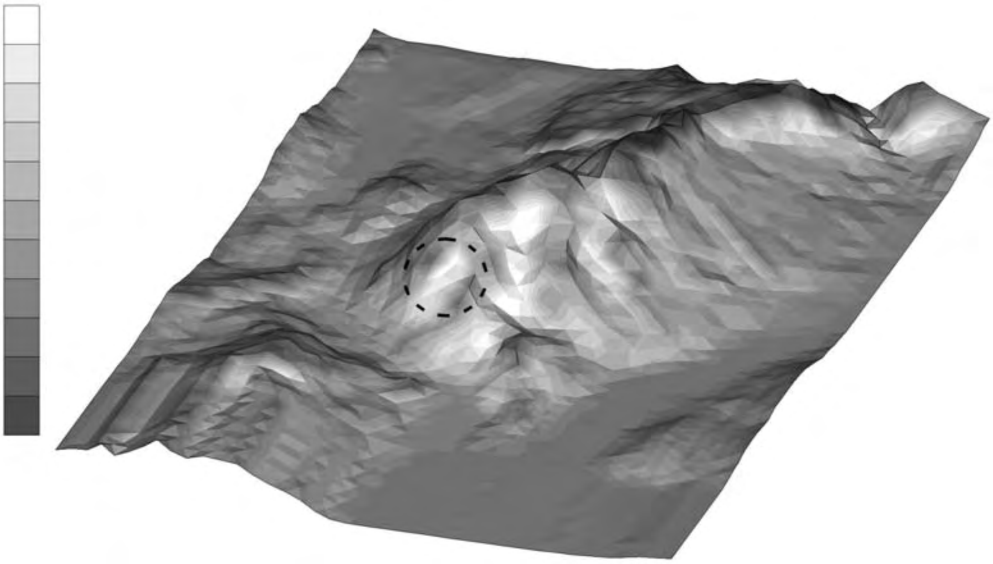

Figure 1 Snow distribution on mount Grimming. White corresponds to additional snow loads due to snow drift and dark gray to erosion zones.

5. CONCLUSIONS

The results of the snow drift simulations including precipitation show the applicability of the new simulation method for operational avalanche warning. Compared to punctual snow depth measurements, the numerical simulation provides an area-wide distribution of the snow depth. Therefore, snow drift simulations provide important additional information for the local avalanche commissions. In terms of risk management, the threat by avalanches can be identified in-time because the model simulated forecasts: *E.g.* For traffic routes closing. Finally, the residual risk of avalanche barriers can be identified by determining the dead load of the snow cover in potential avalanche fracture areas.

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The design of avalanche protection dams based on new design criteria: Three different case studies

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ABSTRACT

We report on three different snow avalanche defence structures designed using new and improved design criteria based on shallow-layer theory for granular flows. Two rows of braking mounds upstream of a catching dam in the Drangagil area in Neskaupstaður, eastern Iceland, were designed by VST Consulting engineers Ltd. in 1997−1999 and built in 2002. The geometry of the mounds resembles small dams. The two rows are spaced such that an avalanche can be launched ballistically over the upper row of mounds and will land upstream of the lower row. A deflecting dam at Bíldudalur, on the Westfjords peninsula in Iceland, was designed by VST in 2005 and is scheduled to be built in 2008. The height of the dam was determined based on the shallow-layer theory. The confined geometry of the gully upstream of the deflecting dam creates a thick, low Froude number avalanche stream hitting the dam. The shallow-layer theory predicts that a somewhat higher dam is needed to deflect the design avalanche than the traditional design methods do. A splitter, or two short deflecting dams, was designed by VST in 2005 and built in 2007 above the switchgear house of the Kárahnjúkar hydroelectric plant in Fljótsdalur, eastern Iceland. The shallow-layer theory predicted that a considerably lower dam would fully deflect the design avalanche than traditional design methods predicted.

1. INTRODUCTION

Recent experimental and theoretical work, combined with field studies on the interaction between rapid shallow granular flows, such as snow avalanches, and dams has led to an improved understanding of the dynamics of the interaction. The accumulated knowledge has resulted in improved criteria for the design of avalanche protection dams in Iceland; first braking mounds (Jóhannesson and Hákonardóttir, 2003) and more recently also catching and deflecting dams (SATSIE, 2006).

The improved theoretical framework is derived from shallow-water theory. It provides a consistent way of describing different flow phenomena, such as shocks occurring in the interaction. The shallow-layer theory can furthermore be used to predict important aspects in the design of dams, such as: the necessary height of a dam to fully deflect or stop an avalanche; the height of a dam for an avalanche to be launched ballistically over the dam; and the maximum allowed deflecting angle of a deflecting dam. We present and discuss the difference between the traditional and the shallow-layer theory for three different protection dams which have been built or are under construction in Iceland.

2. THEORY

The traditional design of dams to deflect or stop snow avalanches has been based on simple considerations of the energy of a point-mass in the flow (Salm and others, 1990; McClung and Schaerer, 1993). The required height of a catching- or a deflecting dam has traditionally been determined based on the equation

$$H_{trad} = \frac{(u \sin \gamma)^2}{\lambda 2g} + h_s + h_1, \quad \text{Equation 1}$$

where H_{trad} is the necessary height of the dam, γ is the deflecting angle of the dam, u is the speed of the avalanche, g is gravitational acceleration, h_s is the thickness of the snow cover, h_1 is the thickness of the dense core of the avalanche, and λ is a dimensionless constant accounting for dissipation of energy through the impact of the avalanche with the dam. It is usually chosen in the range 1–2 (Salm and others, 1990). Values towards the upper part of the range are in particluar selected for catching dams with a steep upstream face where large energy dissipation may be expected through the impact of the avalance. The value is usually chosen equal or close to 1 for deflecting dams due to less potential for energy dissipation.

The point-mass model cannot be used to describe flow phenomena such as jumps between flow states or shocks, which can occur in the interaction of a dense rapid granular avalanche with an obstacle (Savage, 1979; Jóhannesson, 2001; Gray and others, 2003; Hákonardóttir and Hogg, 2005; Baillifard, 2007). A theoretical framework based on the shallow-water theory provides a way to consistently describe such flows (Gray and others, 2003; Hákonardóttir and Hogg, 2005; Baillifard, 2007). The theory has been applied to formulate new design criteria for dams and braking mounds (SATSIE, 2006) and the main results are briefly summarised below.

The theory predicts the necessary height of a dam, here termed critical dam height, h_{cr}, such that a shock may form upstream of the dam by:

$$h_{cr} = h_1 \left[1/k + \tfrac{1}{2} (k\mathrm{Fr} \sin\gamma)^2 - {}^{3}/_{2} (\mathrm{Fr} \sin\gamma)^{2/3}\right] + h_s, \quad \text{Equation 2}$$

where k is a dimensionless constant accounting for dissipation of momentum in the direction normal to the dam in the initial interaction with the dam, before a shock has formed upstream of the dam. The guidelines (SATSIE, 2006) suggest using a value of k as a function of the steepness of the upstream dam face, with $k = 0.75$ for steep dams, based on experimental results (Hákonardóttir, 2004; Baillifard, 2007) and observations of snow avalanches hitting dams (see SATSIE, 2006). The Froude number of the flow, Fr, is defined by:

$$\mathrm{Fr} = \frac{u}{\sqrt{g \cos \xi \, h_1}}, \quad \text{Equation 3}$$

where ξ is the slope of the terrain. The Froude number of the dense core of a natural dry-snow avalanche can be expected to be in the range 5–10 (Issler, 2003) or in the lower end of the range as suggested by Sovilla and others (2008).

If the dam is lower than the critical dam height, h_{cr} the flow will be launched ballistically over the obstacle in a supercritical flow state (Hákonardóttir and others, 2003). If the dam is higher than the critical dam height a bore will form upstream of the dam and, in the case of a catching dam, travel upstream into the oncoming avalanche stream. Parts of the avalanche may overflow the dam as the flow front hits the dam. The height needed such that none of the avalanche front overflows the dam is given by:

$$H_{cr} = h_1\,[1/k + \tfrac{1}{2}(k\,\mathrm{Fr}\sin\gamma)^2 - \tfrac{1}{2}(\mathrm{Fr}\sin\gamma)^{2/3}] + h_s, \qquad \text{Equation 4}$$

if effects of pressure impulse are neglected (Peregrine, 2003).

The depth of the bore formed upstream of a catching dam ($\gamma = 90°$ in Equation 4) is solved from:

$$\mathrm{Fr} = \frac{h_2}{h_1}\sqrt{\frac{1}{2}\left(1 - \frac{1}{h_2/h_1} - \left(\frac{1}{h_2/h_1}\right)^2 + \left(\frac{1}{h_2/h_1}\right)^3\right)}. \qquad \text{Equation 5}$$

If the deflecting angle of a deflecting dam is less than a certain maximum deflecting angle a stationary oblique shock is formed upstream of the dam. The depth of the shock is given by:

$$h_2 = h_1\frac{\tan\beta}{\tan(\beta-\gamma)}, \qquad \text{Equation 6}$$

where the shock angle β is given by:

$$\tan\gamma = \frac{4\sin\beta\cos\beta(1-\mathrm{Fr}^2\sin^2\beta)}{-3+4\cos^2\beta(1-\mathrm{Fr}^2\sin^2\beta)-\sqrt{1+8\mathrm{Fr}^2\sin^2\beta}}, \qquad \text{Equation 7}$$

The guidelines (SATSIE, 2006) give exact and approximate solutions to Equations 5 and 6.

The final dam height needs to be larger than the shock depth and the critical dam height needed for a shock to form such that none of the avalanche overflows the dam:

$$H = \max(H_{cr}; h_2) + h_s. \qquad \text{Equation 8}$$

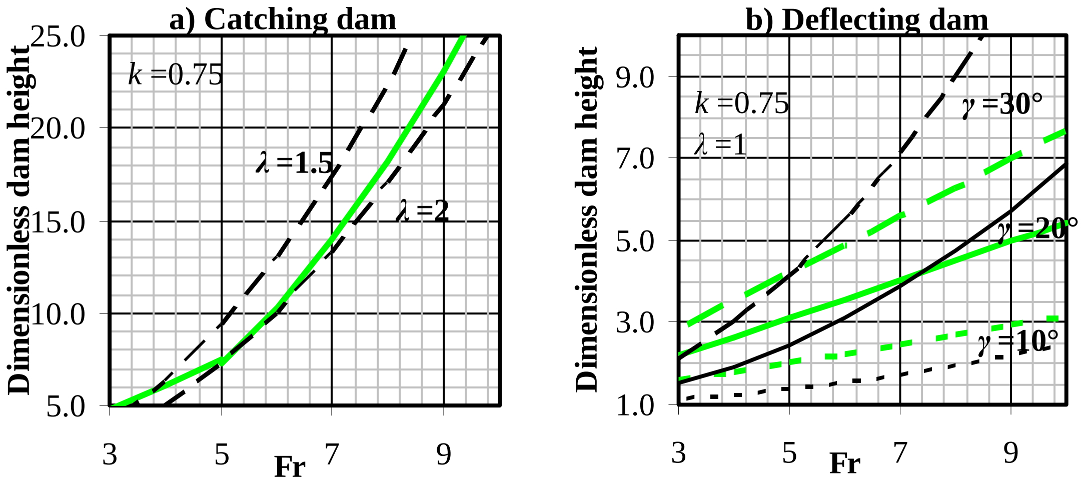

Figure 1 The dimensionless dam height, H/h_1 as a function of the Froude number for the shallow-layer theory (green lines, Equation 8) and the traditional design (black lines, Equation 1) for steep **a)** catching dams and **b)** deflecting dams with $\gamma = 10°$, 20° and 30°.

A comparison of predicted dam heights between the traditional design and the design based on the shallow-layer equations is shown in Figure 1 for dams with a steep upstream face. From the Figure, one notes that the shallow-layer theory results in similar heights of steep catching dams as the traditional theory ($\lambda \approx 2$). In the case of deflecting dams at low deflecting angles ($\gamma = 10°$) the shallow-layer theory predicts higher dams than the traditional design and at large deflecting angles ($\gamma = 30°$) the dams become lower. One further notes that at low Froude numbers, the theory predicts higher dams than the traditional design.

3. RESULTS AND DISCUSSION

3.1 Braking mounds below Drangagil in Neskaupstaður

Neskaupstaður is located in eastern Iceland. A large part of the residential area is threatened by avalanches from several well defined avalanche paths. A large avalanche from Drangagil reached into the current residential area in 1894. The design of avalanche defence structures for the Drangagil area was initiated in 1997 and they were built in 2002 (Sigurðsson and others, 1998).

A total of 13 mounds were placed in two staggered rows in front of a catching dam to reduce the speed of an avalanche which would finally be arrested by the catching dam, see Figure 2. The geometry of the mounds resembles small dams. The mounds have a steep front facing the mountain, are 10 m high and each mound is approximately 10−12 m wide at the top.

Figure 2 Braking mounds and catching dam in the Drangagil area in August 2002.

The design avalanche had a return period of 1000 years with a 3 m thick dense core, a speed of 38 m s^{-1}, and thus a Froude number of 7 upon hitting the upper row of mounds. The shallow-layer theory predicts that a dam with an effective height of 32 m is needed such that a shock will form upstream of the mounds (h_{cr} given by Equation 2). The theory therefore predicts that the flow will be launched in a supercritical flow state over the mounds. Parts of the avalanche will be deflected between the mounds, also in a supercritical flow state. The two rows of mounds were therefore spaced such that an avalanche could be launched ballistically over the first row of mounds and would land upstream of the lower row and of the catching dam downstream of the mounds. With this design it is guaranteed that both rows of braking mounds will effectively participate in dissipating energy from the avalanche before it hits the downstream catching dam.

The new design guidelines (Jóhannesson and Hákonardóttir, 2003) also lead to a mound geometry which was quite different from the more common cylindrically shaped mounds.

3.2 Deflecting dam below Búðargil in Bíldudalur

The mountain Bíldudalsfjall on the Westfjords peninsula, rises up to 460 m a.s.l. above the town Bíldudalur. The gully Búðargil is deep and steep and cuts Bíldudalsfjall above the north part of the settlement. A large part of the residential area sits on the alluvial fan underneath the gully. A few snow avalanches down the gully have been recorded since the town's settlement along with more frequent events of waterfloods, mudslides and slushflows.

Proposed defence structures for the area were designed in 2005 and consist of a 300 m long deflecting dam, to deflect snow avalanches to the north away from the more densly populated part of town directly below the gully and into the ocean through a less populated part of town (houses in this area which will be abandoned during winter) as shown in Figure 3 (Sigurðsson and others, 2005). The dam is highest 20 m above ground level close to the mouth of the gully and there its deflecting angle is 22°. The height of the dam decreases gradually towards the settlement. The north bank of the avalanche channel was enhanced on a 20 m stretch at the downstream end of the channel in order to prevent avalanches from spreading out to the north. The dam is scheduled to be built in 2008.

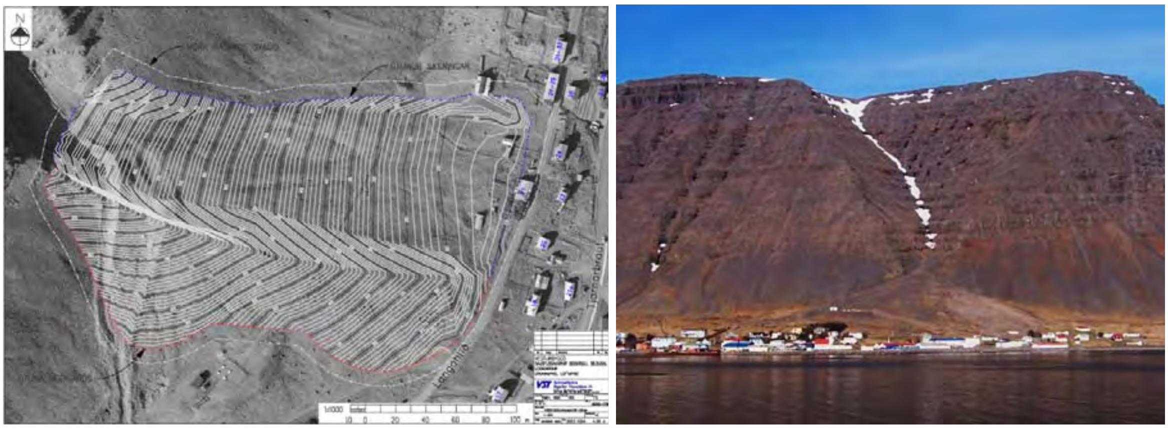

Figure 3 A contour map of the Bíldudalur deflecting dam superimposed on an area photo and a photograph looking up into Búðargil.

The height of the dam was determined based on the shallow-layer theory. The confined geometry of the gully leading to the deflecting dam creates a thick, fast flowing avalanche stream out of the gully. The design avalanche had a return period of 1000 years with a 5 m thick dense core flowing at 38 m s^{-1} as it flows out of the gully ($Fr = 6$). The shallow-layer theory predicts that a stationary oblique shock with a thickness of 18 m will form at an angle of 10° to the dam in the interaction. It was additionally assumed that the snowcover on the ground was 3 m deep, reducing the dams´ effective height. A dam with a maximum height of 21 m was therefore predicted by the theory, compared with an 18 m high dam using the traditional design methods.

3.3 Splitter in Fljótsdalur

The switchgear house for the Kárahnjúkar hydroelectric plant sits under the mountain Teigsbjarg in southern Fljótsdalur. The mountain stretches up to 500 m a.s.l. The switchgear house is positioned in a 10° slope only 60 m from the steep hill. Under normal conditions there is not much snow accumulation in the mountainside, but occasionally large amounts of snow can drift from the flat mountain top into a small bowl and cause potential avalanche conditions.

People will not be based permanently in the switchgear building. The design of the defence measures is therefore based on fulfilling strong requirements for operational safety of the powerlines. To meet these requirements, the defences are designed to prevent an avalanche with a 10 000 year return period from damaging the building and the powerlines downstream.

A triangularly shaped dam, here referred to as a splitter, was designed by VST in 2005 and built in 2007, see Figure 4. The splitter is designed to split avalanches heading towards the building and deflect them to either side of the house. The splitter is positioned close to the switchgear house and reaches as high up into the hillside as possible in order to keep the size of the structure down. All three sides of the splitter are steep or almost vertical. The splitter is 60 m long and 9 m high closest to the slope. Its height increases to 13.5 m above the ground on a 15 m long stretch.

Figure 4 The splitter above the switchgear house in Fljótsdalur, during construction.

The technical avalanche design was based on the shallow-layer theory. The design avalanche had an estimated thickness of 1.5 m and speed of 35 m s^{-1}, with a Froude number of 9 where it would hit the splitter at an angle of 27°. The shallow-layer theory predicts that an oblique shock with a thickness of 10 m will form at an angle of 6° to the dam in the interaction. It is additionally assumed that the snow on the ground is 3 m deep, reducing the dams´ effective height. A dam with a maximum height of 13 m is therefore predicted by the theory while traditional design would lead to a 17.5 m high dam.

4. CONCLUSIONS

The shallow-layer theory provides a consistent means of describing the physics of the avalanche flow. For the three cases presented above the use of the shallow-layer theory has lead to a somewhat different dam design from the traditional design methods. The two deflecting dams are examples of dams that are both higher and lower than the traditional design predicts. A higher dam was needed for the thick lower Froude number avalanche in Bíldudalur and a lower dam was predicted for the thinner higher Froude number flow in Fljótsdalur. The shallow-layer theory further provides an explanation why one expects avalanches to be launched ballistically over the braking mounds in Neskaupstaður and not be deflected around them. It also identifies the important mechanisms leading to energy dissipation and thus an optimal geometry of the mounds.

The maximum deflecting angle of a deflecting dam has not been discussed but is an important by-product of the theory. The theory also has the potential to be used to estimate spreading of an avalanche downstream of a deflecting dam (Hogg and others, 2005).

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Snow drift measures as protection against snow avalanches in Iceland

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ABSTRACT

Snow drift measures have been proposed as a part of a protection plan above the avalanche prone Urðir area in Patreksfjörður in western Iceland. The appraisal study was conducted by VST Consulting engineers Ltd. in co-operation with a specialist on snow drift measures at the SLF in Switzerland. Snow drift is the main reason for snow accumulation in starting zones of avalanches in the area and the break up of cornices is known to have initiated some of the largest avalanches in the area. The flat mountain plateau above Patreksfjörður, coupled with the local weather conditions lead to feasible conditions for the construction of snow fences in order to reduce snow drift into the avalanche starting zone below the mountain plateau. Wind baffles at the edge of the plateau are additionally proposed to prevent the formation of large continuous cornices in the cliffs above the starting zone. High wind speeds on mountaintops in Iceland pose a problem to the design of the structures. The snow drift measures are considered to be extremely valuable to additionally reduce the avalanche risk in the complex situation of constructing suitable protection dams in the Urðir area. Snow drift measures have not yet been built as integrative avalanche protections above inhabited areas in Iceland and experience on optimal design and durability is thus lacking.

1. INTRODUCTION

The avalanche situation in the Urðir area above Patreksfjörður is severe. The risk associated with the avalanche path is one of the highest of such paths in Iceland creating an approximately 200 m wide gap in the village where the older part is to the east and a newer residential area to the west of the path. Residential houses have been built increasingly closer to the avalanche path and the mountainside making it hard and complicated to protect the area sufficiently with dams. The plateau above the mountain acts as a large catchment area for snow drift which accumulates in the starting zone below the plateau. The conditions at the mountaintop are favourable for constructing snow fences to prevent snow from drifting into the starting zone.

Snow drift measures have not been built in Iceland yet as snow avalanche defence measures above inhabited areas, they are however widely used as such elsewhere, *e.g.* in the Alps. The climatic conditions in Iceland differ somewhat from the Alps, especially regarding higher wind speeds on mountain tops. The high wind speeds could pose problems to durability and effectiveness of the structures.

Figure 1 A 4 m high snow drift fence in Switzerland with a porosity of 50 %. The structure consists of steel posts and wooden boards. The fence is founded using ground anchors. Note that the bottom gap helps to reduce snow deposits close to the fence.

Useful experience has been gained with snow fences in Iceland by the Icelandic road authority through constructions and experiments with different types of snow drift measures to prevent snow accumulation on roads (Kiernan, 1999; Kiernan and Jónsson, 2000; Auðunn Hálfdánarson and others, 2003). Snow fences have also been constructed in skiing areas in Iceland to collect drifting snow. Snow drift measures could additionally become a valuable and cost effective addition to the installation of snow supporting structures and protection dams in certain areas in Iceland, since a lot of avalanche problems are related to snow drift, not the least in the Westfjords, where the mountaintops are generally flat and the catchment areas for snow drift are large.

2. SNOW FENCES AND WIND BAFFLES

Snow fences are linear installations, which influence the wind flow in such a way that snow is accumulated or withheld downstream of the fence and not transported into the starting zone below (see Figure 1). It is important to foresee a sufficient distance between the fence and the starting zone. Typical setback distances vary between 15 and 20 times the fence height. The structures should be installed in areas of strong winds where one wind direction is dominant in order to function properly. The design of snow fences is in most countries based on design guidelines by Tabler (1991) which were updated in 2003 (Tabler, 2003). Icelandic guidelines for snow drift measures to prevent snow accumulations on roads were published in 2000 (Kiernan and Jónsson, 2000) based on the work of Tabler (1991) and experience gathered in Iceland.

Experience of using snow fences for avalanche protection is limited in Iceland to one experiment. The experiment was conducted in Auðbjargarstaðabrekka in northern Iceland during 1997−1999. The aim of the study was to test the effectiveness of the fences in preventing snow drift into the avalanche starting zone and thereby reducing the frequency of avalanches on the road below (Kiernan, 1999). The study showed that snow accumulation around the structures was similar to that predicted by Tabler (1991) and snow was not being eroded from the lee side of the fences due to high wind speeds. The design of the fences used in the test were however not optimal according to Tabler (2003) and Swiss experience (Margreth, 1997) and can therefore not be used to conclude on optimal design of the structures under Icelandic weather conditions.

Figure 2: Snow fences to the left and wind baffles to the right in use in Switzerland (photos: Stefan Margreth).

Nothing has been written about the design of wind baffles for Icelandic conditions. Such structures consist of one or two cross-shaped boards with one or two posts and are widely used elsewhere to break up large continuous cornices or to separate avalanche starting zones (see Figure 2). A wind baffle forms a discontinuity in the snow distribution by increased snow erosion around the structure. The snow erosion is caused by an increase in the wind speed in the vicinity of the baffle and the effectiveness of the baffle is not affected by the exact wind direction. If several wind baffles are built side by side the formation of a large continues cornice can be prevented.

One of the biggest challenges in the use of snow drift measures in Iceland is designing durable structures, especially when integrating such structures into avalanche protection plans for inhabited areas. The uncommonly high wind speed and sudden changes in wind direction on mountaintops in Iceland might also affect the optimal design of the structures and pose problems regarding snow erosion on the lee side of the structures. Complicated wind patterns on mountaintops could be modeled with high resolution computer simulations in order to evaluate the possibilities of installing useful snow fences, such as was done in the Hafnarhyrna starting zone in Siglufjörður in northern Iceland (Þórðarson and Jónsson, 2005).

3. SNOW DRIFT MEASURES ABOVE PATREKSFJÖRÐUR

The town of Patreksfjörður is located on the Westfjords peninsula. The town sits under the mountain Brellur which rises up to 400−500 m a.s.l. The avalanche prone area Urðir is located above the harbour (see Figure 3). The main starting zone for the avalanches is a relatively shallow but wide depression at 200−340 m a.s.l. Above the bowl there are 10−20 m high steep cliff bands. The mountaintop is flat and extensive.

Figure 3 The mountain Brellur above Patreksfjörður with its flat and extensive mountaintop. The Urðir area is located on the left side of the photo where there is a gap in the residential area (photo: Kristín Martha Hákonardóttir).

The mountaintop acts as a huge catchment area for snow drift. Northeasterly winds, which seem to be dominating in the area according to available data on weather conditions, can cause strong snow drift into the starting zone and the formation of big cornices (Margreth, 2006). Snow drift is the main reason for snow accumulation in starting zones of avalanches in the area and the break up of cornices, as those shown in Figure 4, is known to have initiated some of the largest avalanches in the area (Jóhannesson and others, 1996). Installation of snow fences and wind baffles is therefore considered to be an effective way of reducing the risk of avalanches at the Urðir area in Patreksfjörður.

Figure 4: Cornices in the cliffs in the avalanche starting zone in Patreksfjörður in 1995. The height of the cornices is estimated 5−10 m (photo: courtesy of Þröstur Reynisson).

Margreth (2006) designed a scheme combining snow fences and wind baffles for the Urðir area in an appraisal study for avalanche defences for the Urðir and Klif areas in Patreksfjörður. The proposed snow drift measures are shown in Figure 5. They consist of 25−30 wind baffles to break up cornice formation and 1700 m of snow fences positioned normal to the prevailing wind direction in multiple rows. The wind direction, wind speed and the local snow distribution need to be analysed in advance for an effective application of the snow drift measures, followed by testing the function of a small portion of snow fences and wind baffles prior to the final construction.

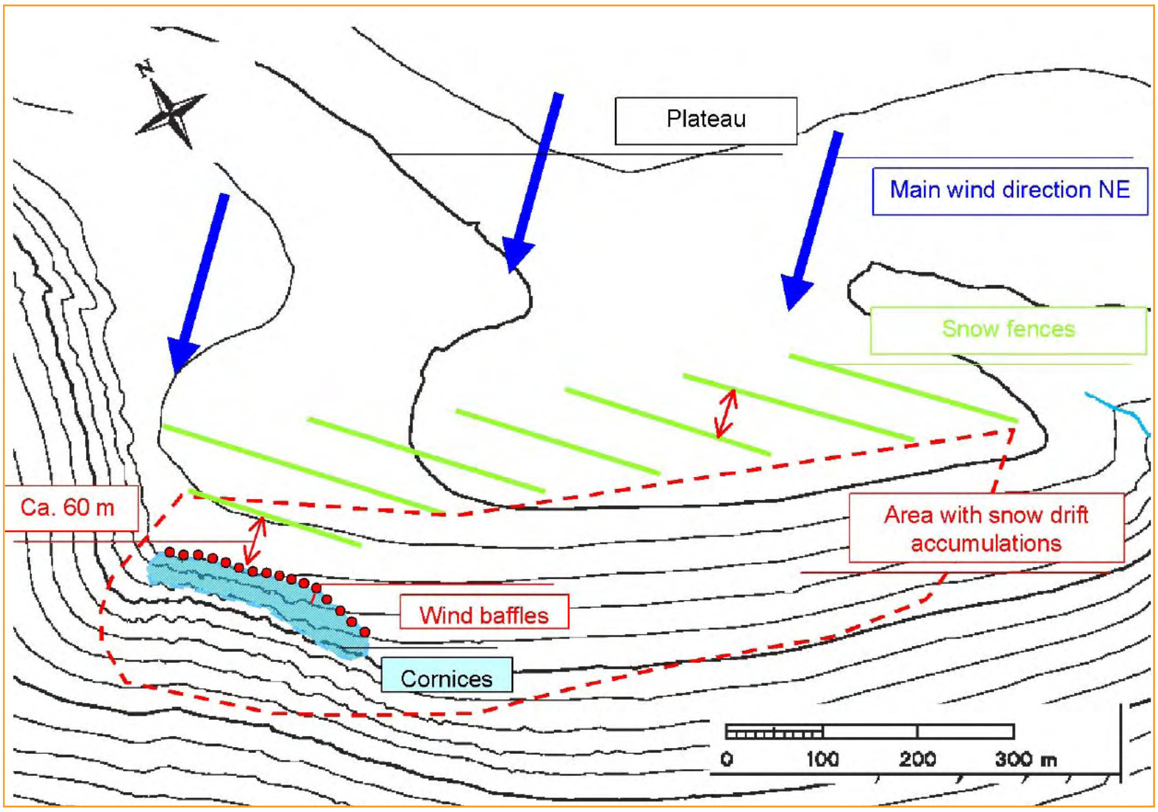

Figure 5 Proposal for a complete protection of the starting zone above Patreksfjörður with snow fences and wind baffles (Margreth, 2006).

The cost of the structures including the test period is estimated as a quarter of the cost of dams to protect the area. The initial test period for evaluating the effectiveness of the structures would cost a tenth of the total cost of the snow drift measures.

4. DISCUSSION AND CONCLUSIONS

Snow drift measures could become a valuable and cost effective addition to snow supporting structures and protection dams in certain areas in Iceland, since a lot of avalanche problems are related to snow drift, not least in the Westfjords, where the mountaintops are generally flat and the catchment area for snow drift is large. It is however not clear how to integrate the use of such structures into modified hazard maps since their effectiveness cannot be guaranteed in all weather conditions leading to avalanches. The design and construction of the structures above Patreksfjörður will provide a valuable base for evaluating the effectiveness of such structures under harsh wind conditions and could pave the way forward for construction of such protection measures in Iceland.

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Development of a new helicopter gas device for avalanche preventive release

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ABSTRACT

The Daisy Bell® system combines the advantages of a gas system and a helicopter to release avalanches after snowfalls: performance and reliability with a powerful and controlled explosion, and mobility. With Daisy Bell®, important areas can be treated and about fifty explosions, so as many releases, are possible with its gas reserves. Thanks to its weight, most of helicopters can bring it with an about 20-meter sling. This sling is the only connection between the helicopter and Daisy Bell® because the system has gas and power autonomy and is remotely controlled by radio. The operating of the system has been designed to favour safety and to bring a real new device in the field of avalanche prevention control systems.

1. INTRODUCTION

Except at the end of the winter, periods just after snowfalls are the most dangerous regarding avalanches. So, important means to purge and preventively release avalanches are necessary, especially for roads and ski resorts (Margreth and others, 2003). Different solutions exist; most of them are not mobile (Gubler and Wyssen, 2002). Let see the example of the Gazex® system (Schippers, 2002): there are more than 1600 Gazex® in the world that operate safely, in particular for the main avalanche paths. But they are not mobile, so they can treat generally only one or some paths (Rice and others, 2004). When an important area must be secured, these devices are not sufficient and mobiles ones must be used.

Many times, these mobile devices use explosive (Gubler, 1977) that is transported to the starting area of the avalanche with different means and according to the regulation of the country: cable systems, ski patrol, helicopter, military artillery (Perla, 1978) or equivalent. However, many constraints exist, such as respecting very strict procedures about explosive transport and storage, and handlings that remain delicate to the ignition. For the matter, accidents evenly happen with explosive, even though there are more and more specialized trainings.

Another solution is the gas mixture that is simpler and safer to use. Indeed, as long as the gases are separated and in bottles, risks are nearly null and facilitate transport and storage. Then, it is relatively easy to master the mixture with usual industrial equipment: fittings, flexible foils, pipelines… Moreover, it is very difficult to create, into the open air, an explosive atmosphere just by releasing gas: another safety lies in the concentration range when the gas becomes dangerous, improved if the gas is very volatile: for example, hydrogen is explosive only for concentrations between 4% and 74.5% in the air. Actually, the true challenge that consists in developing a gas system in fields implies to confine a minimum of gas. For example, the Gazex® uses an oxygen-propane mixture, heavier than the air that remains at the base of the pipe during injection.

Figure 1 Gazex® system

2. DAISY BELL®: PRINCIPLE OF OPERATION

Daisy Bell® project is born from a desire for a gas system movable and operable, hung under a helicopter. The Avalhex® and Avalanche Blast® systems, which are already movable, use a latex balloon to confine the gas mixture. They are very useful to treat avalanches but they raise technical difficulties. Indeed, precise and complex mechanisms are necessary to connect gas reserves to the balloon to be pumped up and then to the next one. They are hardly compatible with use conditions (cold, frost…) and pose mechanical problems. Moreover, using balloons raises autonomy problems and these systems enable finally only a limited number of avalanche releases.

All these observations have led to the development of Daisy Bell® with an initial idea: to replace the balloon temporary volume by a permanent metal one. At the beginning of the development, a flap system was foreseen to be closed during the gas injection and opened just before the ignition. Using an oxygen-hydrogen mixture was the second basic idea. This mixture is lighter than the air, so a system directed towards the bottom can be designed. Moreover, the explosion of an oxygen-hydrogen stoechiometric mixture is explosive and releases maximum energy, so it is very interesting for an artificial avalanche release.

After that, different types of bells have been tested, first being hung to a crane. These first experiments had many goals:

- Choose the best shape and check its compatibility with the initial containment of the gas mixture injected from the top
- Check the ability to make a detonation
- Sort the explosion consequences according to the mixture parameters: proportion, volume.

These consequences of an explosion must ensure a compromise between the efficiency of the wave directed towards the ground and the reaction on the system and consequently on the helicopter. Indeed, the explosion causes a reaction on the volume to the top, which then falls under the effect of gravity. Concerning the helicopter, the constraint is to limit the fall of this mass that must remain compatible with sling and hook systems and the flying abilities of the helicopter.

Figure 2 shows drawings of the three tested volumes: the first one was too large and could not confine correctly the gas mixture during injection without a supplementary closing system of the opening. The second one was the first to be equipped with a cylindrical room: its smaller shape limits the turbulences and the external rejections of gas before the explosion to ensure, in every case, the explosion. Therefore, the advantage is not to have to close the opening during injection, and consequently not to have a flap system. Finally, the cone was retained: it is easier and simpler to make and it has the same advantages as the second volume limiting, on the top of that, the rise effects.

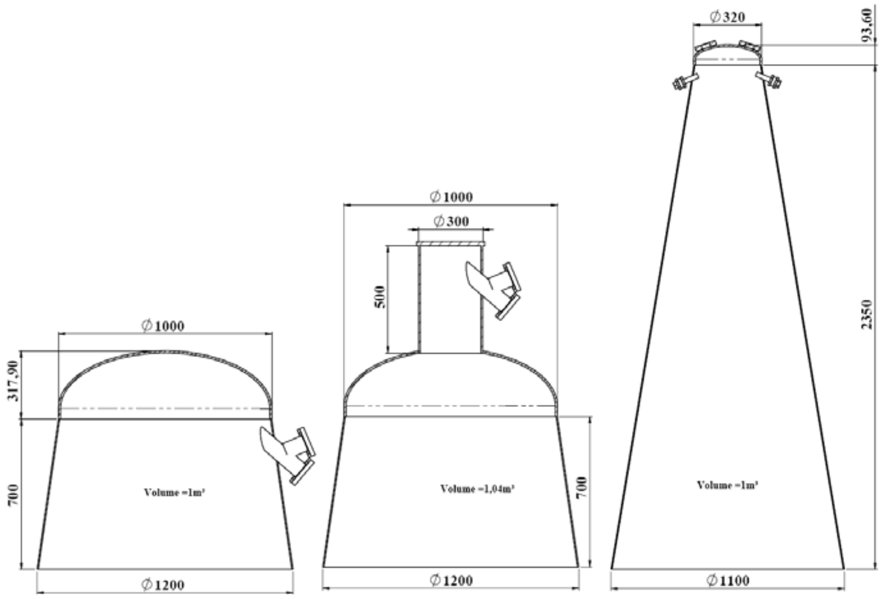

Figure 2   Drawings of the three tested volumes

3. DESIGN FEATURES

Figure 3 shows the equipment installed on the conical volume. Two bottles of hydrogen and one of oxygen are fixed on a damped support linked to the metal cone. Both gases are injected separately from the top of the volume. For that, the initial 200-bar pressure is reduced to some bars by a double-expansion system linked to a calibrated hole: this combination enables to know with precision the injected flow and so the characteristics of the mixture before the explosion. Its volume has been set at 0.5 m^3; it is lower than the total volume of the cone to ensure the containment before the explosion. Furthermore, as the system is at about twenty meters under a helicopter, the associated air flow is important: a secondary deflective cone has been added to limit the effects of the mixture suction to the outside. This secondary cone enables also to protect the equipment in case of contact with the ground.

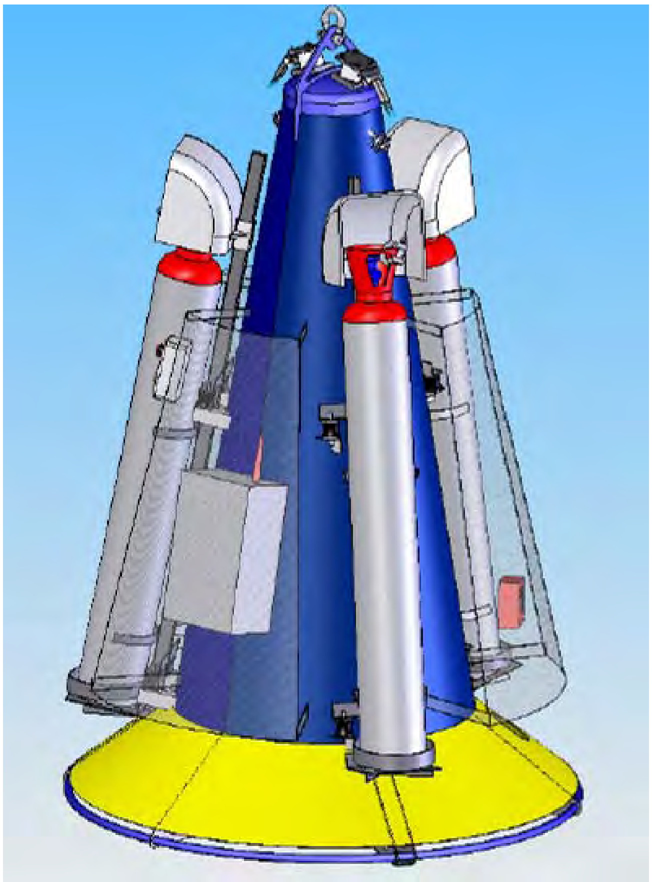

Figure 3 Typical drawing of the Daisy Bell® system

Two plugs, placed on the top of the system, launch the explosion, where the mixture accumulates. Concerning the injection, systems of check valves prevent the explosion from going to the gas reserves.

The control system is placed in a protected box, remotely controlled by an operator from the helicopter. The firing procedure is semi-automatic because the operator just needs to remain pressing on two buttons to automatically start the operations: simultaneous injection of both gases during 7 seconds and ignition of the sparks. In case of trouble and to exploit human reflexes, the simple release of at least one button stops the procedure. It can be started again within 30 seconds or the system will start the draining of the volume. It consists in saturating the volume with oxygen to make the injected mixture non-explosive: it can be activated to secure the system in case of problem.

A system of distance measurement with the snow cover surface has been added to well place the system above snow from the helicopter: an about 2-meter distance is in principle desirable. All in all, the system weighs about 600 kilos.

With the gas reserves fixed on the main cone, about fifty fires can be made before refilling with new bottles. It takes about ten minutes with two people.

4. PERFORMANCE

The shape of the volume will direct the explosion vertically to the snow cover, creating a detonation that will hit this cover. As shown in the figure 4, it is a typical profile of detonation with first an overpressure front followed by a depression period: it has a double effect on the snow cover; first to break its resistance and then to lift it and ease its move.

Measurements made with an air overpressure sensor on ground without snow give positive results: the maximum overpressure obtained at a 12-meter horizontal distance reaches 80mbars for the wave reflected on the ground, which is equal to the 0.8m^3 Gazex® system. The main difference is the duration of the detonation, which is twice shorter than the propane detonation (Gazex® system). The influence of this parameter will be tested during the 2007-2008 winter. A priori, Daisy Bell® would stand between the classical explosive and the explosion of the propane-oxygen mixture, in terms of effects and wave speed.

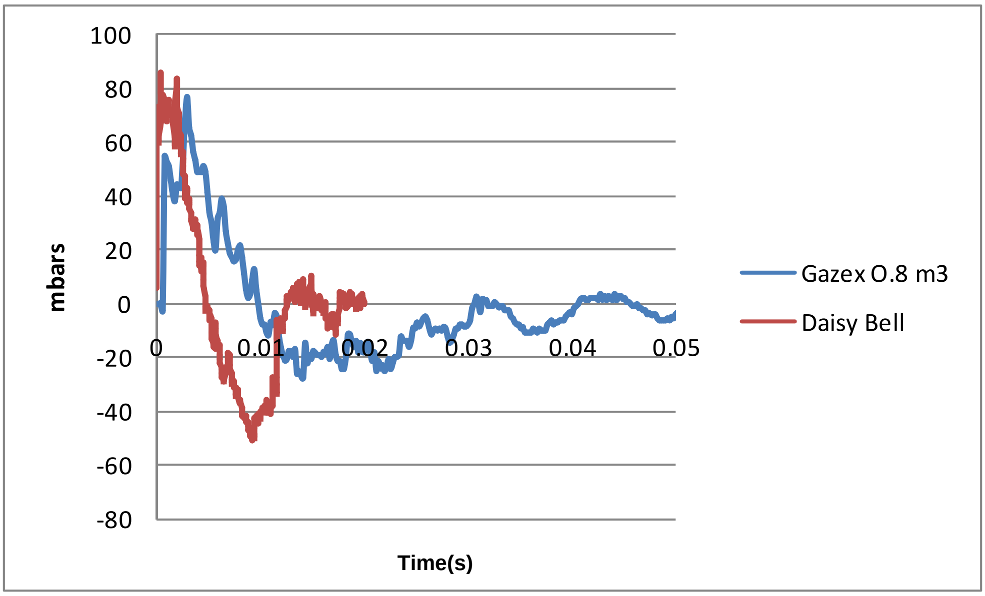

Figure 4 Air overpressure obtained at a 12m horizontal distance for a fire at 3m above a ground without snow and compared with the Gazex® system in similar conditions

NB: to improve the performance of the system, the introduction of a tightening (or sonic pass) at mid-height inside the cone is planned. Preliminary tests show a gain of 20 to 30% on the total amplitude of the wave. To date, no major limitation due to the air flow of the helicopter has been seen.

5. CONCLUSION

Daisy Bell®, this new system of avalanche prevention release, transported by helicopter, has many advantages to secure an important area after snowfalls. Its simplicity is the guarantee of the reliability and its transport by helicopter ensures a great mobility and a rapidity of treatment.

This first winter will be dedicated to validate performances and the use of the system with 10 devices. In parallel, the development is being validated and approved by INERIS, French National Institute for industrial risks.

Moreover, additional measurements campaigns are planned to improve the influence of the different parameters, and, especially, of the characteristics of the gas mixture.

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The avalanches at Súðavík and Flateyri in 1995. First actions on behalf of the District Commissioner of Ísafjörður

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INTRODUCTION

An avalanche fell on the village of Súðavík in Álftafjörður, northwestern Iceland, at 06:25 in the morning of January 16th 1995. The population of the Súðavík community at the time was about 220 inhabitants, most of which were in their homes. Súðavík lies about 20 km away from the town of Ísafjörður in a nearby fjord.

The District Commissioner is also Police Commissioner in his district and is appointed by the Minister of Justice of Iceland. The Police Commissioner is according to Icelandic Civil Defence law responsible for handling and managing rescue actions and safety measures that are taken in response to a natural disaster. In this particular case, the weather in the West-fjords of Iceland was extremely bad. It had snowed heavily from Friday the 13th of January and all roads were closed for traffic and weather conditions prevented air traffic for days.

There are no professional rescue teams in Iceland but strong volunteer rescue teams that can be moved between different parts of the country.

When an alarm call came concerning the avalanche in Súðavík there was no clear picture of what had happened until outside help was in Súðavík at about 09:40. The crucial question was how to get help to the village. Roads were closed and would remain so until 24:00 Wednesday 18th January, for almost three days. Police started by trying to get trawlers to come to Ísafjördur harbour and fetch a rescue team and bring it to Súðavík. There was no success due to the adverse weather conditions. Finally, the Police Commissioner called the captain of the ferry Fagranes and asked him to bring the ship from the inner harbour to the outer harbour and stop there to load the rescue team and rescue gear to bring to Súðavík. The captain was willing to try, although pointing out that this would be almost an impossible task.

The coming days brought with them more almost impossible tasks and many great feats of many people, both men and women. The ice was broken by the desperate but in the end successful attempt to take the Fagranes ferry to Súðavík. The situation in Súðavík was terrible. For more than three hours the avalanche stricken inhabitants had been struggling to save lives of neighbours, relatives and family members in a heavy snowstorm without any tools other than a couple of shovels and their bare hands.

Less than a year after the accident in Súðavík, disaster struck again in the Westfjords with a catastrophic snow avalanche that hit the village of Flateyri at 03:55 on the 26th October 1995. Similar to Súðavík, Flateyri lies about 22 km away from Ísafjörður in a nearby fjord and had about 430 inhabitants at the time. Rescue actions were also in this case carried out in bad weather under very difficult conditions.

This presentation gives a brief description of the local civil defence management during the first week after the accidents at Súðavík and Flateyri. The presentation will also touch upon the human factor involved with the rescue operations based on the author's experience of the disasters at Súðavík and Flateyri in 1995.

SÚÐAVÍK

The accident at Súðavík may be summarised as follows:

- The avalanche overran or touched 25 houses with 63 people. Of those 14 died and 10 were injured.
- The estimated volume of the snow in the avalanche deposit was 150 to 200 thousand cubic meters or around 60 to 80 thousand metric tons.
- First measures were to save lives and then to attend to properties and make sure that safety of rescuers was taken care of.
- Last person to be found alive was rescued almost 24 hours after the avalanche fell.

Figure 1 A house damaged by the avalanche at Súðavík on 16 January 1995.

Additional information:

- A storm in December 1994, which also caused avalanches, had left a very slippery surface in the mountains. Very high winds and a lot of precipitation led to an enormous accumulation of snow in the starting zones of avalanches.
- The wind direction before the avalanche fell was between northerly and northwesterly with snow drifting over the edge of the mountain and into a depression in the cliffs.
- It is considered likely that the main accumulation of snow in the starting zone started six hours prior to the event after the wind direction became more westerly.
- The initial starting zone may have been about 200 meters wide and once the avalanche came down below the cliffs it released a 400 m wide area in a secondary starting zone.
- When researchers got up to the starting zone, all signs of the outbreak of the avalanche had disappeared.

- The starting point was at almost 600 m above sea level. The avalanche ran 1275 m horizontally, and stopped 10 m above sea level. The avalanche occurred shortly after the beginning of the storm and the avalanche cycle lasted for 5 days in total.

FLATEYRI

The avalanche fell on the village of Flateyri on 26th October 1995, 9 months and 10 days after the Súðavík catastrophe, killing 20 people. A tunnel through the mountain between the fjords was being built at the time to replace a road over the mountain that was closed due to weather conditions at the moment.

The tunnel was used to get outside rescuers from mainly Ísafjördur to Önundarfjördur where Flateyri lies. Then another problem arose. The road from the tunnel to the village had to be closed down due to avalanche danger. A transport was established from a pier at the other side of the mountain with a fishing boat sailing between the pier, which was in bad condition, and the Flateyri harbour.

The transportation of rescuers was not as serious problem as in the case of Súðavík, but it took longer to get the first outside help from Ísafjörður to Flateyri. As was the case in Súðavík, the locals had to deal with first measures practically the same way, knowing that their family, relatives and friends were missing and probably dead if not injured.

The accident at Flateyri may be summarised as follows:

- The avalanche overran 32 houses with 54 people. Of those 20 died and 5 were injured.
- The estimated volume of the snow in the avalanche deposit was 430 thousand cubic meters or around 180 thousand metric tons.

Figure 3 Rescue workers working in the tongue of the avalanche at Flateyri, 26 October 1995.

Additional information:

- There were extremely high winds, *e.g.* average wind speed continuously above 50 knots (25 m/s) for 3 days prior to the avalanche, reaching above 90 knots (45 m/s).
- Wind direction was N–NE, blowing snow at an enormous rate into a large bowl somewhat to the east of the village.
- The fracture height reached a maximum of 3.7 m, the average was estimated 2.5 m.

- The starting point was at 620 m above sea level, running 1930 m horizontally, stopping at sea level.
- The area of the deposit was 350 thousand square meters, max. width 450 m.
- The track is partly confined but the avalanche spread out after it escaped the confinement.
- Avalanche occurred at the end of the storm.
- The avalanche cycle lasted 4 days, several avalanches occurred all over N and NW Iceland.

LESSONS

Preparedness

- Existing hazard zoning vastly underestimated the avalanche danger. Risk was much to high. No estimation had been made as to the actual risk in the threatened villages.
- No building code existed with regard to avalanches.
- Warnings were issued but were not forceful enough, people did not realize how large the avalanches could be.
- Evacuations were in effect in both disasters but obviously insufficient.
- Lack of preparedness by the inhabitants, lack of rescue equipment in the village, lack of avalanche beacons (only a limited number of rescuers allowed on site), *etc*.

Rescue actions

It was extremely difficult to get outside rescuers to the accident location in both cases. Volunteers outside organized volunteer rescue groups did not show up at Flateyri, probably because the experience from Súðavík was too difficult to deal with. It took much shorter time to get help from other parts of Iceland than the Westfjords to Flateyri than to Súðavík although it took longer to get help from other parts of the district into Flateyri.

Information prior to the event was limited, information during the event was based on facts and given earlier on at Flateyri than in Súðavík. Information following the event was given in public meetings and instruction booklets.

The last part of the presentation will discuss the personal part of the Police Commissioner’s activity, regarding among other things how to act given the fact that both communities were small and in most cases the deceased were known to many taking part in the rescue operation, the PC not excluded. Another important factor was that most of the actors had families living in the area and it was not known if danger could await them at the time of the rescue operation.

As a final remark, the presentation will end with some personal thoughts about decision making in the time of crisis and the effect on the person responsible.

ACKNOWLEDGEMENT

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Icelandic voluntary rescue teams in the Súðavík and Flateyri avalanches in 1995

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ABSTRACT

The presentation is about work of the voluntary rescue teams in Iceland following the avalanches in Súðavík and Flateyri in January and October 1995. How the teams were structured and organized and how they responded, operated and what were the lessons they learned from the response. Did it change the way the teams operate today? What effect did it have on the rescuers themselves? The author was a member of the voluntary rescue teams at the time of the disasters. The presentation is based on his experience during and after the disasters. The conclusion is that the rescue teams operated well under difficult conditions, the command system worked well and the training and experience of the people in the teams came to good use. But there were some things that needed improvement regarding the training of the rescue teams in the avalanche and urban search and rescue and in providing the teams with safety devices such as avalanche beacons.

INTRODUCTION

Two avalanches struck the town of Súðvík in Iceland on 16th of January 1995. They went through a large part of the community and destroyed or damaged 25 houses. Sixty three people were in the houses at the time of the disaster. Of them 14 died, 10 were injured and 39 were escaped or were rescued unhurt.

A few months later on 26th of October another disaster struck the town of Flateyri. In Flateyri, 32 houses with 54 people were hit by the avalanche. Some people were able to self rescue, some were rescued but twenty people were killed. Voluntary rescue teams played a key part in the rescue work following the disasters.

In this presentation I will go through the work of the Icelandic voluntary rescue teams in the avalanche disasters in Súðavík and Flateyri. I will explain the organisation of the teams and the national associations at the time and how the work was organized. Then, I will briefly go through the work in the field and the command system of Icelandic authorities at the time. Finally, I will address the question what the teams learned from the disasters.

Today and at the time of the disasters, the author was a member of the National Search and Rescue command of the voluntary organisations representing the rescue teams. My personal experience and work has given me insight in the issue I address in addition to other sources I have been able to refer to.

ORGANIZATION OF THE RESCUE TEAMS

The Rescue teams were not operating for the first time in response to avalanches in build up areas. The teams responded to avalanches in Patreksfjörður in 1983 were 4 people died and in

Neskaupsstaður in 1974 were 12 died. But in the time between the response to these disasters in 1974 and 1983, the voluntary rescue organizations in Iceland hand gone through substantial changes. In 1983, there were three organizations of voluntary rescuers in Iceland and the cooperation between them in Search and Rescue was on an "*ad hoc*" basis during operations. The only truly joint factor was one VHF communications system they operated together. During operations, such as when avalanches struck build up areas, the rescue teams of the three organizations were under command and control of the local police chief, and on a national basis the coordination was done through the National Civil Defence command center in Reykavík. At the center, all three organizations were represented by a member of the respective organizations as the crew of the command center during operations. In 1985, the organizations build up in cooperation with the Ministry of Justice their own command structure. That was done by setting up a joint National SAR Command of the rescue teams and under that system of 18 area commands to work for the authorities responsible (Police, aviation authorities and those responsible for Search and Rescue at sea). And in 1991, the three organizations became two when two of them, the Association of Air-Ground Rescue teams and the Association of scout rescue teams merged together in Landsbjörg-Association of Icelandic Rescue teams. The other organization was the Slysavarnafélag Íslands-National Life-saving association of Iceland-NLAI. (Today there is only one organization – ICESAR Icelandic Association for Search and Rescue.) In 1994, National SAR Command was representing the rescue teams in the National Civil Defence Command Center.

TRAINING IN AVALANCHE/URBAN SAR BEFORE THE DISASTERS

Training of the teams at the time came from various sources. But in 1994, Landsbjörg and NLAI started to operate a joint Rescue school – The Icelandic Rescue School. (It was a follow-up on the work of a school with the same name operated by Landsbjörg and its former associations since 1977.) The school was already working on standardizing training both in avalanche and Urban SAR at the time. But since 1989, a part of the Urban Search and Rescue (USAR) training of the NLAI was based on experience of rescuers from the 1974 avalanches in Neskaupsstaður. Several rescuers in the area of Súðavík and Flateyri, for example Jón Svanberg Hjartarson, who was the incident commander in Flateyri for the first hours after the disaster struck, has confirmed that the USAR training he attended with NLAI made it possible for him to organise the work during the initial hours (Arnalds, 1996).

SÚÐAVÍK AVALANCHE

The first avalanche struck the town in the early hours of the morning of 16th of January 1995. The weather conditions were horrible and it was impossible for the rescue teams from the nearest towns to respond to the area by road. In the end, they had to sail by ships. So for the first hours, the local population, including the local rescue teams tried to do what was possible. Twenty people were missing and the local mayor asked all the population to go to the local freezing plant by the sea, both to get status on who was missing and also to start SAR work in the area. The rescue team's National SAR Command was not informed of the disaster until 90 minutes after the avalanche fell. At 09:40 the National SAR Command

was asked to provide rescuers from the Reykjavík area to go with a coast guard vessel to the area. Transportation by air was impossible because of the weather. The coast guard vessel left Reykjavík at 14:40 hours with rescuers and medical staff (Bernharðsdóttir, 2001). Soon after that, the trawler Engey left Reykjavik with additional rescuers. At the same time, ships and boats from various towns and municipalities closer to the area, were sent to Súðavík. In all 300 rescue team members were in action during the operation.

The first wave of rescuers coming to Súðavík arrived at 09:42 hours in the morning, more than three hours after the avalanche struck. With them were trained avalanche dogs, command and medical staff. A collection point for rescuers was set up in the local freezing plant and rescuers were sent to search at likely locations; the dogs worked very well and marked likely positions and the rescuers started to dig at these locations. All rescuers that went from the collection point had to carry avalanche beacons for safety. More rescuers arrived from Ísafjörður and towns around the area. The coast guard vessel arrived with rescuers from the Reykjavík area at 14:20 hours on 17th of January. At that time the local rescuers and volunteers from the area had been working for 36 hours. Only two of those originally buried by the avalanche were still missing. At 18:00 hours on 17th of January all missing persons had been found.

The work of the rescuers in the field became more and more difficult as time passed during the operation. This is common in urban search and rescue. First you rescue those who are easy to access and after that you dig deeper and deeper into the rubble. A number of huge rafters had to be cut and the rescuers used chain shaws, crowbars and other manual tools. Snow shovels were the main tool to gain access to the houses needed to be searched. The local incident commander used an old town map to mark in the avalanche and likeliest spots survivors could be found. Other indicators that the searchers used were blood trails that were found in the snow (Avalanche 95).

When rescue operations finished, it took until Thursday 19th of January to get every rescuer back to his home because of adverse weather. In the following week, rescuers from all over country were sent on rotation to help the local rescue teams to collect belongings of those caught up in the avalanche. But the horror was not over. On 26th of October the same year, another avalanche struck.

FLATEYRI AVALANCHE

Everyone in Iceland was shocked after the avalanches in Súðavík. A national collection for the victims of the avalanches was organized and collected some 200 million Icelandic kronas. And the rescue teams wanted to learn from this experience. On 26th of October same year the snow tiger struck again. The conditions were similar, bad weather making transportation by air difficult. Most of the rescuers from nearby communities could go by road most of the way. A coast guard vessel left Reykjavík 3 hours after the avalanche hit. Rescuers and those in charge could draw on their experience after the avalanche in Súðavík. Around noon on the 26th, the weather improved to make it possible for helicopters to fly into the town with dogs and rescuers. But there were some differences between the two incidents. Around 13:00 hours four people had been rescued alive but after that nobody was found alive in the rubble. In Súðavík, a young boy was the last one rescued 23 hours after the avalanche. The same incident commander and command staff were present on the scene and the experience from Súðavík gave the rescuers a plan of action for the rescue. The local rescue team had already started to plan the search and had rescued several victims by the time rescuers arrived from the Ísafjörður area. For the first hours, members of Flateyri rescue team worked alone. Two rescuers were sent by snowmobile to assess the size of the avalanche. The local team only had 9 avalanche beacons and only seven rescuers with beacons were allowed into the area at a time. Deputy team leader of the local rescue team, Jón Svanberg Hjartarson, was in charge of the search. An hour before rescuers arrived from Ísafjörður, he allowed some rescuers to go to the lower part of the avalanche without beacons. He and his men also used the time to gather information about the number of people missing. This made the work of the incident commander and command staff arriving from Ísafjörður easier when they arrived 5 hours after the avalanche struck. With the rescuers arriving from Ísafjörður came several search dogs and trained rescuers. The rescue operation took new course with the arrival of the Ísafjörður team. The experience from Súðavík made the work easier, it was like rescuers knew exactly what to do. The command center was set up and a collection area for the rescuers. Maps were used to mark the avalanche and rescuers were sent out in organized groups to search. The work was like in the Súðavík disaster, a mix of avalanche and urban SAR. Dogs marked positions and information about people staying in houses was used to search in the most likely areas. As mentioned before, a coast guard ship was sent from Reykjavík, rescuers were also sent by air to the Snæfellsnes area to meet up with another coast guard vessel that was at sea. Helicopters of the Icelandic Coast Guard and United States Air Force based at the Keflavik Naval Base base managed to fly with search dogs and rescuers to Flateyri around 13:00 hours on 26th of October. The people at Flateyri said when the helicopters arrived "It was like we were back in contact with rest of the world" (Arnalds, 1996). The last victim was found 36 hours after the avalanche and the last 24 hours of the rescue operation were devoted to the search for that person, a little girl. The rescuers had to dig all the snow from the house she was in. It was a

difficult job because a lot of debris was mixed with the snow. It is estimated that snow had to be removed from an area of around 3000 square meters. As in Súðavík, avalanche rescuers from all over Iceland took turns in helping with debris removal and collecting belongings of the people living in the avalanche area. Some anger was from the teams because Firefighters from Reykjavík were put in charge of the removal groups of the teams but not those in charge of the teams (Tómasson, 1999).

WHAT DID THE RESCUE TEAMS LEARN?

A lot of experience came from these two difficult missions. In addition to these two disasters, a local farmer in the area of Reykhólar in western Iceland was killed on 18th January when avalanche hit some farmhouses. His son was rescued after 12 hours, alive. The experience of the rescue teams can be classified into five categories:

Command and control

The changes in organisation of the rescue associations in the Icelandic Civil Defence Command center made the organization of the work easier under the civil defence command. The rescue teams area commands in the area of the accident and in other areas provided function in the command centers both on a local and national basis. The experience from Súðavík and Flateyri was also important in the development of single Joint Rescue Coordination Center (J-RCC) which has taken over function of the Civil Defence Command center. In the J-RCC, all national command and coordination is now done; on land, sea and in the air.

Training

Training of rescuers in the field of avalanche rescue was adapted to the experience from the disasters. As before, training in Urban SAR continued to focus on avalanches as a main reason for response in that field, as well as earthquakes and other natural disasters.

Equipment

Lack of avalanche beacons in the early hours of the response was quickly repaired. In the next two years, rescue teams all over Iceland bought 400 avalanche beacons. Also since 1995, some rescue teams have in their equipment caches electronic USAR search equipment such as cameras and listening devices as well as rescue equipment for Medium USAR work.

Dogs

The number of SAR dogs available for avalanche work was increased following the disasters. The experience of dog handlers that took part in the missions was put into the training of the dogs. For example, covering the dog’s feet because injuries to their feet because of broken glass was common in the search.

Other

A conference was held by the National SAR Command and the local area commands in November 1995 in order to relay lessons learnt in Súðavík and Flateyri to rescuers at the conference, lessons from the command side of things were looked into. There was a presentation from the incident commander on both missions. Also there was an independent report that National SAR Command made about the Súðavík response. Slide presentation with pictures from the scene´s were shown to rescue teams all over Iceland (Magnusson, 2008). No special analysis was done by the associations on how the work in the. In NLAI yearbook of 1996, articles were written about the work of the teams in both disasters. The articles are the main source of information about the field work. Some issues were addressed on training courses both in USAR and avalanche training. The reason for the lack of proper analysis can in some ways be explained by the fact that this time there were two associations that provided rescuers. Today it would be different because there is only one national organization of rescue teams in Iceland. One thing made the work of the rescue teams confusing. With the rescuers sent from Reykjavík were professional Firefighters from Reykjavík Fire Department. These professional rescuers worked side by side with the volunteers and after the rescue operations were over they were in charge of the volunteers working in debris removal. The Firefighters had good medical and general rescue training but did not have special training in avalanche rescue (Bernarðsdóttir, 2001).

CONCLUSION

The response of the Icelandic voluntary rescue teams to the avalanches in Súðavík and Flateyri is without a doubt some of the most demanding missions of the teams in recent years. All aspects of the organization of the rescue teams were put to a test. The command structure, training, equipment, dogs, and, last but not the least, the people filling the ranks of the rescue teams. And overall it worked very well. The fact that the work was a mixture of Urban and avalanche SAR was something that the teams were able to work on very well. To call trained mountain and USAR rescuers and send them in horrible weather conditions by sea to disaster areas was a challenge that they stood up to. The experience was transferred to other rescuers in training, articles and presentations. The only thing lacking in hindsight was proper analysis of how the on-scene rescue work in these exceptional conditions functioned.

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INTERVIEWS

Magnússon Thor – from the National Life-saving Association, 12th of January 2008.

Sustainable safety based on active risk management by a controlled use of temporary measures

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ABSTRACT

The small village of Samnaun (Grisons, Switzerland) is the only settlement in the Alps where the protection of permanent residential areas and major traffic routes threatened by potential avalanches is predominantly based on temporary measures. In this context, remote avalanche control systems, *e.g.* the so-called Wyssen Avalanche Towers play a key role by enabling a supervised artificial release of avalanches by controlled explosive shots. Since 2001, 44 avalanche towers have been installed in both the area above the settlement and the ski resort of Samnaun, thus providing the data for a detailed analysis of such a new concept of avalanche risk-management, which might be seen as a kind of paradigm change.

In a first step, pros and cons of a protection system which is strongly related to temporary measures will be discussed. Key aspects, like the number of shots, the relation of snow fall events, snow depth and shots, run-out dimensions will be demonstrated showing that this active concept is the basis for a better control of the overall avalanche situation than traditional ideas which are mostly based on a more passive attitude. Besides these technical and natural scientific views, a major intension is laid on highlighting the legal situation in Switzerland in general and in the province of Grisons defining the framing conditions for establishing such a new protection system which is far beyond what has been applied so far in any country in the Alps.

In a second step, potentials and limitation regarding the transferability of the strategy which has successfully be applied in Samnaun to Austria will be discussed. As the laws and regulations in Austria are different to the situation in Switzerland, the discussion of potentials and limitation due to the legislation is a vital pre-requisite before starting to plan for applying this new way of coping with avalanche related risks in Austria. As in the small village of Neustift (Stubai, Tyrol), the environmental situation is somehow comparable to Samnaun, this settlement is used as a test area.

Besides the legal and technical side, economical aspects will be discussed. A comparison of overall costs related to the more classical mode of a prevention of the endangering processes to the temporary measures is presented. This paper also highlights the sustainable character of the new technology. In a final step, transferability to other mountain areas, *e.g.* Iceland, are considered.

Avalanche protection in Austria – present stage and future development

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ABSTRACT

Protection against natural hazards such as debris flows, land slides or avalanches is as old as settlement activities in Alpine areas. To look for safe places was the first kind of mitigation and therefore the oldest houses in a village are normally situated in the safest places. The number of inhabitants in the mountainous part of Austria and in particular the number of tourists increased considerably in the last decades. This development leads to a high need for protection work and nearly 500 km of steel supporting construction were built to protect settlements and roads against snow avalanches. Several kilometres of avalanche sheds along roads and a highly developed system in avalanche warning allows winter tourism in valleys that were close to relocation several decades ago. How does the future of Alpine valleys look? Beside unknown influences such as socio-economical development and climate change it is clear that sustainability in protection is necessary. This contains comprehensive mitigation concepts, the development of an adapted risk culture and a life cycle management of protection measures.

1. INTRODUCTION

The Alps cover three quarters of the entire Austrian territory, which means that Austria has the highest share of the Alps of all Central European countries. More than half of the state territory (83,855 km²) are zones of intensive protection against Alpine natural hazards. Snow avalanches, debris flows, landslides, floods and rock fall threaten people and their living space, their settlements and economic activities as well as traffic routes. The growing settlement pressure and the development of roads in the Alps as well as a strong expansion of tourism have resulted in an increase of endangered zones over the last few decades. Forests that grow on the steep slopes of the valleys offer natural protection against these natural hazards in many ways. This has not always been the case. Excessive timber exploitation for mining purposes (iron-ore, salt) almost entirely deforested whole valleys in former centuries. Natural catastrophes of unexpected dimensions were the result. Particularly, the avalanche disasters in the winter of 1689 were the worst of their kind ever recorded in history. Today Austria is well equipped with healthy and effective protection forests the state of which is constantly improved by adequate tending operations. Thus, forests offer an important contribution to protecting life and space in the Alps. However, there are limits to the protective capacities of forests. Avalanches, debris flows and storms repeatedly cut large gaps into the protective forest belts and pave the way for other natural hazards. Protective woods are not effective against threats that originate above the timer line (1900 – 2100 m a.s.l.) as snow avalanches are. Most of the starting areas of avalanches are situated between 2000 m – 2400 m a.s.l. Several natural catastrophic events in the last decade such as during the heavy

Figure 1 Typical U-shaped inner Alpine valley with scattered settlements, protection forest on the steep valley slopes and avalanche starting areas above.

Avalanche winter 1998/99, the floods in June 1999 and 2005 in the western part of Austria and the flood in 2002 in the eastern and northern part of Austria have instigated a public and political discussion about new strategies in protection against natural hazards under the prospect of possible climate change. The first short term political reaction was to increase the public funding for technical and forest biological protection work by an amount of 35 Mio Euro/Year.

2. PRESENT CIRCUMSTANCES

2.1 Socio economy

The second part of the last century was a time period of intensive and manifold socio-economical changes in the Alps. According to Bätzing (1991) it was the most intensive change in settlement pattern and inhabitant behaviour since the Neolithic revolution 5000 years before. Several mountain valleys in the Alps were abandoned due to a lack of working places and hard living conditions. The need for high flexibility in the modern economy and society requires permanent open roads and permanent reach ability. Other valleys, mainly those with ski resorts have developed into regions with the highest population density in Europe. Only 12% of the land is usable for settlement and economic purposes in western Austria. While the growth of the population in Austria during the last century amounts to 34%, the growth of population in the same period in Tyrol, a western Federal County of Austria, amounts to 153%. The number of tourist overnight stays increased by a factor of 20 during the last 50 years in Tyrol.

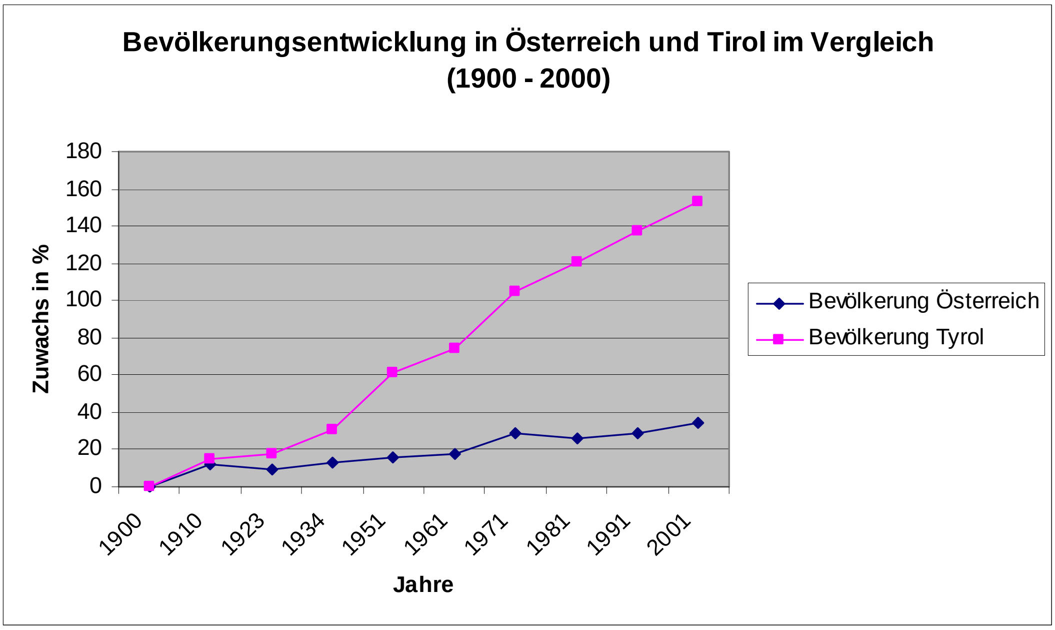

Figure 2 Comparison of population growth in Austria and the Federal County Tyrol.

2.2 Protective measures

The number of protected areas and extent of protection work is not exactly known in Austria. Since the 19th century (1884) much debris flow protection work has been done by the Austrian Service in Torrent and Avalanche Control. Technical avalanche protection became important after the disastrous avalanche winters of 1951 and 1954. 135 and 143 people, respectively, were killed during these avalanche cycles in Austria. The estimated total length of steel bridges implemented since this time is about 500 km, 300 km of them in Tyrol. Beside this, many deflecting and retarding dams and avalanche sheds were built. We estimate that there are also about 25 000 check dams against debris flows along many gullies only in Tyrol. There is no comprehensive information about the quality of these constructions. The total amount that is invested in protective measures in Austria is about € 150 Million/year. In Tyrol, 40% is used for avalanche protection on average, the rest is used for debris flow protection, landslide and rockfall protection and restructuring of protection woods. An exact value is not known, because of different responsibilities and different models of financing. In some building sites the unsatisfactory condition of the constructions is obvious, above all the constructions that were built in the sixties and the seventies of the last century. The standard at that time was by far not as high as today and the dimensioning was much lower than nowadays. The technical basis for the avalanche protection work are the Swiss guidelines. The legal basis is the water right, the environmental right and the Forest law, the basis for the financing is the “Wasserbautenförderungsgesetz”.

2.3 Hazard situation

One should think that the country must be safe after all the expenses that have been invested for protection against natural hazards. This is not the case and there are a numerous buildings and roads in hazardous areas. The reason for this development is:

Figure 3 Steel snow bridges in an unsatisfactory condition; implemented in 1960–1970

- Strict regional planning based on Hazard maps started too late in Austria and is still not fully implemented. Responsible for regional planning are the Federal Counties and a uniform consideration of Hazard maps is not guaranteed. The legal basis for hazard mapping is different within organisations.
- The number of houses has increased very rapid also in Yellow hazard zones because of the economic development of many Alpine valleys.
- The first generation of hazard maps contained in many cases too small hazard zones. Revision of hazard maps because of new regulations and new methods normally shows a larger extent of hazard zones.
- Speed and extent of economic development caused by tourism was not expected nor predictable.

There are no comprehensive statistics about endangered values in Austria, but such statistics exist for buildings situated in hazard zones in the Federal County of Tyrol. These statistics are provided by the Regional planning office of the Federal County of Tyrol and includes all buildings with house numbers. The size of houses and the number of people which are living in the houses is not yet known.

Table 1 Number of houses in Tyrol in Avalanche and Torrent hazard zones.

Total number of buildings in Tyrol	167 383	
Number of buildings in Hazard zones	21 119 (12,6 %)	
Number of houses in Avalanche zones	933 (Red)	1 725 (Yellow)

Number of houses in Torrent zones	798 (Red)	17 104 (Yellow)

To show how the endangered houses are distributed, one needs to look at the number of communities with buildings in Red hazard zones.

Table 2 Number of communities in Tyrol with buildings in Red hazard zones.

Total Number of communities in Tyrol	279
Number of communities with buildings in Red avalanche hazard zones	75
Number of communities with buildings in Red torrent hazard zones	141
Number of communities with buildings in both Red avalanche and torrent zones	46

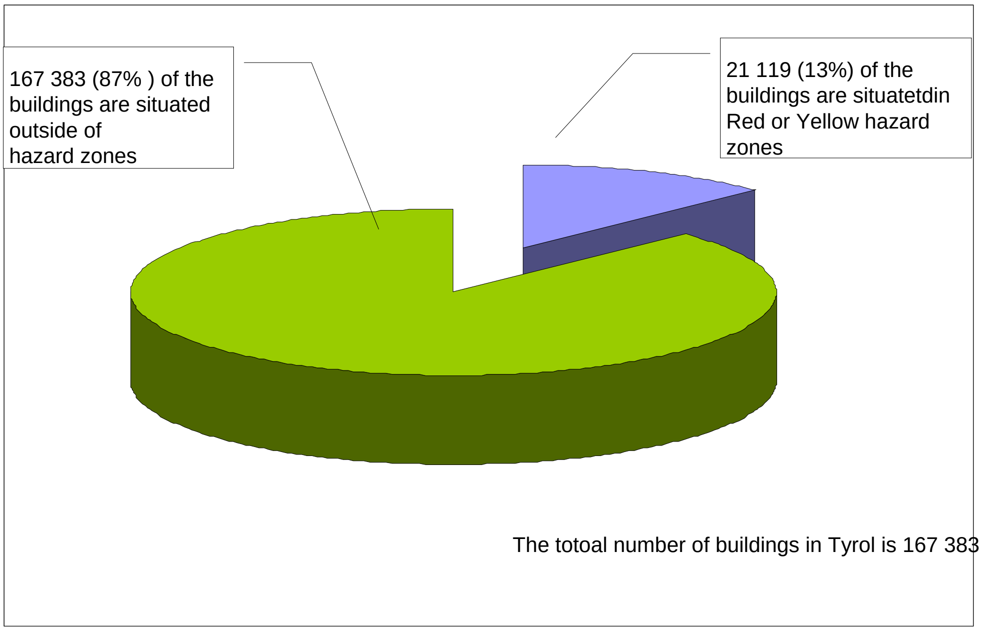

Figure 4 Number of endangered buildings in Tyrol.

3. FUTURE DEVELOPMENT

3.1 Socio economic development

There is no doubt that rapid change will take place within the Alpine living space in the next decades. Reiter (2005) describes three possible scenarios as to how the Alps could be found in 2040. There is an excessive lifestyle scenario (Cool Mountain) compared with an Alpine wellness scenario and a high risk scenario (Intra Muros) caused by high temperature increase and therefore destabilisation of mountain slopes.

In fact a serious prediction? is not possible. Alpine agriculture is no longer needed for supplying the population with food. Bavarian farmers alone produce a milk volume which is three times greater than the Austrian demand (Keuschnigg, 2005). Alpine valleys are probably one of the most intensively used tourism areas in Europe at present and also in the future and Agriculture has more and more the role of landscape conservation. Somebody has to pay for it.

3.2 Climate change

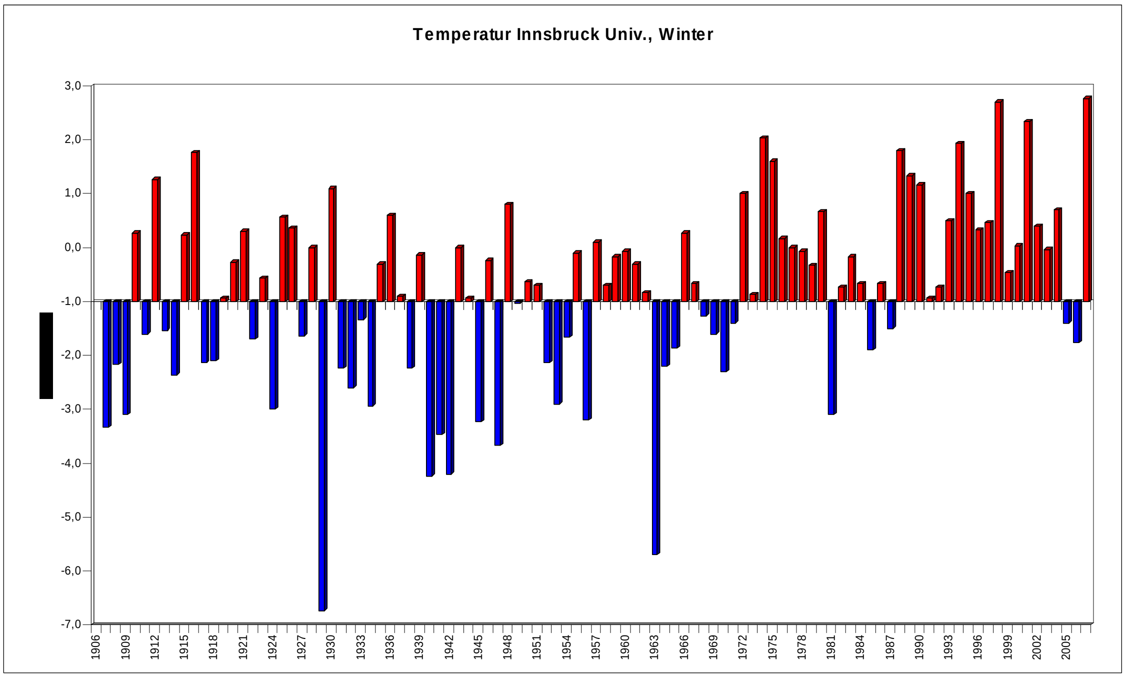

Figure 5 Winter temperature (monthly mean values Dec – Feb) in Innsbruck 1906 – 2004 (Gabl, 2005)

Global warming is evident and is also expressed in the winter temperature over the last century. An expected, an increase of heavy precipitation events is described in the third IPCC report (2007) for Europe. An exact regional forecast is not possible due to the lack and the shortness of data rows (Gabl, 2005). Climate models are not able to predict changes on a regional scale. Martin and others (2001) tried to find out how avalanche hazard will change under changed climate conditions in the French Alps. They found – although their study should be considered preliminary because of the very simple scenarios – that avalanche hazard will decrease slightly in winter, but the decrease is more pronounced in February. The frequency of major avalanche events can hardly be assessed. Formayer and others (2004) describe that about 50% of total precipitation is expected to occur in form of heavy precipitation in 2100. At the moment this value is approx. 35%.

3.3 Protective measures

To implement new protection work and maintain the old one in a sufficient way is not possible with the same monetary and personal input. At the moment the amount of money that is needed for maintenance for avalanche protection constructions is approx. 5 –7% of the annual Avalanche protection budget in Tyrol. Maintenance of check dams in gullies is much higher because of the age of the dams (approx.30%). A lot of them were built in the first half of the 19th century and earlier. A topic for the next decades must be a stepping up in effort for quality control and maintenance programs. Necessary is the

- Implementation of a life cycling program based on a database, where all protection work is collected, described and valued particularly in view of its function during a design event. An Austrian standard is under development on the Austrian Standard Institute. The first part of this regulation came into force in Autumn 2007 (ONR 24803 – Schutzbauten der Wildbachverbauung, Betrieb, Überwachung, Instandhaltung und Kontrolle), the second part is to expect in Autumn 2008 (ONR 24807 – Technischer Lawinenschutz; Instandhaltung und Kontrolle).
- Consequent cost/benefit investigation and a ordering of requests for mitigation measures based on this results.
- Comprehensive risk based regional protection systems which contain permanent technical protection methods as well as forest biological methods and temporary methods.

4. CONCLUSION

A great amount of protection work has been implemented in Austria in the last 120 years. Despite this intensive effort to reduce the threat by Natural Hazards, a much property is still situated and many people are still living in hazardous areas. An exact view to the future is not possible because of the unknown socio-economical and political circumstances in the future. Climate change may bring some additional aggravation, in particular in flood hazard. Exact forecast is not possible. Nevertheless, life cycling management programs have to be established with high emphasis.

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Monitoring avalanche danger for Icelandic villages

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ABSTRACT

The Icelandic Meteorological Office (IMO) is responsible for avalanche monitoring and evacuation of people from areas endangered by impending snow avalanches in Iceland. The office has made evacuation plans and accompanying maps in collaboration with local authorities in villages that are endangered by avalanches. Evacuations are made based on predefined zones that are intended to be evacuated under prescribed weather conditions. The evacuation plans are based on the hazard zoning of the area and take into account protective measures, such as dams or supporting structures, that have been constructed. Local snow observers in the endangered areas make snowpack observations, monitor snow depth in the mountainsides above settlements and participate together with employees of the IMO in Reykjavík in assessing the avalanche danger and order evacuations when necessary.

1. INTRODUCTION

Following two catastrophic snow avalanches in Iceland in 1995, which killed a total of 34 persons, laws and work procedures regarding avalanche monitoring and avalanche preparedness in Iceland were changed. The new law made the Icelandic Metrological Office (IMO) responsible for deciding, in consultation with local authorities, when to evacuate a village at risk to an impending avalanche (Magnússon, 1998). In each village, the head of police can decide independently whether to evacuate other areas or to evacuate an area larger than IMO has stipulated.

The evacuation powers of IMO currently apply only to snow avalanche danger in populated areas with existing hazard assessments. Evacuations due to debris flows and landslides are the responsibility of the local head of police. The same policy applies to avalanche threats in rural areas, where hazard zoning has not been made and evacuation maps do not exist.

2. EMPLOYEES

At the IMO, avalanche forecasting is undertaken for 16 towns and villages threatened by avalanches. There are five avalanche forecasters working at the IMO, and they take part in shift work throughout the winter. Four forecasters are based at the main office in Reykjavík, and one forecaster is located in Ísafjörður in the northwestern part of the country. All of them do other avalanche-related work alongside forecasting tasks. Around the country there are 19 snow observers working in 13 towns and one rural area. Five of the snow observers work full-time during the winter, but the remaining 14 are part-time employees.

3. TRAINING

Avalanche forecasters at the IMO do avalanche-related work as their main remit, taking shifts as an avalanche forecaster every fifth week. In addition to education and specialisation in

Icelandic avalanches, “Canadian Level 2” course experience is preferable. The avalanche forecasters meet regularly each week, and this opportunity is partly used for education purposes. Three or four times during the winter the forecasters receive outdoor training on snow structure and avalanche safety. Additionally, the forecasters occasionally assist snow observers with measurements of avalanches, measurements of snow depths, and repairs to weather stations.

The snow observers have varying backgrounds. They have either “Canadian Level 1” experience or a similar level of Icelandic training. Annually, they meet for a two-day seminar, in addition to working each year with avalanche forecasters or more experience avalanche workers.

4. WEATHER MEASUREMENTS AND OTHER INFORMATION SOURCES

The most valuable information for the avalanche forecasting comes from the snow observers who monitor the local avalanche activity and the stability of the snow-cover. In the north-west peninsula, avalanches frequently cut across roads, serving as an indicator of further avalanche activity above towns and villages.

Seven automatic, acoustic snow-depth meters have been placed in starting zones or on slopes that allow direct measurements of snow accumulation. Six more temperature-based, snow-depth measurement stakes are presently being tested. For many years, the snow observers have used theodolites from fixed locations to manually survey snow depth on stakes in avalanche starting zones.

The French model Safran-Crocus-Mepra is run at IMO; this model forecasts theoretical avalanche danger and it models the metamorphism of snow.

The Meteorological Office operates a few automatic weather stations on mountain tops and has established several automatic weather stations in the lowland regions threatened by avalanches. The Highway Agency has useful weather stations as well, with many located on mountain roads. These additional data are available to the avalanche forecasters.

5. WORK PROCEDURES

Code grey

The work of the avalanche forecasters in Reykjavík follows a fixed routine that is well documented. During the normal winter day (code grey) each avalanche forecaster is on shift for a week. Every morning, the forecaster meets with the duty meteorologist at IMO to discuss the weather forecast for the following days. The forecast is signed by both people and it is catalogued. The avalanche forecaster talks to the snow observers at least twice during the shift period, but more often if weather or snow conditions are likely to result in avalanches. The snow observer estimates local avalanche danger using a colour scale, and the estimate is updated twice a week. The scale of the danger is not communicated to the public at present, but a change in that policy is under discussion. Data on snow profiles and other related information are placed on a Web-page, which is open to the snow observers, as well as members of the civil defence and the police.

Code green

If snow conditions are critical and/or snow storms are forecast that could lead to avalanche danger, code green comes into force. The avalanche forecaster changes the code situation after discussions with the duty meteorologist and the local snow observer. When code green is activated the shifts change so there is an avalanche forecaster at IMO continuously, and all other avalanche forecasters are on call outside their shifts. Also, a meteorologist is available to make detailed local weather forecast for the area under control. The National Civil defence (part of the national commissioner of police) and the local chief of police are formally notified via fax. The chief of the police activates local civil defence committees and they are informed about the latest weather forecast and other related information.

In practice, the change to code green is delayed until there is high certainty that the weather forecast is correct, and that evacuation will be necessary. Several hours usually pass from the change to code green to the decision to evacuate houses (code yellow). Code green is often kept for a day or even longer after people have been allowed to go back to their homes while the snow cover is settling and natural avalanches are no longer expected. Code green is always activated for whole regions, while code yellow is always for local areas where houses have been evacuated.

Code yellow

The lead forecaster on duty makes a decision about evacuating houses in discussion with the second avalanche forecaster, weather forecaster and the local snow observer. Furthermore, the situation is discussed with the local chief of police. The chief of police can decide to evacuate an area independently, or decide to evacuate an area larger than that stipulated by IMO; however, the chief of police cannot evacuate an area smaller than that specified by IMO. Whenever possible, several hours are given for people to evacuate their homes and decisions are made early in the evening if conditions might lead to avalanche danger during the night.

6. EVACUATION PLANS

A new evacuation plan for villages threatened by avalanches was released in November 2007, replacing 10-year-old maps (IMO, 2007). Avalanche hazard zoning has been done for all those villages. The evacuations maps follow the hazard zoning for the most part. Only when avalanche danger is estimated as slight but the terrain is capable of larger avalanches, is the evacuation area extended farther than the hazard zone.

The new plan has, as the older one from 1997, three levels of evacuation, based on the degree of avalanche danger (see Figure 1).

- The first level is mainly defined based on the extent of known avalanches and is intended for conditions with moderate snow accumulation. The extent of an evacuation area may be smaller than indicated by the avalanche history of the area.
- The second level is determined by the largest known avalanches and other paths with similar topological conditions, and is intended to be used in serious avalanche cycles with heavy snow accumulation.
- The third level indicates an area which is threatened by catastrophic avalanches that need not be included in the known history of the area. The extent of the area is estimated mainly with dynamic and statistical avalanche modelling and is in most cases the same as the hazard zone on the official hazard map. This level also includes

areas which may be threatened during extremely rare meteorological conditions which are judged so rare in the hazard zoning that the area is not included in the official hazard zone of the village.

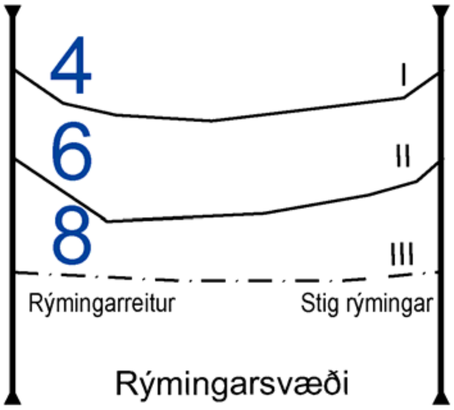

Figure 1 Schematic illustration of zones of an evacuation map. The level of the zones is indicated with roman numerals on the right and the id-# of the zones is indicated with arabic numerals on the left.

Vertical lines on the evacuation map separate avalanches from different avalanche paths and horizontal lines show how far downhill each level extends. Each area is given a specific number that is used when an order for evacuation is issued. To prevent misunderstandings between the new and old maps, numbers are used to refer to areas on the new maps, but letters are used to identify the old ones.

A small booklet explaining the evacuation map for each town or village was distributed to every house in each community. The evacuation maps and accompanying reports for each village were also made available to the public on the IMO web (http://www.vedur.is/ofanflod/vidbunadur”) together with the hazard map and other information relevant to avalanche safety. Figure 2 on the following page shows an example of an evacution map from the village of Súðavík, northwestern Iceland.

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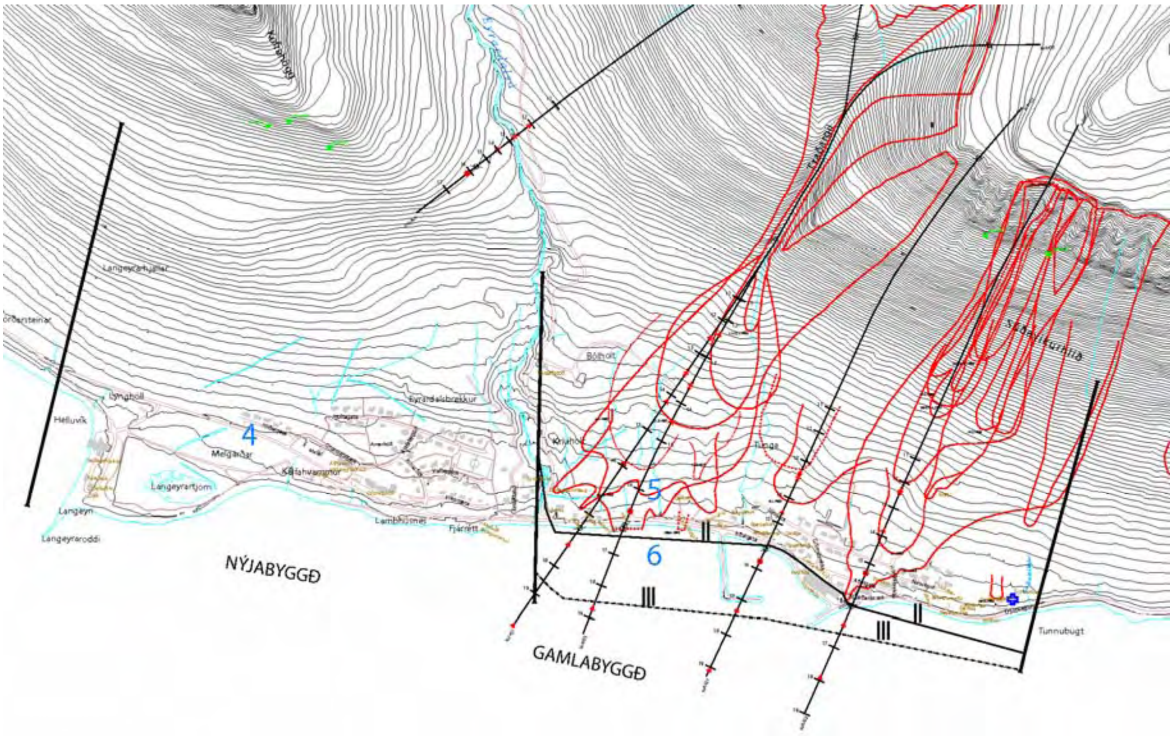

Figure 2 The evacuation map of Súðavík in northwestern Iceland. The map shows an evacuation zone of level II (id# 5) that was affected by the catastrophic avalanche on 15 January 1995 which killed 14 persons (the longest outline from the avalanche path on the right side of the figure). A zone of level III is intended for even more extreme events (id# 6). The new settlement after relocation since 1995 is in a zone where no evacuations are foreseen (id# 4).

The Gazex® avalanche release system

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ABSTRACT

The Gazex® system uses the detonation of a mixture of oxygen and propan to release avalanches thanks to different effects. The complete process is now perfectly adjusted to constitute a powerful preventive avalanche managing system in all weather conditions. New developments and improvements have been made and the system is foreseen to remain a leading product for customers of all mountainous regions.

1. INTRODUCTION – HISTORY

From 1973 to 1990, the Schippers company manufactured 150 C.A.T.EX (Cable transporting Explosives) for preventive avalanche release. However, this effective system presented some disadvantages relating to rim ice on cables, handling of explosives, duration of release, and danger to helicopters due to the long and high spans of cables and many hours spent on maintenance. A new system was researched then from 1987 (Schippers, 1992).

The objective was to achieve the following:

- Leave the device on site during the winter to avoid entering a risky zone.
- Have a static device.
- No more use of explosives and fuses.
- Control the system from an easy access place such as down in the ski patrol office
- Be able to release avalanches in any weather conditions at any time.
- Simplify the PIDA (Planning of intervention for avalanche release) or avalanche forecasting.

Among several probable projects, a system of release by gas was chosen. The first experiment was carried out with the explosion of 2 plastic bags filled with oxygen and acetylene which had been scotch-taped together. The explosion was successful thanks to an ignitor and to the use of a preset blow torch. This system was abandoned after a few tests because a bundle with several bags seemed difficult to control in an operational climatic environment because of frost and wind. The pursuit of the experiments led to an exploder tube located in the avalanche path to be controlled.

Various gas mixtures were also tested. Shock wave measures were compared in order to obtain the best mixture and it ended up with oxygen and propane. The shock wave thus depends on the volume of gas being produced and is much more powerful.

The idea of using a solid steel tube (exploder) with an opening towards the down hill side with a 30° incidence resulted in a push directed downhill on the snow mantle. The propane being heavier than air, its injection from the bottom of the pipe fills it progressively without loss before ignition

The various phases of the process led to different volumes of exploders depending on the ground profile and avalanche path size. Another important evolution concerns the possible simultaneous shots from two 0.8 m^3 and 1.5 m^3 exploders.

2. THE GAZEX® SYSTEM

The system is composed of a shelter, exploder tubes, pipelines and a radio control system. The polyester shelter, placed on a wooden platform, houses the gas metering devices, the propane bottles, the valves and the receiver unit. Oxygen is stored outside the shelter.

There are two types of shelters: one ‘’autonomous’’ dedicated to one to four exploders and the classic shelter for maximum 8 exploders. The shelter is equipped with a Faraday Cage, a lightning arrester, and meteo instruments. The receiver unit is powered by solar panel, with storage batteries.

The steel exploder tubes are designed to withstand the explosions and exist in several models *i.e.* volumes: 0.8 m^3, 1.5 m^3, 3 m^3, 4.5 m^3.

Firing is controlled by the opening of the valves which free a predetermined quantity of oxygen and propane gas. Gases are stored in the shelter, and brought separately by pipelines down to the exploder where the mixing of the gases happens. After closure of the valves, the spark plugs of the exploder produce an electric arc which detonates the gas mixture. After each shot, the system refills itself to the pre-adjusted tank pressure in preparation for the next shot.

The different phases of the firing process with Gazex® are the following :

- Detonation of the gas mixture inside the exploder creating an overpressure in the latter (for 2 milliseconds), CO_2 and water steam are obtained.
- Ejection of gas at the open end of the exploder (20 millisecondes); ejection speed towards the mantle of 1200m/s (at the mouth of the exploder).
- The gases shock the mantle with a 30° incidence; the speed of gases at the level of the snow mantle varies between 500 and 600 m/s.
- These gases expand after ejection and disturb the surrounding air which creates a moving shock wave.

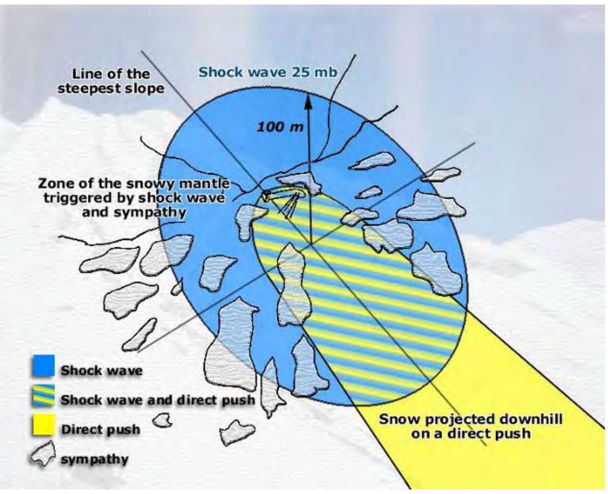

Figure 1 The different Gazex® effects

It is important to note that Gazex® does not release only by shock wave. The following effects can be noted (Chernouss and others, 2006): If the snow mantle is not unstable enough to start the release of the avalanche by shock wave, then the Gazex® causes triggering through a direct downhill push on the snow mantle (release is pear shaped). Then, if the instability increases, but not enough to release only by shock wave, it can be observed that the direct push projected on the central part of the slide path also causes a release in the adjacent areas of the slide path, by transmission and shock wave combined. Releases by shock wave are efficient mainly during the snow fall or just after, because it is when the snow mass to be lifted is the lightest; the density of snow is low and there is more air in the snow mantle. Later the snow becomes more dense and transforms itself structurally.

An important evolution allowed to replace the anchoring rods by a counterweight system when the slope, where the exploder is to be installed, does not have sufficient stability. This inertial system is more and more used.

Figure 2 Classic and inertial Gazex® systems (respective volumes of 4.5 and 0.8 m^3)

The control software is now designed to download the following recorded data:

- the weather conditions at the shelter such as temperature, wind direction and velocity, solar radiation ...
- the amount of gases stored and the battery voltage. The battery is recharged both using a solar panel and a small wind turbine.

Confirmation of the explosion and the avalanche is shown on the screen as a graphic after each shot from a seismometer placed on the ground near the shelter. Evolution of the software allows to import weather data automatically to the NIVOLOG software, to sort and stock the firing data. The control unit and computer are mostly stationery, but it is possible to have a mobile control unit in a vehicle.

To optimize the system, all the components of the ignition box have been duplicated, when sunlight is not sufficient, solar panels and batteries are also doubled.

3. CONCLUSION

Today, nearly 1600 exploders have been installed worldwide to protect ski slopes, skilifts, roads and highways, mining installations and villages mainly in Europe (about 800 in France, 250 in Austria), South and North America. New markets are mainly countries of the former USSR.

TAS, the manufacturer of Gazex®, is constantly looking at technical innovation for avalanche release system. Further developments will consist in a large study about the Gazex® behaviour, the detonation characteristics depending of gas mixture parameters and fatigue consequences. In parallel, the new Daisy Bell® device offers an alternative to the use of explosives in helicopter bombing.

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Avalanche protections in Iceland designed by VST Consulting Engineers Ltd.: Experience and examples

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ABSTRACT

VST Consulting Engineers Ltd. have been involved in the development and design of avalanche protection work around Iceland since 1990. Methodology and design criteria, including legislative framework have evolved considerably during the period, mainly due to enormous increase in safety requirements after the destructive avalanches in Súðavík and Flateyri in 1995. Extensive research on avalanches and protection measures and acquired experience of structural design and constructions of avalanche defences has also lead to improvements.

VST have carried out appraisal studies for avalanche protections at close to fifteen sites around Iceland, occasionally in cooperation with other consultants and specialists. The studies have included the design of deflecting dams, catching dams, braking mounds and steep splitters in the runout zones and supporting structures in the starting zones.

Most of the protection proposals involve the design of dams. Deflecting dams have generally been designed as earth fill dams and catching dams are also designed as earth fill dams with a steep front facing the avalanche constructed with earth reinforcement systems.

The first major avalanche protection project in Iceland was undertaken by VST in Flateyri, northwest Iceland, designed in 1996. The protective structures consist of two deflecting dams, located directly above the village that form a wedge shaped structure in the hillside, with a small catching dam extending between the two deflecting dams in the lowermost part of the area.

1. INTRODUCTION

VST Consulting Engineers Ltd. have been involved in the development and design of avalanche protection work around Iceland since 1990. The work includes hazard assessments, appraisal studies, technical design, preparation of tender documents, supervision during construction and general consulting on technical issues. More than 20 separate projects of various proportions have been completed during this period.

Methodology and design criteria, including legislative framework have evolved considerably for the past 15–20 years, mainly due to enormous increase in safety requirements after the destructive avalanches in Súðavík and Flateyri in 1995. The legislative framework consists of an act on protective measures against avalanches and landslides (Icelandic Ministry for the Environment, 1997a), a regulation with the same title (Icelandic Ministry for the Environment, 1997b) and a regulation on hazard zoning due to snow- and landslides, classification and utilisation of hazard zones, and preparation of provisional hazard zoning (Icelandic Ministry for the Environment, 2000) which is under constant revision, the last one in 2007.

Extensive research on avalanches and protection measures and acquired experience of structural design and constructions of avalanche defences has also lead to improvements in the design of the defence structures (SATSIE, 2006).

2. DESIGN PROCESS

In Iceland local communities represent the buyer of avalanche defences. The bulk of the financial contribution is originated from the Icelandic Avalanche and Landslide fund and project management is carried out by the Government Construction Contracting Agency (GCCA) (Framkvæmdasýsla ríkisins).

Avalanche hazard is assessed by the Icelandic Meteorological Office (IMO) prior to designing avalanche protection and presented and attested by individual Hazard Zoning Committees. Technical reports and hazard zoning maps are evidently the main input when designing avalanche defences. Technical reports describe topographic and climatic conditions and assessment on avalanche hazard based on model estimates.

The design process of avalanche protection measures can be divided into four stages: 1) Appraisal study 2) Environmental impact assessment (EIA) 3) Technical design 4) Construction and supervision.

Protection structures can have striking visual impact on towns and hillsides, leading to negative discussion and criticism. Landscape architects have therefore increasingly been involved in the design process at an early stage. This has often lead to successful integration of defence structures into the environment in addition to creating attractive outdoor and recreational areas for public use. The inhabitants involved should furthermore be kept informed and involved at all stages of the design. Such successful integration along with the added number of occasions when the protection dams have proven useful in deflecting or controlling avalanches has helped to reduce negative criticism.

3. PROTECTION ALTERNATIVES

Avalanche protection structures are considered as a permanent control against avalanches, preventing damage to residential properties as well as casualties or accidents. Supporting structures are installed to support the snow pack in the starting zones. They are usually made of steel. Two basic types include bridges (rigid steel barriers) and snow nets. Grounding conditions and risk of rock fall are ruling factors when determining which type of supporting structures should be selected. Deflecting dams are the most favorable type of protection structures in the runout zone (McClung and Schaerer, 1993, SATSIE, 2006). Deflecting dams are most frequently constructed as simple earth-fill dams with heights up to 20 m. The steepness of the slopes is subject to the soil properties of the earth fill. Catching dams are constructed perpendicular to avalanche paths and function as arresters (McClung and Schaerer, 1993, SATSIE, 2006). Most catching dams are earth-fill dams and many are designed with steep front constructed with the aid of earth reinforcement systems or concrete. The dams have been built up to 20 m high. Braking mounds or retarders are located in avalanche paths in order to dispatch the energy of the avalanche and reduce its speed (Hakonardottir and others, 2003). The mounds have been built in staggered rows up to 10 m high preferably made of earth-fill with steep fronts. In cases where individual buildings or structures need to be protected against avalanches protection structures are designed in a close relation with the structure itself and in some cases integrated into the structure or building. Splitters of various sizes and types are most frequently constructed (McClung and Schaerer, 1993).

4. CASE STUDIES

VST has carried out appraisal studies for avalanche protections at close to fifteen sites around Iceland, occasionally in cooperation with other consultants and specialists. The studies have included deflecting dams, catching dams, braking mounds and steep splitters in the run out zones of avalanches and supporting structures in the starting zones. Following is a description of a few selected projects.

4.1 Flateyri

The first major avalanche protection project in Iceland was undertaken by VST in Flateyri, northwest Iceland in 1996. The village is threatened by snow avalanches from two major avalanche paths. In October 1995, it was hit by a catastrophic avalanche from Skollahvilft, causing 20 casualties. Prior to that, avalanches from Innra-Bæjargil had damaged some houses without causing casualty. VST carried out an appraisal study including risk assessment in co-operation with the Norwegian Geotechnical Institute (Sigurðsson and others, 1998b). Following the appraisal study an EIA was carried out by VST followed by technical design of the protection structures. The defences, shown in figure 1, consist of two deflecting dams, 15–20 m high and 600 m long each, and a 10 m high and 350 m long catching dam. The dams are made of 650,000 m3 of fill material from the site. The avalanche defences were inducted in the year 1998.

Figure 1 Avalanche defences in Flateyri. The dams are completely covered with vegetation (photos: Hallgrímur D. Indriðason).

The defences have already made a difference for Flateyri. Only a year after their completion, in February 1999, a large avalanche originating in Skollahvilft hit the eastern dam and was deflected into the sea. In March 2000 another avalanche from Innra-Bæjargil hit the western dam and was deflected to the shoreline (Johannesson, 2001).

4.2 Ísafjörður, Funi disposal facility

A garbage disposal facility for the community of Ísafjörður has been in operation since 1993. It is located in the valley of Engidalur, beneath an active avalanche path in Kirkjubólshlíð. The facility was hit by an avalanche in October 1995 and was severely damaged. Following the event VST was assigned to design an avalanche protection for the facility. It consists of two 100 m long and 10 m high earth filled deflecting dams which form a wedge shaped structure directly above the facility (figure 2). The front of the wedge (the “bow”) is steep over a 50 m long section but the rest of the dams is built with rock fill and a conventional slope of the fill material used. Construction of the steep part of the dams was completed in 1998 and the complete structure in 2002.

Figure 2 Deflecting dams in Engidalur, Ísafjörður. The dams form a wedge shaped structure (photos: Hallgrímur D. Indriðason).

The dams have repeatedly been hit by avalanches from Kirkjubólshlíð. The first one fell in February 1999 prior to the full completion of the dams, followed by avalanches in: April 2001, January 2004, January 2005 and March 2007. The dams have on all occasions prevented accidents to employees and damages to the facility (IMO, 2003; Arnalds and others, 2007; IMO, 2005).

4.3 Neskaupstaður

4.3.1 Drangagil area

The town of Neskaupstaður is located in the east fjords of Iceland. A large part of the residential area is threatened by avalanches from several well defined avalanche paths. Preparation for the construction of avalanche defences in the Drangagil area was initiated in 1997. Defence structures in the Drangagil area are of three types: 1) Supporting structures, 2) braking mounds and 3) a catching dam. The supporting structures are located in the starting zone of Drangagil and include approximately 1000 m of 3.5−4.0 m high avalanche nets. The braking mounds are positioned in two rows above the residential area, a total of 13 mounds (Tómasson and others, 1998a). The mounds have a steep front facing the mountain, are 10 m high and each mound is approximately 10−12 m wide at the top. The 400 m long catching dam is located at a distance of 100 m from the residential area. The dam is 17 m high with a steep front facing the mountain (see figure 3). The total volume of earth fill comprising the catching dam and the braking mounds is approximately 260,000 m^3. The steep dam fronts facing the mountain are built with earth reinforcement system made of steel. The avalanche defences were inducted in 2002.

4.4 Tröllagil area

The most extensive appraisal study yet, carried out by VST, is a proposal for the Tröllagil-area in Neskaupstaður, which was completed in 2003 (Sigurðsson and others, 2003). Following construction of avalanche defences in the Drangagil area in Neskaupstaður, defence options in the Tröllagil area (western most part of the residential area) were considered. Emphasis was put on two avalanche paths which were considered to be the most destructive ones in that area. Avalanches and mud slides are frequent from those paths and a few avalanches have reached the shore (Ytra-Tröllagil in 1894 and Miðstrandarskarð in 1974 causing 7 casualties).

Figure 3 Avalanche defences in Drangagil, Neskaupstaður. Catching dam with steep front and supporting structures (photos: Hallgrímur D. Indriðason).

The proposed defence structures in the Tröllagil area are of four types: 1) Supporting structures located in the starting zones of the two gullies, 3.5–4.5 m high and approximately 1800 m long. 2) Braking mounds in two rows above the residential area, a total of 23 mounds. The mounds are designed with a steep front facing the mountain. The mounds are 10 m high and each mound is approximately 10 m wide at the top. 3) A catching dam, 620 m long at a distance of approximately 100 m from the houses closest to the dam. It is 16.5–18.5 m high with a steep front facing the mountain. 4) A deflecting dam west of the residential area. The dam is 390 m long and 17 m high and is designed with a conventional slope of the fill material used.

Figure 4 Proposed avalanche defences in the Tröllagil-area, Neskaupstaður. A catching dam with steep front, braking mounds and a deflecting dam (photo: Hallgrímur D. Indriðason, computer illustrated).

The total volume of the catching dam, braking mounds and deflecting dam is estimated to be around 565,000 m^3. The steep fronts facing the mountain will be built with an earth reinforcement system made of steel.

Local residents were in general satisfied with the design of the Drangagil protection measures and the defence structures were therefore, where possible, designed with the same appearance. The proposal has been accepted and construction is expected to start in 2008.

5. CONCLUSION

Avalanche defence structures have been and are being constructed systematically in Iceland in accordance with laws and regulations. VST Consulting Engineers Ltd. have been one of the leading consultants in the design and preparation of avalanche structures in Iceland. The projects have been of various sizes and proportions, including supporting structures in the starting zone of avalanches and dams and mounds in the run out zone. Throughout these projects VST has cooperated with international consultants from Switzerland, France, Austria and Norway. Knowledge and experience on the design and functioning of avalanche defences gained from these projects will strengthen the basis for design and construction of future avalanche protection measures in Iceland.

The avalanche defences which have now been constructed have already established credibility among the public as they have deflected and controlled avalanches over their relatively short lifespan.

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Insuring against the unthinkable: A profile of Iceland catastrophe insurance

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ABSTRACT

Iceland Catastrophe Insurance (ICI) was founded in 1975 as a public undertaking by a special Act of the Althing (parliament) of Iceland. Iceland Catastrophe Insurance functions as an insurance company. The purchase of catastrophe insurance for earthquake, volcanic eruption, snow avalanches, landslides and floods is compulsory for all buildings; as well as for contents insured against fire. Buildings are insured according to their valuation for fire as assessed by the State Land Registry. Since fire insurance of buildings is compulsory in Iceland, all buildings are likewise insured against natural perils covered by the programme. The catastrophe cover is a stand-alone policy; the fire insurance companies collect the premiums alongside fire premiums in exchange for a collection fee. There is a single premium of 0,25 per mille irrespective of location or risk. Infrastructure lifelines – waterworks, geothermal heating systems, sewage systems, electric installations, bridges and harbour installations as well as ski lifts – assets not normally insured against fire, are separately insured with the Corporation. The premium is 0,2 per mille for lifelines. The policy only insures against direct losses resulting from the abovementioned catastrophes. There is a deductible of 5% for each loss as well as a minimum deductible indexed according to the index of building costs.

Snow avalanches are among the perils covered by Iceland Catastrophe Insurance. Direct property and contents losses sustained in the tragic avalanche events of 1983, 1994 and 1995 were assessed and claims paid out. Since then a number of smaller, isolated losses have occurred. ICI was also involved in mitigative measures against snow avalanches (as well as other perils). The Avalanche and Landslide Fund, in its first incarnation, from 1985–1995, received 5% of ICI's gross written premiums. As an interim measure, from June 1995 – June 1997, 38% of the premium income was paid into the Avalanche and Landslide Fund. A further 10% surcharge on catastrophe premiums was also levied during this time for the benefit of the Avalanche and Landslide Fund. Since June 1997, with the adoption of a separate Prevention Tax (of 0.3 per mille) on fire insured property, the Avalanche and Landslide Fund has been self-funded. Since that time, Iceland Catastrophe Insurance has only rarely been involved with snow avalanche loss prevention measures, most notably in the protection of public utility structures.

Extreme runout distance of snow-avalanche transported boulders linked to hazard assessment; some case studies in Northwestern and Northern Iceland

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ABSTRACT

We propose and quantify an α/β ratio for boulders transported by snow avalanches based on the proportional property of two topographic parameters (i) runout distance α and (ii) path steepness β. These two parameters were determined from geomorphological investigations in back country areas where no human infrastructures and major activities have occurred. We suggest that the application of the proposed α/β ratio within inhabited areas helps to determine the expected runout of potential maximum magnitude snow avalanches and thus potentially improves hazard zoning for the mitigation of avalanche danger in populated areas. We tested this approach in areas with towns and villages exposed to avalanche danger. Our results confirm that large snow avalanches have already occurred in some areas, while such avalanches have to be expected in other areas where no or only smaller events have yet been recorded.

1. INTRODUCTION

Among all terrestrial natural hazards occurring in Iceland, including earthquakes, volcanic activity, floods, storms and mass movements, snow avalanches caused the main toll in human lives and economic loss during the last century (Jóhannesson, 2001; Jóhannesson and Arnalds, 2001). Thus, snow avalanches represent a significant hazard in Iceland for settlements and vital infrastructures (*e.g.* transportation corridors). However, since 1995, numerous mitigation measures have been undertaken to protect the threatened areas and extensive modeling approaches have been developed (see the numerous work available for several sites at http://www.vedur.is/ofanflod/haettumat/) (Magnússon, 1996, 2003; Bernharðsdóttir, 2001).

Based on our observations from back country field investigations, we were able to recognize the maximum downhill extension of snow avalanches. Boulders deposited by snow avalanches with extreme runout distances were selected to determine the minimum extreme runout of the avalanches.

Topographic parameters such as the extreme runout and the path steepness are used to establish a proportional relationship that enables the transfer of the observed data from the back country sites into areas where human activities (*e.g.* agriculture, construction sites) have displaced or removed valuable geomorphic indicators (mainly boulders deposited by avalanches). We suggest that our approach will contribute to enhance the safety of people in threatened areas by supplying pertinent information for hazard zoning, because (i) even if snow avalanche events are reported since 1118 in the country (Björnsson, 1980), no village nor town possesses a reliable record of yearly snow avalanche occurrence before *c*. 1950-1970; (ii) the recorded maximum extension of avalanches was fairly approximate before these dates; (iii) several locations where settlements developed were considered to be safe before a dramatic snow avalanche event occurred (Arnalds and others, 2004), and (iv) recent catastrophic events followed new, unexpected paths or reached a larger runout distance than previously recognized.

In the present paper, we test the pertinence of the field data, and discuss the validity of the application of the proposed α/β ratio in inhabited areas based on known runout distance of long reaching snow avalanches.

2. BACK COUNTRY REFERENCE PATHS

In all Icelandic snow avalanche prone areas, numerous scattered rock debris and boulders are visible in the lowland, revealing a recurrent activity up to several tens of meters downhill from the foot of the talus slope (Decaulne and Sæmundsson, 2006). Most of the time, such boulders are the only lasting indicators for avalanche runout after snow melt. Boulders transported by snow avalanches represent the minimum farthest downhill runout of the avalanches, since the snow deposit generally reaches farther downhill than the boulders (Fig. 1). Field observations of such boulders therefore allow an estimation of the spatial extent of large snow avalanches.

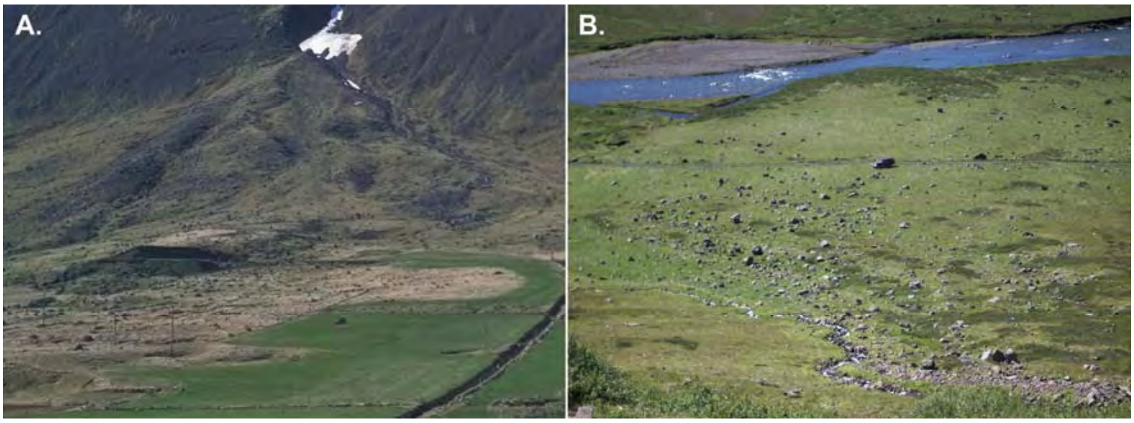

Figure 1 Scattered snow avalanches transported boulders downhill along snow avalanche paths: A – above the village of Hnífsdalur, Northwestern Iceland, B – in the remote part of the valley Fnjóskadalur, Northern Iceland (photos: Armelle Decaulne).

It is important to recognize the original boulder deposits as deposited by the snow avalanches without their subsequent perturbation (*i.e.* displacement, destruction). A further point which has to be taken into account is the fact that boulders deposited by different snow avalanches may have accumulated within the same area. However, it appeared to be possible to distinguish boulders deposited by different avalanches based on the vegetation cover.

Six snow avalanche paths were selected, in four different back country areas (Botn í Dýrafjörður, Reykjaströnd, Fnjóskadalur and Bleiksmýrardalur (Fig. 2). The six paths were analyzed in the field, emphasizing (i) the extreme runout of boulders transported by snow avalanches, *i.e.* point α in this study and its corresponding angle to the top of the snow avalanche starting zone, and (ii) to the path steepness or angle β, measured in the field from the position at which the slope angle equals 10°, using a Suunto inclinometer (0.5° precision). According to McClung and Schaerer (1993) who observed a proportional relationship between parameters α and β, the following expression has been formulated for each investigated path:

$$\alpha = x \cdot \beta$$

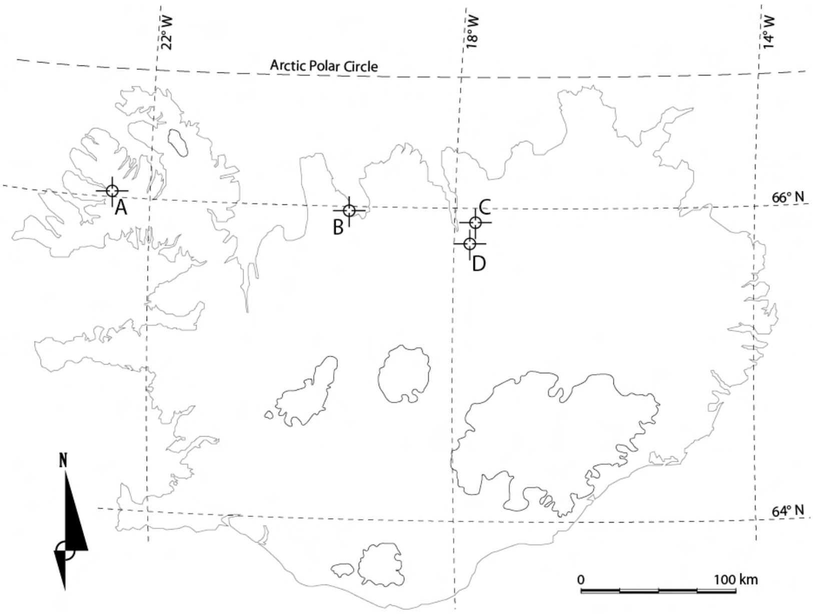

Figure 2 Location of the reference paths: A – Botn í Dýrafjörður, B – Reykjaströnd, C – Fnjóskadalur and D – Bleiksmýrardalur.

3. RESULTS OF THE TRANSFER TESTS IN INHABITED AREAS

3.1 The case study of Patreksfjörður, Northwestern Iceland

Patreksfjörður is a small town (622 inhabitants on December 1, 2007) in the Northwestern Peninsula. The extent of all reported snow avalanches that reached the village are shown in Figure 4A. Several major events are reported in the beginning of the 20th century (Ágústsson and others, 2003), reaching the sea at the location of the present-day harbor. Although the runout of these two events, occurring before 1930 is not exactly known, their runout crosses some of the present-day residence and industrial buildings. Since then, three shorter snow avalanches reached or approached the settlement area and two slushflows devastated the areas by the rivers (another event is known from the mid 19th century). The most recent snow avalanche events, in 1989, 1995 and 2000, were of lower magnitude.

The application of the determined α/β relationship locates the lower part of the runout zone, from where the slope angle reach 10° to the furthest expected reach of transported rocky material. Almost the whole settlement is located within the runout zone of potential snow avalanches, either below or above the β isoline. This highlights the high hazard degree of

Patreksfjörður. Another interesting point of the proposed method is its agreement with known large snow avalanches: the longest reach of snow avalanches in the harbor area matches with the expected longest runout of snow avalanche transported boulders. The application of the α/β relationship in Patreksfjörður also emphasizes the risk in areas where snow avalanches have not yet been recorded (central and eastern parts of the town). However, the topographic based approach proposed here is unable to predict the runout distance of slushflows, as shown by the case of the 1983 event that follows the easternmost river. Slushflows present a particular case of avalanches that are not directly influenced by slope topography.

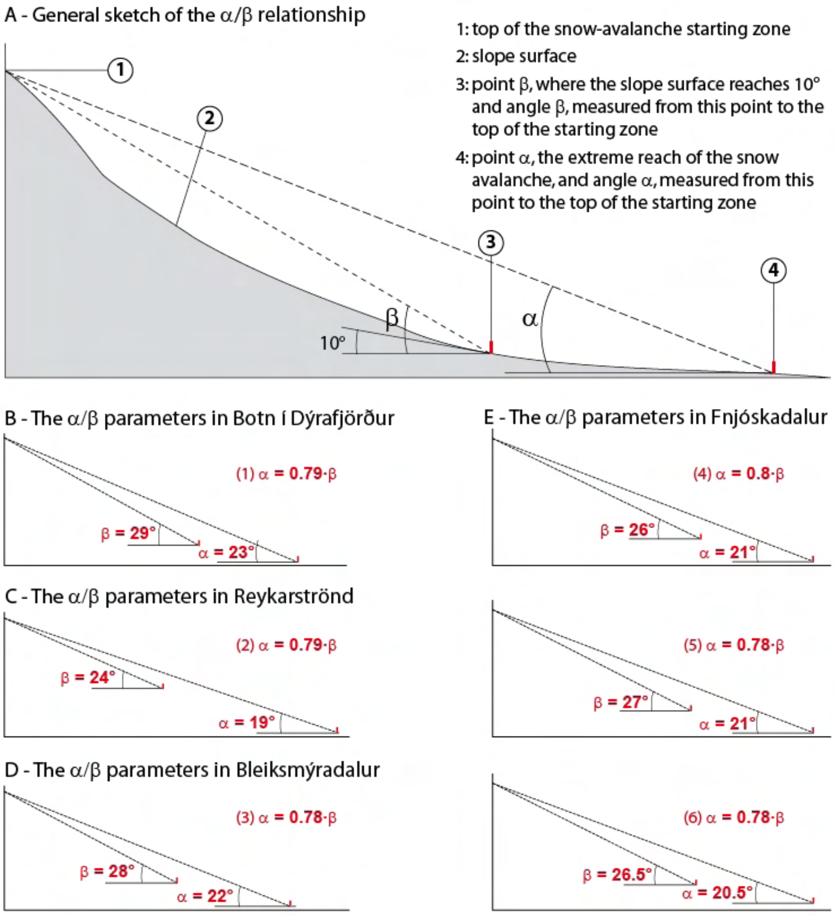

Figure 3 The α/β relationship (A, modified from McClung and Schaerer, 1993) for several snow avalanche paths in Botn í Dýrafjörður (B), Reykjaströnd (C), Bleiksmýrardalur (D) and Fnjóskadalur (E).

3.2 The case study of Hnífsdalur, Northwestern Iceland

Hnífsdalur (235 inhabitants on December 1, 2007) is a small village in Northwestern Iceland. Located at the entrance of a narrow valley, snow avalanches are expected from each of the two valley slopes (Fig. 4B). The northern slope is well known for releasing snow avalanches, while they are far more seldom from the southern slope, at least above the settled area. Several long runout distance snow avalanches are reported since 1673 (Arnalds and others, 2002), and the 1910 event was devastating. However, only a few buildings are located on the already recognized snow avalanche runout zone, and the northeastern part is the most exposed one.

During field investigations, the presence of large boulders far down the northernmost path drew attention as no record reported such a long runout event. According to the analysis of aerial photographs, the position of these boulders was related to snow avalanche activities from the above path. The application of the α/β relationship in this area confirms that snow avalanches reaching close by the river might be expected from the north westernmost path. However, as covering hay fields, the original location of the boulders cannot be confirmed with precision, but still provides an indication of the extension of the snow avalanche. The longest recorded snow avalanche in the area, which occurred in January 2005, is not the longest expected one. The Figure 4B therefore emphasizes that buildings in Hnífsdalur are mostly located within the runout zones of potentially large events.

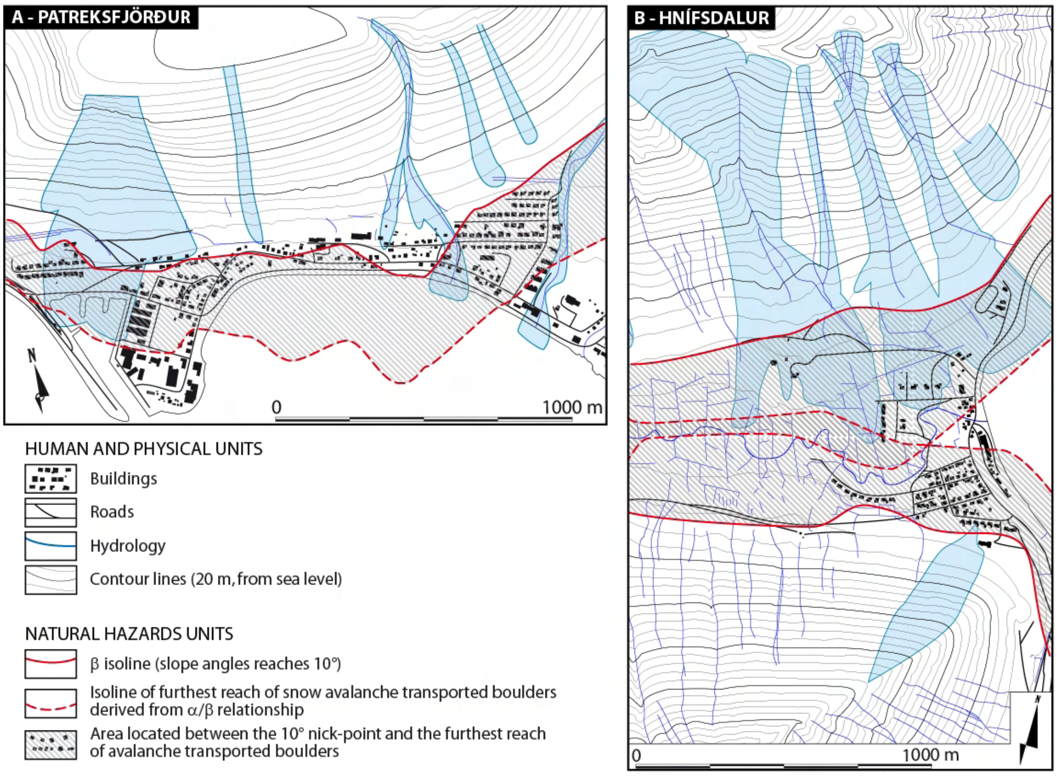

Figure 4 The extent of known events and the results of the α/β relationship in Patreksfjörður (A) and Hnífsdalur (B).

4. DISCUSSION AND CONSLUSION

We have tested a new geomorphic approach based on known proportional relationships between topographic parameters to delimitate snow avalanche hazard zones into inhabited areas. The results obtained in two areas, where snow avalanche records are partly reliable or where field indicators exist, show the capability of the empirical approach to be transferred. Here, the crucial parameters are determined in the field. Moreover, the obtained delineation is obtained through the identification of boulders deposited by snow avalanche and not by the actual runout of the snow avalanche (*i.e.* the extent of the snow itself). Such results are of interest for risk assessment. In Patreksfjörður, the obtained results are in accordance with past events and in Hnífsdalur, our results are in accordance with the observed geomorphological evidence. Also tested in other places, results were equivalent.

The limits of the method were also determined: (i) it is applicable for “normal” path terrain profile, not for slopes with successive benches; (ii) the delineation proposed in inhabited areas is primary, as it does not consider the successive impacts of the snow avalanche with buildings, which slow down the flow; (iii) the approach does not include any magnitude-frequency quantification, instead it determined a recurrence of snow avalanches of maximum magnitude over time, up to 200 years at least. To validate this kind of field based approach, further investigations are in progress.

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Sediment transport associated with snow avalanche activity and its implication for natural hazard management in Iceland

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ABSTRACT

Snow avalanches transport considerable amounts of debris down into the lowlands during avalanche cycles. In that sense snow avalanches are a significant sedimentary transport process. Until recently it has not been regarded as an important mass wasting process in Iceland and not recognized as such. By the use of sedimentological and stratigraphical methods, debris transported with snow avalanches can be recognized in the field. The geomorphologic data can thus be used in combination with other historic, methods to evaluate potential impact of snow avalanches in the runout zones. Studies of this kind have only recently attracted attention in avalanche-hazard assessments. From 1995 extensive studies of morphological impact of full-depth snow avalanches have been carried out in NW- and N-Iceland, mainly focusing on the morphological impact of events that occurred during a heavy snowstorm in October 1995. The path erosion and debris transport were extensive, leaving strong evidence for snow avalanche research.

1. INTRODUCTION

Snow avalanches significantly contribute to slope denudation in mountainous environments (Rapp, 1960; Luckman, 1977, 1978) by affecting the regolith and existing landforms. In North and Northwestern Iceland, snow avalanche contribution to relief development during the Holocene period is attested through the talus cones and talus slopes. Although it attracted only little attention in Iceland until the last few years, other widespread small to medium scale landforms due to snow avalanches are recognized on slopes in the northern part of the country (Sæmundsson, 2005; Decaulne and Sæmundsson, 2006a, 2006b).

The amount of debris transported by snow avalanches is chiefly dependent on the type of snow flowing down, especially based on its water content. This determines the flowing phase of the snow avalanche from source to deposit, and therefore its capability to transfer debris downslope, so its geomorphic impact. Following Blikra and Nemec (1998), snow avalanches are categorized as (1) powder avalanches, (2) dry avalanches, (3) wet avalanches and (4) slush flows. The figure 1 illustrates the relationship between snow, water and debris content: the more water the snow contains, the more efficient is the snow avalanche from a geomorphological point of view. Therefore, the sediment transport is expected to be the most important during slush flows occurrence, while powder avalanches have a very limited impact on regolith. From a human point of view, all snow avalanches are expected to present great danger: the blast prior to the high velocity moving powder avalanches is highly destructive, but the slower motion of dense slush flows represents a real threat for building structures and people involved. The meteorological conditions conducing to the snow avalanche triggering are consequently of primary importance. For the same reason, the timing of the snow avalanche occurrence during the October to May cold season is relevant. The relationship between weather conditions, snow cover thickness and frozen or unfrozen regolith determines the snow metamorphosis, the debris yield involved within the flow, thus the sediment transport and the visible evidence of snow avalanche activity.

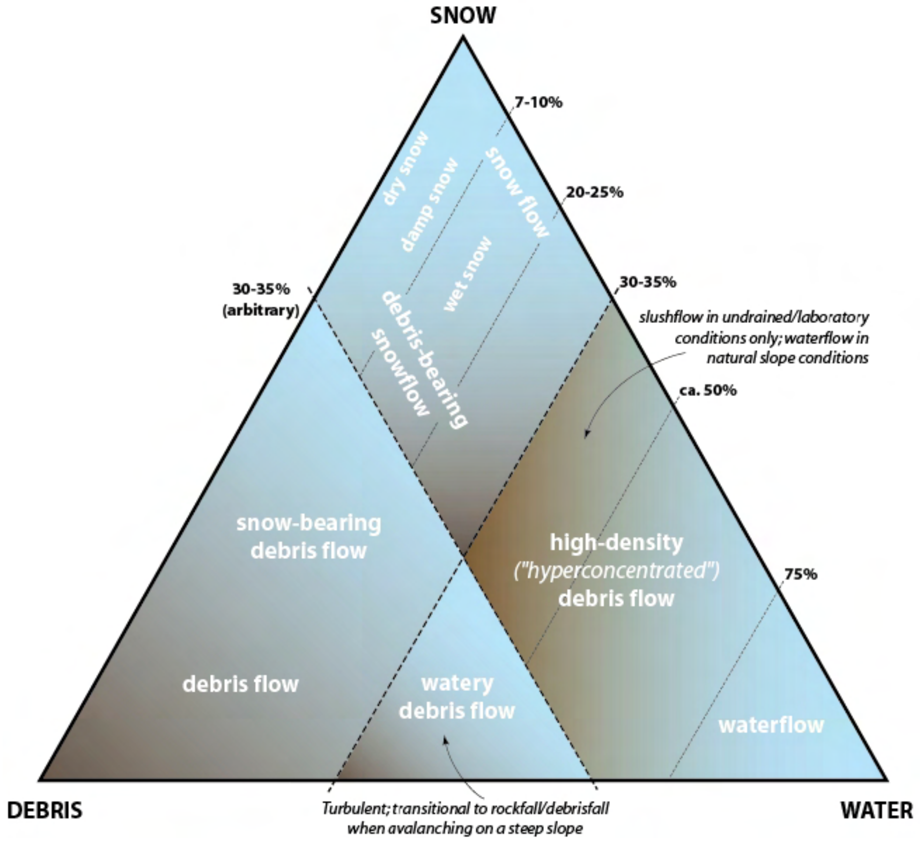

Figure 1 Classification of snow avalanches according to water and debris content: the more the snow avalanche is water rich, the more debris amounts are mobilized (modified from Blikra and Nemec, 1998).

2. THE OCTOBER 1995 SNOW STORM IN NW- AND N-ICELAND

After a mild autumn, a series of low pressure areas struck Iceland, causing severe winter storms from October 21st to 26th, 1995, following unusual pathways (Fig. 2). Due to a high temperature gradient between warm late summer temperature over the British Islands and Northern Europe (+20 to +25°C) and cold winter temperature over Eastern Greenland (–20 to –25°C), strong winds brought heavy snowfall in Iceland, that accumulated during one week on an unfrozen ground. Exceptional amounts of snow were reported from several locations in north and northwestern Iceland, and the strong winds caused heavy snowdrift from the flat plateaux to the leeward upper slopes. It resulted in a high snow avalanche activity over the whole country. Large snow avalanches occurred *e.g.* in the town of Flateyri. The Botn í Dýrafjörður valley, the Fnjóskadalur valley and the Bleiksmýrardalur valley (Fig. 3) were reported to be specifically avalanching. The largest toll from this snow storm

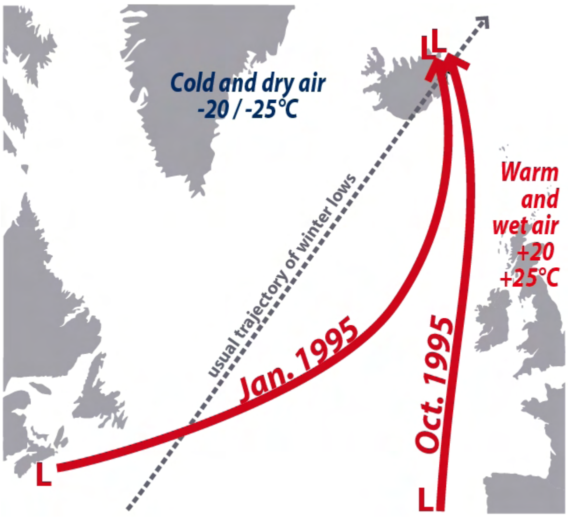

Figure 2 The unusual pathways of the 1995 lows that released series of snow avalanches.

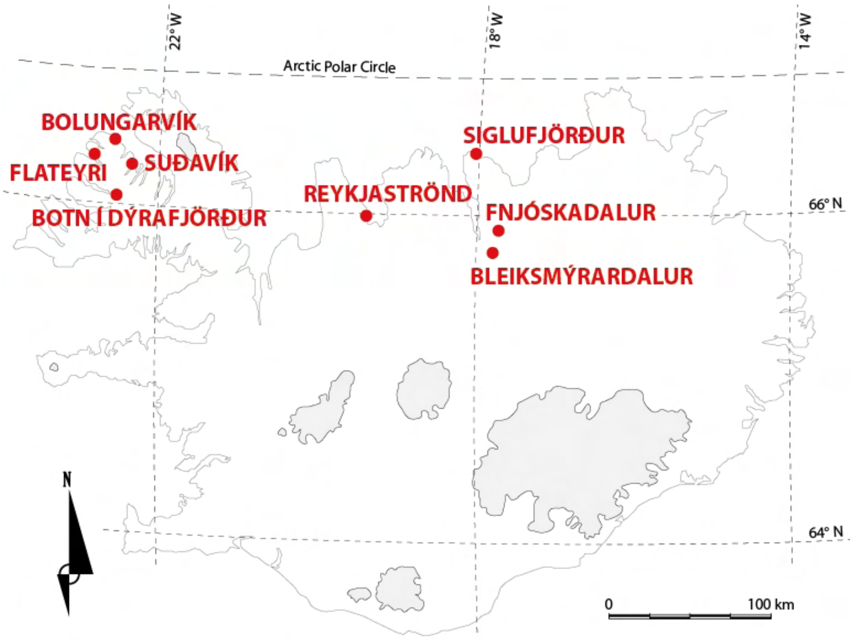

Figure 3 Location of N- and NW-Iceland places cited in the text.

Figure 4 Large boulders transported to the deposition zone by the snow avalanche that hit the town of Flateyri in October 1995 (photos: Þorsteinn Sæmundsson).

occurred in the town Flateyri, where 20 people lost their lives. A severe toll was also inflicted on North-western Iceland in January 1995 when an avalanche hit the village of Súðavík, killing 14 people after a snowstorm originating in an unexpected path, release by unusual winter air circulation.

During the snow avalanche event in Flateyri, large boulders were transported down to the runout zone and/or removed from the depositional zone and deposited within the inhabited area (Fig. 4).

Extensive boulder impacts were also reported from the Botn í Dýrafjörður area. There, large rocks over 25 tons were shifted along the path by the snow avalanche. Some of these boulders were originated from the lower track and the upper deposition zone and were redeposited in the lowermost part of the runout zone, leaving impact marks such as ploughing depressions in their pathways (Fig. 5).

In the Fnjóskadalur valley, the October 1995 snow avalanche occurrences were revealed by a mantle of fresh rock debris of various sizes over the talus cones (Fig. 6), together with impact marks on the regolith, debris tails and perched boulders.

Figure 5 The geomorphologic impact of the October 1995 snow avalanche in the Botn í Dýrafjörður area: ploughing marks and shifted boulders were remarkably visible after the snow has melted. The people on the pictures give the scale – indicated by an arrow on the first one (photos: Þorsteinn Sæmundsson).

Figure 6 Rock debris coating after the October 1995 snow avalanches in the Fnjóskadalur valley. The two first photos are taken shortly after the snow melt, and fresh debris transported downslope are clearly visible during the next summers – people indicated by an arrow give the scale in the third view (photos: Þorsteinn Sæmundsson).

3. SNOW AVALANCHE SEDIMENT TRANSPORT AND HAZARD ASSESSMENT

Sediment included within the snow mass flowing down represent of course an increased danger when an avalanche hits people and human properties. Apart from these direct dangers, sediment transported by snow avalanches provide long-lasting evidence of snow avalanche occurrence, providing crucial information on their frequency, magnitude, especially in terms of runout distance. Due to the recurrence of snow avalanche events of various kinds in the same area, from dry-snow avalanches to slush flows in some cases, the accumulation of sediment transported by the snow flowing down build typical landforms, from tiny (perched boulders) to major (large snow avalanches dominated colluvial cones). Sediment sequences of stratigraphical profiles within snow avalanche prone areas, especially on talus cones, reveal valuable information that attest the past recurrence of snow avalanches. In this way, the work from Blikra and Sæmundsson (1998) in Flateyri (Fig. 7), Sæmundsson (2002a, 2002b, 2005) in Bolungarvík and Siglufjörður present great interest in snow avalanche research related to risk assessment, demonstrating the snow avalanche occurrence of past snow avalanches in the direct surrounding of populated areas, potentially at risk. Linking sedimentological information from back country sites to inhabited areas also present a significant interest in snow avalanche hazard assessment (Decaulne and others, this volume).

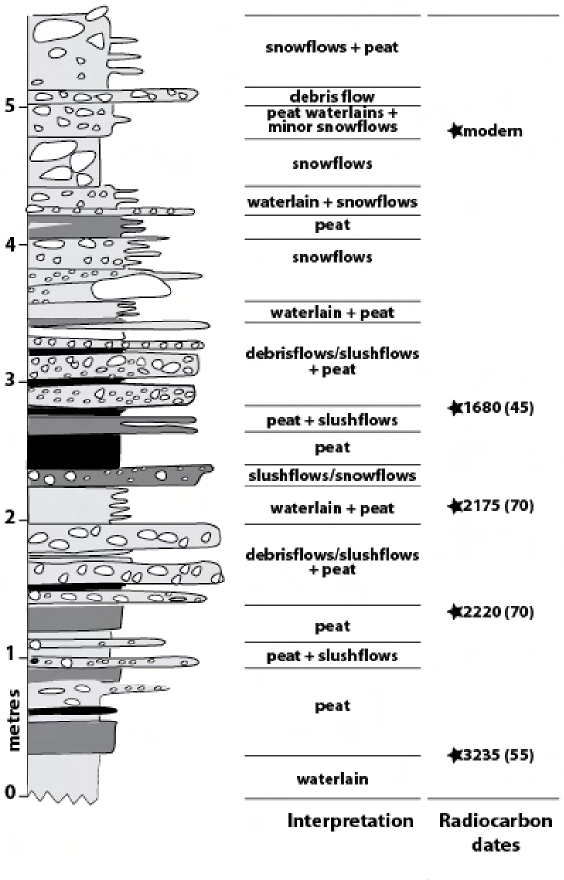

Figure 6 Sedimentary sequences and interpretation of deposits on the Skollahvilft cone above the village of Flateyri. Snow avalanche activity was very common during the last centuries (modified from Blikra and Sæmundsson, 1998).

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Loading of supporting structures under Icelandic conditions. The type of structures and structural requirements in future projects. Results of a field experiment in Siglufjörður

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ABSTRACT

The use of supporting structures and their design parameters under Icelandic conditions have been investigated in an experimental installation of steel bridges and snow nets within a Pilot Project, started in the autumn 1996 above the village of Siglufjörður in northern Iceland. Tension in upper anchors and compressive forces and moments in a post of the D_k = 4 m snow nets have been measured with continuously recording instruments. The maximum tension measured in upper anchors of the snow nets was approximately 350 kN while the maximum compressive force and moment in the snow net post was approximately 150 kN and 15 kNm, respectively. The maximum snow pressure on the steel bridges averaged over the whole construction was inferred to be approximately 30 kPa. The equivalent average snow density for loading computations was found to be 400–500 kg m^{-3} during most of the winter. These observations have been used to formulate requirements for supporting structures under Icelandic conditions based on the Swiss Guidelines for supporting structures from 1990. Lessons regarding the use of snow bridges and/or nets under Icelandic conditions derived from more than a decade of observations and experience in this project are described in this paper.

1. INTRODUCTION

After two catastrophic avalanches in 1995 at Súðavík and Flateyri that claimed 34 lives, a comprehensive national plan for avalanche protection in Iceland was made by the Icelandic government. As a part of this plan, a Pilot Project for investigating the use of supporting structures for Icelandic conditions was organised in a test area in Siglufjörður, northern Iceland. Loading of supporting structures in Iceland may be expected to be different compared with Alpine countries due to a higher snow density that leads to higher loading than in Alpine countries under otherwise similar conditions, but low gliding of the snowpack has a counteracting effect. Guidelines for supporting structures in Alpine countries specify different snow loading on the structures depending on height above sea level and on aspect of the slope (SLF, 1990; FOEN/SLF, 2007). Wet snow metamorphosis and windpacking in the wet and windy Icelandic climate may be expected to lead to more uniform densification of the snowpack in Iceland compared with the continental climate of Alpine countries. Starting zones of avalanches that threaten inhabited areas in Iceland are, furthermore, in the narrow altitude range 300–700 m a.s.l. and there are no indications of a variation in density, gliding or snow loading with height above sea level or aspect of the slope in Iceland. Strength requirements for supporting structures in Iceland need to be based on local observations of density and gliding and should be such that irrelevant variations with height above sea level and aspect of the slope are not imposed.

In addition to the different conditions with regard to snow density and gliding, extreme snow depths in many starting zones in Iceland may be expected to pose serious problems for supporting structures under Icelandic conditions. As a consequence of frequent snow drift in the windy Icelandic climate, snow depth in starting zones is often quite variable. The snow preferentially accumulates in depressions and gullies, where vertical snow heights in excess of 6 m are common, even in average winters, whereas the snow depth on ridges and concave parts of the starting zones remains low throughout the winter. One may expect that supporting structures are impractical due to extreme snow depths in many important starting zones above inhabited areas in Iceland due to this reason. This problem is not unique to Iceland, as similar problems are also encountered in high altitude avalanche starting zones in Alpine countries.

In spite of these problems, it is clear that supporting structures are a viable avalanche protection for several avalanche prone areas in Icelandic villages, especially where conditions are unfavourable for other protection methods and where extreme snow depths in depressions and gullies are not expected. The goal of the pilot experiment was to expose several types of commercially available structures from Alpine countries to Icelandic conditions, measure key quantities related to the loading of the structures, investigate corrosion of the structures under the highly corrosive maritime conditions typical for Icelandic starting areas and test traditional drilling and anchoring methods in Icelandic bedrock and loose materials, which are of volcanic origin and have different properties compared with hillsides in typical Alpine starting areas.

2. THE TEST AREA: LAYOUT AND GENERAL OBSERVATIONS

The supporting structures are located at 490–530 m a.s.l. in Grindagil in the mountain Hafnarfjall west of the village of Siglufjörður. They have D_k in the range 3 to 5 m and are arranged in four rows labelled I, II, III and IV from above (Figure 1, Table 1).

Table 1: Rows of supporting structures in Grindagil in Siglufjörður.

Row	Type	Producer	Length (m)	Number of posts	Height D_k (m)	Cost (kIKR/m)
I and IV	bridges	J. Martin	110	38=24+14	3–5	161
II	nets	Geobrugg	50	14	3–4	156
III	nets	EI	41.5	15	3–5	158

The structures were installed during a five week period in the autumn of 1996 (Hopf, 1996). A separate account was kept of the cost of the structures and installation work for each type of structures. The average cost per m for each type of structures was similar as tabulated in the last column in Table 1 in Icelandic kronas at the 1996 price level. All the supporting structures were hot-dip galvanised, as is generally the rule for out-door steel structures in Iceland. This led to a relative increase in the price of the steel bridges compared with Alpine prices as steel bridges are typically not galvanised in Alpine countries.

The snow depth in a part of the test area became very high during several winters and the structures have become partly overfilled and heavily loaded. In addition to the measurement results, several lessons have been learned from the performance of the structures under these conditions. A part of the snow bridges from J. Martin was damaged in a storm that lifted the footplates of the structures shortly after their installation in the fall of 1996. This was repaired by drilling anchors through the groundplates of all the posts that are mounted on groundplates. Several micropile post foundations in loose material failed in the Geobrugg net row during the first winter. This was repaired in the fall of 1997 by replacing the micropiles of these posts with groundplates. A part of the EI net row with a short spacing between net posts has failed, indicating a design failure in this net type. The wire rope in the top loop of one upper anchors in the Geobrugg net row broke in 2006 indicating that an improvement in the tube shield of these anchors is desirable. Serious corrosion problems have been encountered in all wire ropes of the Geobrugg and EI nets indicating that corrosion protection of traditional Alpine snow nets are unsuitable for Icelandic conditions. These failures have been taken into account in requirements that are made to supporting structures in Iceland which have been formulated based on the results of the experiment in Siglufjörður (Jóhannesson and Margreth, 1999; Jóhannesson, 2003).

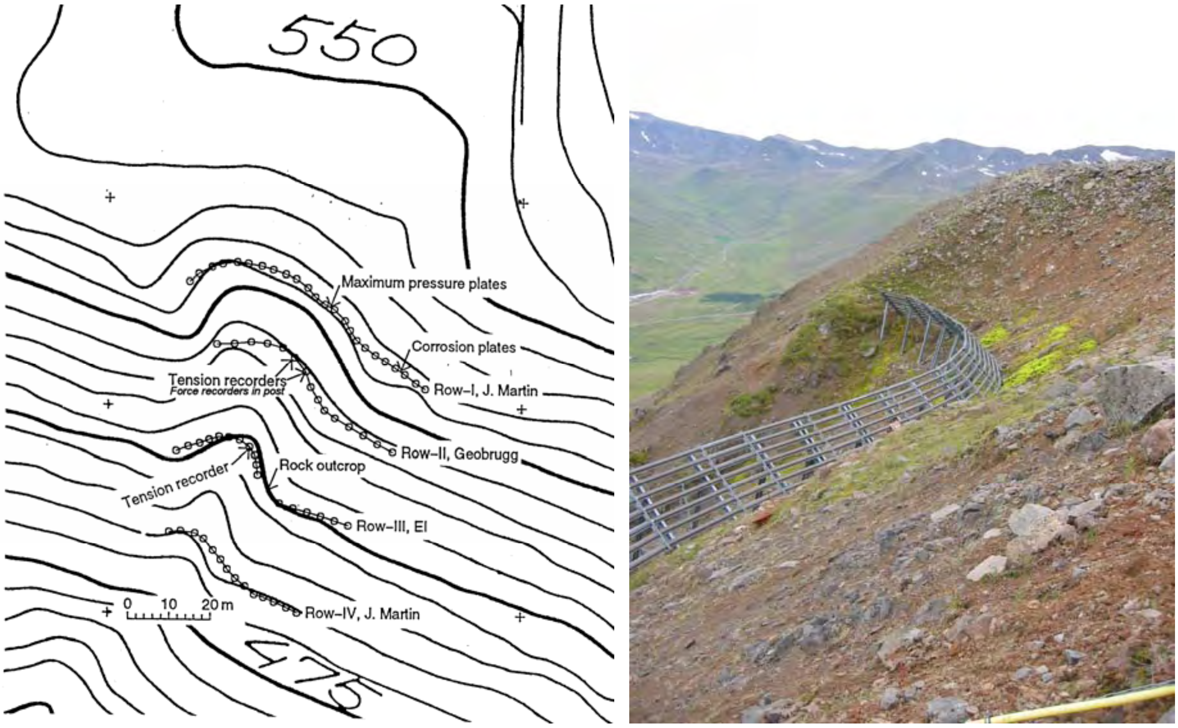

Figure 1 Location map of the supporting structures in Grindagil in Siglufjörður showing the installed instruments (left) and a photograph of the uppermost row of steel bridges (right).

3. LOAD MEASUREMENTS

Tension in three upper anchors of the snow nets, and compressive forces and moment loads in one net post have been measured with continuously recording instruments. Maximum pressure at different height levels in the steel bridges has been measured with maximum pressure plates with an area of 0.5 m^2 (Fig. 2). Snow thickness in the test area, snow density and gliding of the snow pack, as well as corrosion of the structures, have also been monitored.

Figure 2 Uppermost row of J. Martin snow bridges. The line is adapted to the curved terrain. Plates for measuring maximum snow pressure are seen on the left side.

Figure 3 The snow bridges are designed for snow heights up to seven meters.

The height of the highest steel structures in a part of row I is up to D_k = 5 m, which corresponds to a vertical snow depth of more than 7 m (Fig. 3). This part of the row has been overfilled several times by up to more than 2 m (!) without this leading to any detectable damage of the structures.

Figure 4 (left) shows a part of the Geobrugg net line with a tension instrument in one of the upper anchors. Strain recording instruments are located in one of the posts below. This part of the nets has also been repeatedly overfilled by up to 2 m, which in the end led to a break of one of the upper anchor wire ropes as seen in Figure 5 (right). The experience with the overloading of the structure indicates that the steel bridges have greater reserve strength to withstand local overloading without damage. The flexible net structures have not withstood the overloading as well.

Figure 4 An instrument for measuring tension in the Geobrugg net row (left) and a broken top loop in a wire rope anchor from the same row (right).

Figure 5 shows the tension recorded by one of the two instruments in rows II for the eleven winters since the start of the experiment. The tension increases with increasing snow depth in the early part of the winter and typically reaches a maximum between 150 and 350 kN in March to April. The maximum tension varies from year to year, depending mainly on the maximum snow depth of the winter. The onset of melting, typically in the beginning of May, leads to a sharp decrease in the tension. There are no indications of an increase in the loading due to deformation or gliding introduced by melting.

Figure 6 shows the compressive force and the moment from the winter 1997/1998 computed from the strain recorded by four vibrating wire sensors that are mounted about 1 m above the ground on a post in the Geobrugg nets in row II. The maximum force and moment of the winter are found to be 160 kN and 19 kNm, respectively.

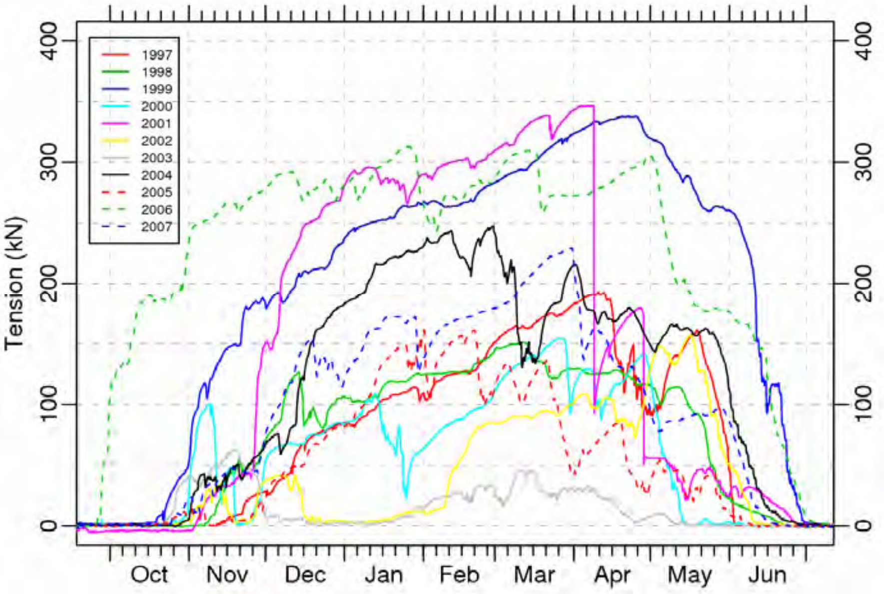

Figure 5 Measured tension in an uphill anchor in the Geobrugg and EI nets in Siglufjörður from eleven winters, 1996/1997 to 2006/2007. Note that a d-link shackle connecting the instrument to the anchor broke in the winter 2000/2001 resulting in the abrupt drops in the tension for the curve from that winter.

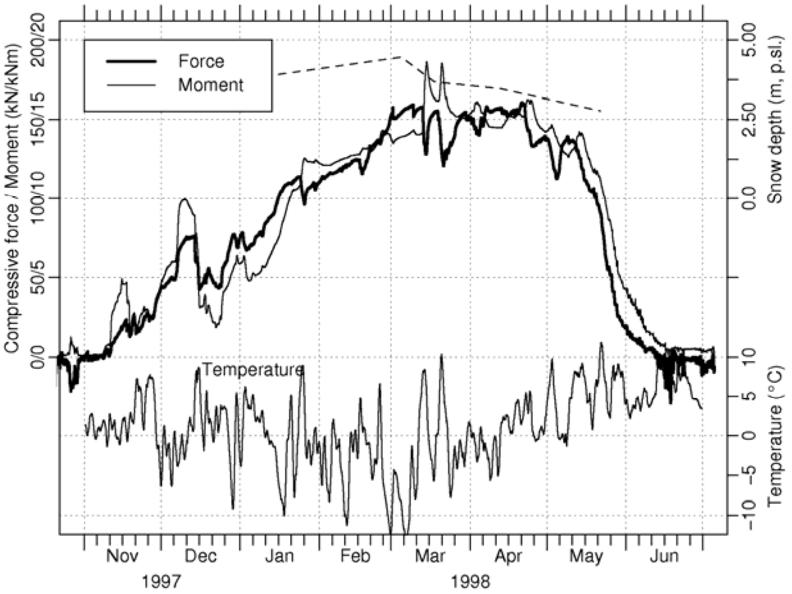

Figure 6 Compressive force (kN) and moment (kNm) in a post in the Geobrugg nets in row II in Siglufjörður. Wiggles in the force curve near the beginning and end of the record are due to differential heating of the post by the sun on clear days.

The measured tension in the upper anchors of the nets appears to be within the design assumptions of the Swiss Guidelines (SLF, 1990). The moment load is, however, considerably higher than assumed in the guidelines. The guidelines give a design moment load of only 5.7 kNm when allowance has been made for the high density of the Icelandic snow. This is less than one third of the measured maximum moment in Siglufjörður. The guidelines are based on the assumption that the snow pressure on the post is given by the depth averaged snow pressure on the construction applied over the width and length of the post (this is the assumption $\eta = 1$ in eq. (58) in the guidelines). In practice, the effective width of the post may be expected to be substantially larger than this because the post will support more snow than corresponds to its width.

4. CONCLUSIONS

The pilot experiment in Siglufjörður has provided many lessons for design of supporting structures for Icelandic conditions after more than a decade of observations. The main conclusions may be summarised as follows.

4.1 Snow properties

The gliding of the snow pack along the slope was found to be low, only several cm during the winter. Reference values for snow density during maximum snowpack thickness (400–450 $\mathrm{kg\,m^{-3}}$) and for spring loading with a higher density (500 $\mathrm{kg\,m^{-3}}$) were determined.

4.2 Loading

Measured loads on the structures were in general within the corresponding design loads of the Swiss Guidelines from 1990, with the exception of the moment load on net posts which turned out to be substantially larger than assumed. The maximum loading of the structures occurred around the time of maximum snow depth. The onset of melting led to a sharp decrease in the loading. There were no indications of an increase in the loading due to deformation or gliding introduced by melting.

4.3 Reliability and performance under overloading

There have been much more damages of the rows of the snow nets than for the steel bridges due to overloading of a similar magnitude as described above. The continuous rows of the steel bridges with a varying structure height were better adapted to the terrain and to local variations in snow depth than the snow nets. Furthermore, the continuous rows of the steel bridges provide much better lateral stability than the snow nets. Lack of lateral stability appears to be an important failure mechanism for some of the damages that have been observed in the snow nets. The stiff steel constructions appear for this reason to be able to survive more overloading than the nets without damage. Failure of net posts with micropile foundations in loose materials and of snow nets with narrow post spacing has given valuable experience about proper design of supporting structures for the heavy loads experienced in Iceland. This experience indicates that the steel bridges have greater reserve strength to withstand local overloading without damage and that maintenance costs due to failure will in general be higher for snow nets than for steel bridges.

4.4 Corrosion

Serious corrosion problems have been encountered in all wire ropes of the Geobrugg and EI nets indicating that corrosion protection of wire ropes traditionally used in Alpine snow nets are unsuitable for Icelandic conditions. These problems are very serious and hard to solve. It is recommended that steel bridges are in general hot-dip calvanised for Icelandic conditions. The experience in the test area indicates that with that type of protection, corrosion is not a problem for steel bridges.

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Figure 7 Comparison of galvanized and black type of snow bridges in the lowest row of the J. Martin snow bridges (left). The row with EI snow nets was deformed by the heavy snow loads, partly due to lack of lateral stability.

4.5 Environmental aspects

Undoubtedly the landscape is less interfered with nets than with snow bridges, especially if those are not galvanized. In time the galvanization leads to a gentle grey colour, well adapted to the Nordic environment, especially during winter, as can be seen after ten years in the test area. Also for that reason the use of black steel should not be an option for supporting structures in Iceland.

4.6 Recommendations

An important result of the Pilot Project is that traditional formulations for snow loading of supporting structures, which are used in Alpine countries, appear with relatively small modifications to be adequate for Icelandic conditions when proper account has been taken of the higher snow density and the lower gliding in Iceland. An adaptation of the Swiss Guidelines for Icelandic conditions have thus been formulated (Jóhannesson and Margreth, 1999; Jóhannesson, 2003). As a consequence of the problems that have been encountered with snow nets, a formal recommendation has been made to communities in avalanche-prone areas in Iceland, that steel bridges are in general a more suitable type of construction unless special circumstances need to be taken into account (Jóhannesson, 2004).

ACKNOWLEDGEMENTS

The Icelandic Avalanche and Landslide Fund provided support for the pilot experiment in Siglufjörður. The supporting structures were installed by the Austrian company Fels- und Sprengtechnik with participation of Icelandic workers from the Icelandic construction company Ístak. The Icelandic Coast Guard provided helicopter transportation. The work group carried the installation out successfully under difficult conditions in a professional manner. Örlygur Kristfinnsson, IMO's snow observer in Siglufjörður, has made snow observations in the test area since 1996. Stefan Margreth has participated in interpretation of the measurements from the Pilot Project and assisted with the adaptation of the Swiss Guidelines for Icelandic conditions. His involvement has been instrumental in the success of the project.

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The SM4 snowpack temperature and snow depth sensor

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ABSTRACT

An instrument for measuring snow depth and snowpack temperature has been developed by POLS engineering in Ísafjörður. The SM4 snow sensor consists of a series of digital thermistors mounted with a fixed interval on a pole that extends through the snowpack. Measurements from the thermistors are logged with a few minutes interval and are transferred regularly to a central computer.

The Icelandic Meteorological Office (IMO) is operating SM4 sensors together with ultrasonic sensors for comparison in three avalanche starting areas. The first winter of operation shows that SM4 is a promising tool for monitoring snow depth and snow-temperature. SM4 was able to measure snow depth during icing periods when the ultrasonic sensors did not work.

INTRODUCTION

Continuous monitoring of snow depth in avalanche starting areas is valuable for avalanche forecasting. A few types of instruments have been developed for this purpose. Due to the nature of avalanche release areas, the instruments are often located at high elevation levels on steep hills where weather conditions can be harsh. Snowstorms and icing conditions occur frequently. Therefore, the operation reliability is often a problem and the operating cost can be high.

An instrument for measuring snow depth and snow temperature has been developed by POLS engineering in Ísafjörður. The goal was to develop a simple, robust unit with a low operating cost that may be easily installed on steep hillsides. The technical details of SM4 are explained in the first section.

IMO operated SM4 sensors together with ultrasonic sensors in a steep hillside above the town of Bolungarvík during the winter of 2006–2007. The preliminary results are described in the second section.

THE INSTRUMENT

The SM4 snow sensor consists of a series of digital thermistors mounted with a fixed interval on a pole that extends through the snowpack. Measurements from the thermistors are logged with a few minutes interval (*e.g.* 10 minutes) to an internal memory card and are transferred regularly to a central computer through a wireless GSM telephone connection.

Figure 1. SM4 attached to a snowdepth-pole.

The SM4 measures snow depth by identifying thermistors buried in the snow based on the damping of temperature fluctuations that is caused by the snowpack compared with temperature fluctuations in air.

The IMO has located series of snow depth poles in many starting areas above settlements. The purpose is to be able to measure the snow depth manually from below with a theodolite. Attaching SM4 to such poles has been an easy way of installing them.

PRELIMINARY RESULTS FROM THE FIRST WINTER

The Icelandic Meteorological Office (IMO) has used ultrasonic snow depth sensors for some years for monitoring snow depth in avalanche starting zones. Those instruments provide important data for the avalanche warning service of IMO. However, due to their sensitivity to icing and snowdrift, they sometimes do not work for long periods, especially during avalanche cycles when reliable measurements are particularly important.

The initial plan of POLS and IMO for the winter 2006–2007 was to operate a SM4 snow sensor together with an ultrasonic sensor in three starting areas. The SM4 was attached to the towers that keep the ultrasonic sensors in place. However, the towers went down in two of those areas due to strong winds. Therefore, the avalanche starting area in Traðargil above Bolungarvík was the only location providing usable data during the winter 2006–2007.

The SM4 unit was connected to the Campbell communication equipment within IMO's automatic weather station in Bolungarvík. Also, the SM4 sends the data through the GSM system and to the Internet.

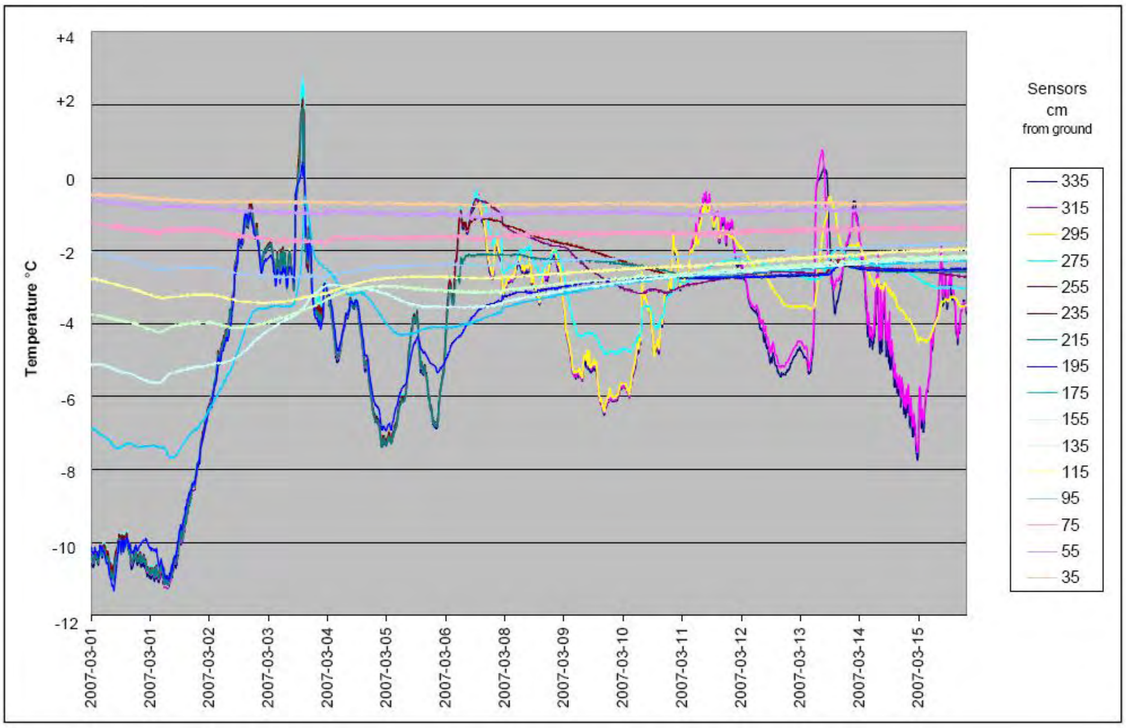

Figure 2. A graph showing data from individual thermistors on a SM4 snow depth sensor. The thermistors buried in the snow can be easily identified from the damped temperature oscillations.

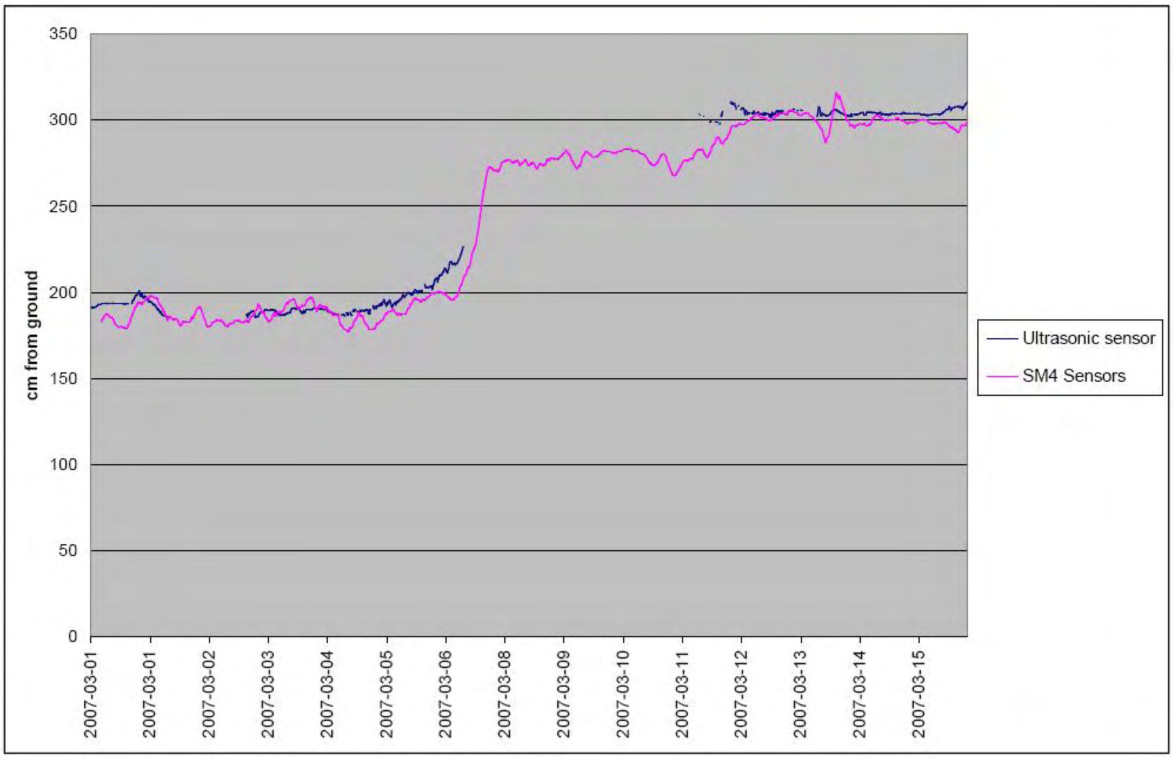

Figure 3. The calculated snow_depth using a preliminary algorithm from SM4 compared with the snow depth data from an ultrasonic sensor.

After some initial reliability problems were resolved, the SM4 was able to measure the snow depth with acceptable accuracy for avalanche forecasting. From the data, it is easy to distinguish the sensors buried in snow from the ones above the snow surface. Figure 2 shows data from all the sensors of a SM4 unit. The graph shows very little fluctations for the sensors buried in snow, while the sensors above the snow surface display greater fluctation in temperature. The blue line shows an example of a thermistor that is above the surface in the beginning of the period, but becomes covered by snow on March 6th. Figure 4 shows the temperature profile from an SM4 sensor located in Kistufell by Ísafjörður. The snow depth is at the upper brake of the gradient. During this period, the snow depth increased from 180 cm to 250 cm.

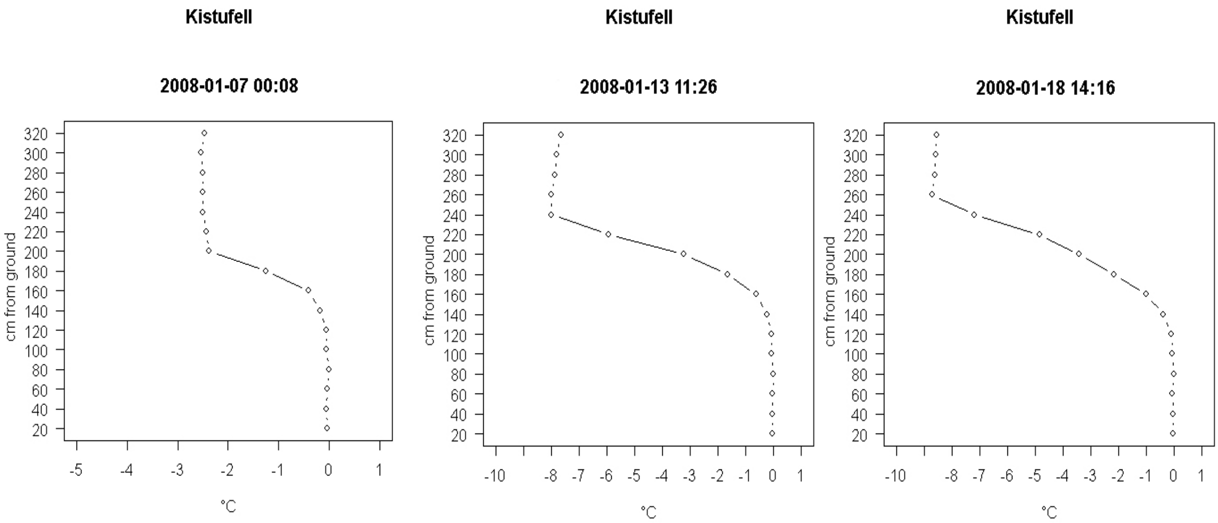

Figure 4. Temperature profiles measured by SM4 with five days interval.

An algorithm that calculates the snow depth from a time-series of temperature profiles through the snowpack has been developed, and gives promising results. Figure 3 shows the calculated snow depth and compares it with snow depth data from the ultrasonic sensor. (Note that the timespan is the same as for Figure 2.) The gap in the data from the ultrasonic sensor is considered to be due to icing. The challenge regarding the algorithm is greatest when the temperature of the atmosphere approaches the temperature of the snowpack.

For IMO it is of special interest to test the reliability of SM4 during icing periods since the ultrasonic sensors do not work well under those circumstances. The following picture (Figure 5) was taken on December 9th and shows the instruments with an icing coat. The ultrasonic sensor had not been working in the days before, and it is considered very likely that the reason was icing. The data from SM4 seems correct from those same days (Figure 6), and therefore, it can be concluded that icing in this magnitude does not interfere with the air temperature measurements of SM4.

Figure 5. An ultrasonic sensor and the SM4 snow depth sensor covered with ice. SM4 is attached to the upper stanchion. The sensors are located in Traðargil above Bolungarvík and the picture was taken on December 9th, 2007.

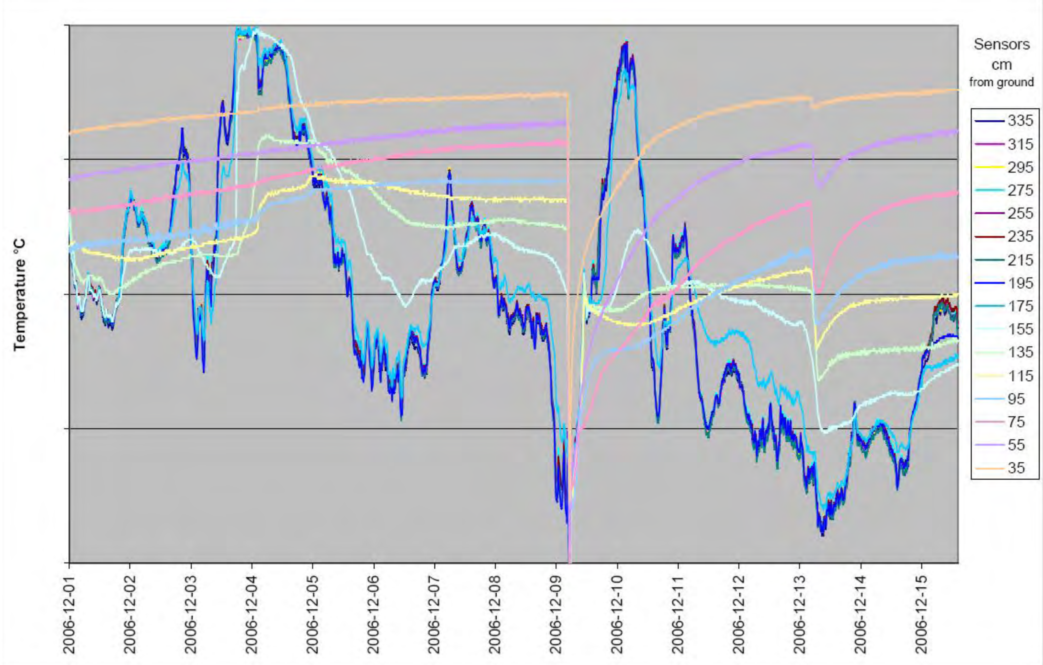

Figure 6. Data from SM4 during a period of icing. On December 9th the instrument was dug up from the snow, which causes the disturbance in the graph.

CONCLUSIONS

In general, this first winter of testing showed that SM4 is a promising tool for continuous monitoring of snow depth. Furthermore, the temperature profile through the snowpack is obtained as additional information and may be useful for avalanche forecasting. The development of SM4 is being continued in order to increase the robustness of the unit. IMO is operating a total of 5 SM4 sensors during the winter of 2007–2008, with no reliability problems by the end of February.

ACKNOWLEDGEMENT

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The effect of avalanches on the spatial development of settlements in Iceland

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ABSTRACT

The planning history and spatial development of Icelandic settlements is discussed in the light of avalanche history. During the first decades of urbanisation in Iceland, most towns developed without an official plan. Avalanches had very little effect on the spatial development of settlements at that time, unless they had caused death or great destruction. In the 1920s, the first planning laws were authenticated. The first plans were an attempt to steer the development of settlements away from paths of known avalanches. In many cases, the plans expanded later into known avalanche areas. In the 1960s and 1970s, the population of many fishing towns grew rapidly and houses were built closer to the mountains than before. In the 20th century, up until 1995, there are many examples of houses and buildings being constructed in the paths of known avalanches within 10–20 years after the avalanche's occurrence. In 1985, the first laws on avalanche protection were approved. New laws and hazard mapping legislation were issued after the avalanche disasters in Flateyri and Súðavík in 1995. Since that time, estimated avalanche risk, and not only known disastrous avalanches, has for the first time had a significant effect on the development of towns in Iceland.

INTRODUCTION

The Icelandic nation has always lived with natural hazards. Volcanic eruptions, earthquakes and landslides have caused great damage. However, snow avalanches have taken the greatest number of human lives through the centuries, when fatalities due to storms at sea and wilderness areas are excluded. During the first centuries after the settlement of Iceland, the greatest number of avalanche victims were people travelling in the mountains. After the urbanisation began during late 19th century, most avalanche victims in Iceland have been in houses or working places. In this paper, the effect of avalanches on the spatial development of villages in Iceland is discussed. The conclusions are partly based on comparison of avalanche maps of Icelandic villages to maps made by the Icelandic Meteorological Office (IMO), that show the building years and location of houses and buildings in towns where avalanche hazard is significant.

THE FIRST DECADES OF URBANISATION IN ICELAND

Iceland was settled in the years 870–930. Most farms in the mountainous regions in Iceland were located close to running water and, therefore, often beneath gullies. The houses were turf houses that did not last for very long and they were rebuilt and even relocated a bit quite frequently. As a result, it seems like the farms often ended up in the best possible location within a certain area, in terms of avalanche and landslide safety. Nonetheless, over the centuries, a number of farms have been destroyed by avalanches.

The urbanisation in Iceland has been more rapid than in most of the Western world. During the years 1880–1900 urbanisation started for real along the seaside, prompted by the fishing industry.

Before the 1920s, the only plans for the towns in Iceland were impromptu plans by occasional local governments. In most towns, no plan existed during the first decades of urbanisation. Therefore, the spatial development of settlements at that time should reflect the view of the public towards snow avalanche and landslide risk to a greater degree than today. However, the landowners had a great influence on the development.

Soon after the towns started to form in Iceland, the first big avalanche accidents in urban areas occurred. In 1885, an avalanche killed 24 people in *Seyðisfjörður*. It is considered that between 75 and 80 people were caught in the avalanche which damaged or destroyed around 16 houses. In 1910, 20 people were killed in an avalanche in *Hnífsdalur*. Some houses, fisherman huts and sheds were destroyed. In 1919, an avalanche killed nine people and destroyed a herring factory, two houses and other buildings, in *Siglufjörður*. The avalanche occurred on the opposite side of the fjord from where the settlement is now and caused a tsunami that damaged boats at the harbour in the village.

In general, it can be considered that avalanche history only had a very temporary effect on the spatial development of towns during the first decades of urbanisation in Iceland. Avalanches that caused death or major destruction lived longer in the memories of people, or were taken more seriously than avalanches that caused only minor damage, and that is reflected in the spatial development. There are quite a few situations where areas within and close by the paths of large avalanches had become densely populated 10–20 years after the avalanche fell.

The avalanche catastrophes in Seyðisfjörður, Hnífsdalur and Siglufjörður most likely had no effect on the population development of those towns in general. In fact, all of the towns had a major increase in population in the years after the accident, which was driven by booms in the fishing industry.

THE EFFECT OF PLANNING

The first planning laws were approved in 1921 and were valid for all towns and fishing villages with more than 500 inhabitants (Líndal, 1982). A planning commission was founded by the government. The commission hired specialists for the survey part, but the commission itself was involved in most of the planning reports.

The planning committee in many cases took natural hazards into account in their plans. According to the laws, it was obligatory to identify areas with avalanche hazard on the planning maps, however, no frame of reference was given. In practice, houses were not planned in areas where the commission knew about avalanches. It is not known how careful the commission was in obtaining historical records, but it is likely that it was mostly in the form of conversations with local people. In some cases, the first plans were an attempt to move towns towards greater safety, especially where it was known that large avalanches had caused damage in the area. However, there has not always been an agreement between local governments and the commission on these matters.

In the next decades the towns grew steadily with the exception of the depression years in the 1930s. No avalanche disasters with many fatalities occurred in urban areas.

During 1965–1980, the population increased in many fishing towns in Iceland. Many houses were built and avalanche risk was not a top priority in the plans. During that period, many settlements expanded towards the mountainsides. Since the towns were reaching into areas where no houses or buildings had been before, avalanche records were often scarce. However, many houses were built in areas were avalanches were still in the memories of people. In some towns, like Patreksfjörður and Siglufjörður vacant areas existed where building of houses was not allowed due to avalanche hazard. However, there was often a pressure to allow buildings in such areas from individuals or local governments. The off- limit areas gradually became smaller and it seems like in some cases that the outline of the most resent large avalanche defined the boundary.

When two avalanches killed 12 people in *Neskaupstaður* in 1974, it took the inhabitants of the town and the rest of the Icelandic people by a surprise. It seems like nobody had imagined this could happen. Nevertheless, in 1936, avalanches had threatened houses in both of these avalanche paths.

HAZARD MAPS

The first avalanche hazard maps were made shortly after the avalanche accidents in Neskaupstaður by local governments No actions followed the hazard maps in terms of relocating or protecting the settlement, however, the first organised snow observations started at that time.

The first laws on avalanche protection were approved in 1985 after avalanche accidents in Ólafsvík and after that, the first legislation based hazard maps was made. At that time, the growth of the fishing towns had stopped and very few houses were built during the rest of the century.

In 1995, two avalanche disasters in Súðavík and Flateyri, with a total of 34 fatalities, marked a change in the attitude towards avalanche risk in Iceland. Most of the victims were in houses that were outside of the hazard zones according to the hazard maps at that time. During the next years, the methodology of hazard mapping was reviewed in Iceland, and new laws and legislation were approved. Since then, hazard maps have been made for most of the towns with the greatest avalanche risk. Where houses in urban areas are in hazard zone C (the greatest risk), the local governments are obliged to make a plan for either protecting or relocating the settlement. There are examples of both in Iceland, however, the trend now is to build defence structures rather than to relocate houses.

In 1995–2005, the population in most of the towns outside of the Reykjavík area was shrinking. Very few houses were built and, therefore, the new hazard maps did not have a great effect on the spatial development of the towns. In the last few years, however, construction of houses has started again, and the spatial development is directed outside of the hazard zones.

NESKAUPSTAÐUR – CASE STUDY

The town of Neskaupstaður is located in a fjord named Norðfjörður. After 1870, fishing industry replaced agriculture as the main industry in Norðfjörður and became the basis of urbanisation. During the 1910s and 1920s there was a great population growth in Norðfjörður and it became the authorised market town named Neskaupstaður in 1929 (Geirsson, 1983 and 1993).

During the first years of urbanisation in Norðfjörður, a few large avalanches fell in the area. In 1885, an avalanche destroyed two houses and killed three people in Naustahvammur. In 1894, a large avalanche from the Drangagil avalanche path fell where the farm Þiljuvellir was located. It destroyed sheds and killed livestock. Two people were saved from a snow tunnel which had been dug between the houses and the river. The same year, a large avalanche from Tröllagil went to the sea in an area that was uninhabited at that time. It caused a minor damage to some houses.

When the population started to surge in the 1910s and 1920s no official town plan existed. In the beginning, most houses were close to the sea. When the settlement started to develop towards the mountain it was especially in two areas: beneath the gullies Tröllagil and Drangagil. Those areas had become densely populated only 15–20 years after the large avalanches in 1894. The Naustahvammur area did not develop to become a part of the residential area of the town.

Interviews with people born in the early 20th century were conducted in 1997 (Grímsdóttir, 1998). The purpose was to get a view of the attitude of people in the first half of the 20th century towards snow avalanches and debris flows. The interviews indicated that people in Neskaupstaður were not concerned with avalanche risk during the first decades of the century. The annual risk of death from all causes was much higher than it is today. Fatal accidents at sea were frequent and had an important effect on the society in fishing villages. The tolerance towards avalanche risk was, therefore, much higher than it is today when the safety standards are greater. People knew about the avalanches from 1885 and 1894, but that was in the form of legendary tales and not considered a real threat. Yet, there was a talk about great avalanche risk in Seyðisfjörður.

People were more concerned about debris flows. It was customary to practice farming alongside other work, and therefore, debris flows could affect the support for living. The concern was associated with fear of material damage rather than fear of loosing one’s life. The area west of the town, Ströndin, was considered uninhabitable due to risk of debris flows, and there was a lot of talk in town about the improvidence when the first house was built in the area.

The first official plan for the town came in 1928 and it is quite interesting. The report states that all of the western part of town is located in avalanche hazard area. It says that the conditions are favourable for the development of a big fishing town, and it would not be acceptable if it is built in avalanche hazard areas. The commission recommends that the town should slowly be moved towards the east, and that no new buildings should be allowed in the western part of town. The town council should provide people who already own houses in the hazard areas with a lot in a safer place (Zoëga and others, 1928).

The next decades after the authentication of the first plan, the plan was gradually expanded towards the west. In 1942, the mayor of Neskaupstaður wrote the planning commission and asked for the western part of town to be planned. In 1947, the approved plan was expanded towards the west, and after that the plan expanded slowly all the way to the bottom of the fjord, however, always with words of warning about avalanche and landslide risk (Pálsson 1990). The westernmost part of town (Ströndin) has, however, always been scarcely populated and industrial buildings been prominent. The main reason is most likely risk of avalanches and debris flows.

The avalanche accidents in 1974 occurred west of the main residential area of the town. The two catastrophic avalanches destroyed fishing factories and other industrial buildings, as well as one residential building. The accident knocked back people in Neskaupstaður who realised that they had not been aware of the avalanche risk at all. The local government had a hazard map made and the spatial development of the town was towards the east during the next years as was recommended in the first plan for the town. According to the newest hazard map, the majority of the town is within avalanche hazard zones, and extensive protection plans are being made. One large catching dam has been constructed and another one has been designed. Most new houses in the past few years have been built in the easternmost part of town, or filled in empty spaces beneath the dam.

CONCLUSIONS

The experience in Iceland shows that when no concrete laws or legislations exist that limit the usage of land due to avalanche hazard, the effect of avalanches on the spatial development of settlements becomes very little, especially in times of rapid rise in population. There are many cases where houses have been built in an avalanche path within 10–20 years from a large avalanche, both in the beginning of the 20th century when no plans existed, but also later, up until 1995.

Avalanches that cause death or major destruction have had greater effect in general on the spatial development of settlements than avalanches that fall over areas with no buildings or avalanches that only cause little damage. The latter ones look innocent and their destructive power and the likelihood that they will happen again have constantly been underestimated.

With the first official hazard maps, estimated avalanche risk in areas with avalanche potential but no avalanche history, started to affect the spatial development of villages. The effect of the new avalanche laws on the spatial development of settlements has not been as great as it could have been since most local governments have decided to protect existing endangered settlements rather than relocate the settlements.

ACKNOWLEDGEMENT

During the work of gathering the building years of houses for the hazard mapping process, many senior informants gave invaluable information on the history of houses. Magnús Guðmundsson, Einar Guðmundsson and Stefán Þorleifsson are acknowledged for giving me their time and wisdom in interviews during the work of my B.S. thesis in 1997.

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Informants:
Magnús Guðmundsson, teacher and director, b.1923, d. 1999
Einar Guðmundsson, small boat fisherman, b. 1919, d. 1998
Stefán Þorleifsson, teacher, b. 1916.

Application of two-dimensional avalanche model simulations at the Icelandic Meteorological Office

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ABSTRACT

The Icelandic Meteorological Office (IMO) has used two-dimensional avalanche models for various applications since the year 2000. This paper summarises some results of this work and briefly outlines methods and operational guidelines that have been established. The IMO has been running the samosAT model for a couple of years following an initial calibration and verification. The concepts developed at IMO, of a standard path and run-out index scale for the run-out distance of avalanches, have now been expanded into two dimensions using samosAT. Model parameters that allow simulation of avalanches over a wide size range have been specified. This simplifies the operation of the model and allows comparison of results for different avalanche paths. It also allows a more systematic use of 2D models in hazard mapping and other applications that require study of avalanche motion. Examples of such applications are described.

1. INTRODUCTION

The SAMOS model was developed for the Austrian Avalanche and Torrent Research Institute in Innsbruck by the consulting company AVL in Graz (Zwinger and others, 2003). Initially, an earlier version of the model, now referred to as SAMOS99, was used at IMO and the model runs were performed at AVL. Before that work commenced, the model was run for the catastrophic avalanche from Skollahvilft at Flateyri in northwest Iceland in 1995 in order to check the applicability of the parameter values that are traditionally adopted for the model in Austria. It was concluded from these runs that the same input parameters can be used for the SAMOS99 model for Icelandic conditions as are traditionally used in Austria (Jóhannesson and others, 2001).

A new version of the SAMOS model has now been introduced, referred to as samosAT. The IMO has been running this version of the model for a couple of years. The application of the new samosAT model version at the IMO was initiated with a study of the performance of the model for several well known Icelandic avalanches and a comparison of simulations of the new model with simulations of SAMOS99. For this purpose, the avalanche path of Skollahvilft at Flateyri was again of great significance because of the well-known avalanche history and the earlier modelling attempts. It was found that the default parameters of samosAT, with the “samos classic” fiction model, did not give good results for the Icelandic avalanches that were modelled. After calibration and verification of the model, a recommended set of model parameters to be used in Iceland was established (Gíslason and Jóhannesson, 2007).

The Icelandic Meteorological Office (IMO) has used the SAMOS model for various applications since the year 2000. In the following, some results of this work are summarised and methods and operational guidelines which have been developed are outlined briefly.

2. SIMULATION OF AVALANCHES OVER A WIDE SIZE RANGE

The concept of the standard path was introduced by Jónasson and others (1999) to define a general scale for measuring the run-out distance of avalanches. This measure of run-out is called the *run-out index* and is defined as the horizontal distance, in [hm], to the stopping position of an avalanche that has been transferred to the standard path from its original path. The run-out index is traditionally a scalar since the avalanche path is represented by a single flow-line on which the stopping position is a single point that can be explicitly defined by the one-dimensional system horizontal distance along the flow-line [hm]. The evaluation of run-out indices relies on a slight modification of the traditional 2-parameter PCM snow avalanche model. Run-out indices have proved to be useful both to simplify the comparison of different avalanches and to carry out a statistical analysis of the run-out of avalanches in a collection of different avalanche paths. The run-out index scale has been used extensively at the IMO and has gained an increased expectance since its introduction.

2.1 2D run-out index

A two-dimensional model for snow avalanche motion may be used to extend the run-out index concept to two dimensions. It is possible to create run-out index isolines by determining run-out indices on multiple flow-lines along a mountainside and interpolate between matching values. This could be suggested as a two-dimensional run-out index. However, this method is limited because of the inherent limitations of flow-line models.

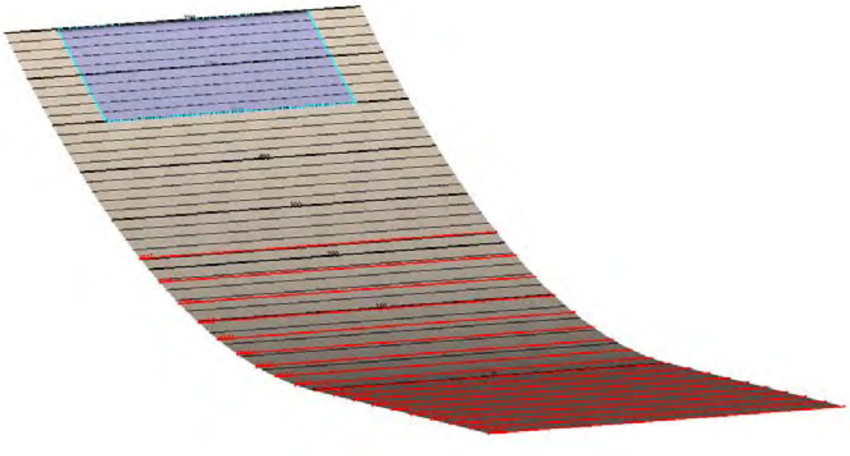

Figure 1 A birds view of the three-dimensional standard path. The parallel lines in red mark horizontal distance from the top in 100 m increments in the range 1000–2000 m. The corresponding run-out indices are defined as the distance in [hm] and are thus in the range from 10–20.

Flow-line models only consider the geometry of the path in the downstream direction. This might be sufficient in an unconfined mountainside, but frequently, topographical features such as gorges, gullies and ridges stretch along avalanche paths. These features, which tend to channelise or spread the flow of the avalanche, can either magnify or reduce the run-out depending on lateral position in the run-out area. Two-dimensional models do not rely on a single longitudinal profile, but simulate the flow on a three-dimensional surface representing the actual landscape. A two-dimensional model may, thus, be used to compute a two-dimensional run-out index, which describes the effect of various landscape features on the run-out. One may expect a run-out index of this kind to have a more distinctive shape than interpolated points of flow-line models indices. The line representing a two-dimensional run-out index will stretch farther away from the mountain below channels in the topography and then retreat farther uphill below ridges compared with the corresponding isoline of run-out indices along multiple flow-lines determined by 1D model calculations.

Identically to the original approach, the two-dimensional run-out indices are determined by transferring an avalanche from its original path to the standard path, which has been transformed to a surface, maintaining the original longitudinal profile. Figure 1 shows the 3D standard path.

2.2 Parameter axis

It was concluded from the experimental simulations that in order to simulate avalanches that vary in size it is advisable to change release snow depth, *d*, and the friction angle, δ, simultaneously but keep other model parameters constant. An important point to consider is that a unique backcalculation of the model parameters, *d* and δ, based on information about run-out distance solely, is impossible because an infinite number of parameter pairs can explain a given avalanche run-out. In other words, increased friction, δ, can be compensated by an increase in snow depth, *d*. It is of practical interest to define a single d/δ pair corresponding to each run-out index. Similarly to the approach of Jónasson and others (1999), a way to get around this problem has been developed. This is achieved by defining a so called *parameter axis* in the d/δ plane on which d/δ pairs for simulations of avalanches with run-out indices in the range from 10 to 20 are located (Gíslason, 2007). The parameter axis currently used for systematic two-dimensional avalanche simulations at the IMO is plotted on Figure 2.

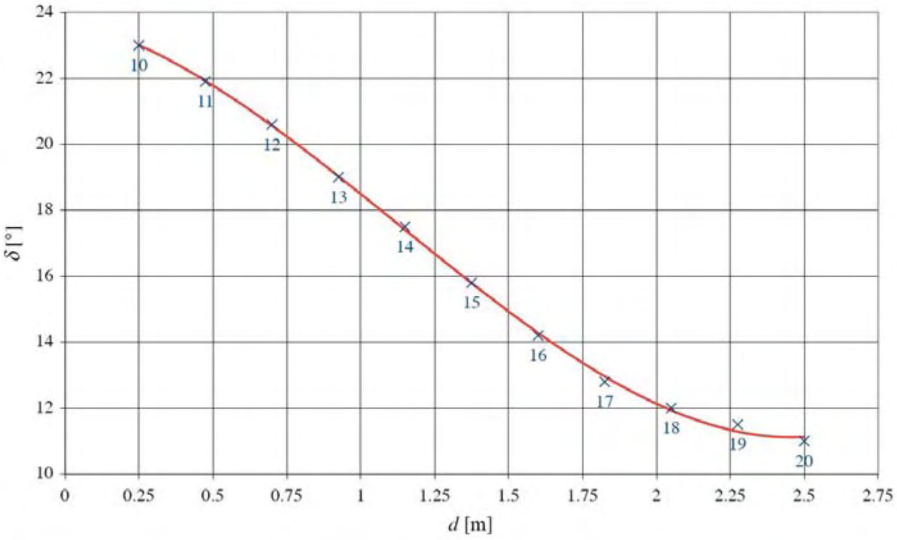

Figure 2 A set of parameter pairs that can be used to simulate avalanches with run-out indices in the range 10–20.

3. APPLICATION OF TWO-DIMENSIONAL SIMULATIONS

3.1 Hazard zoning of settled areas

As mentioned earlier, the SAMOS model has been used in the hazard zoning process, described by Jónasson and others (1999) and Arnalds and others (2004), for several Icelandic villages since the year 2000. The two-dimensional simulation results have proved to be valuable for showing the direction of the main avalanche tongues from the starting areas, in particular the influence of ridges and gullies and to estimate the shortening of avalanche run-out due to lateral spreading . The use of the 2D run-out index scale and the parameter axis has already been implemented to this process in a recent project (Jóhannesson and others, 2007).

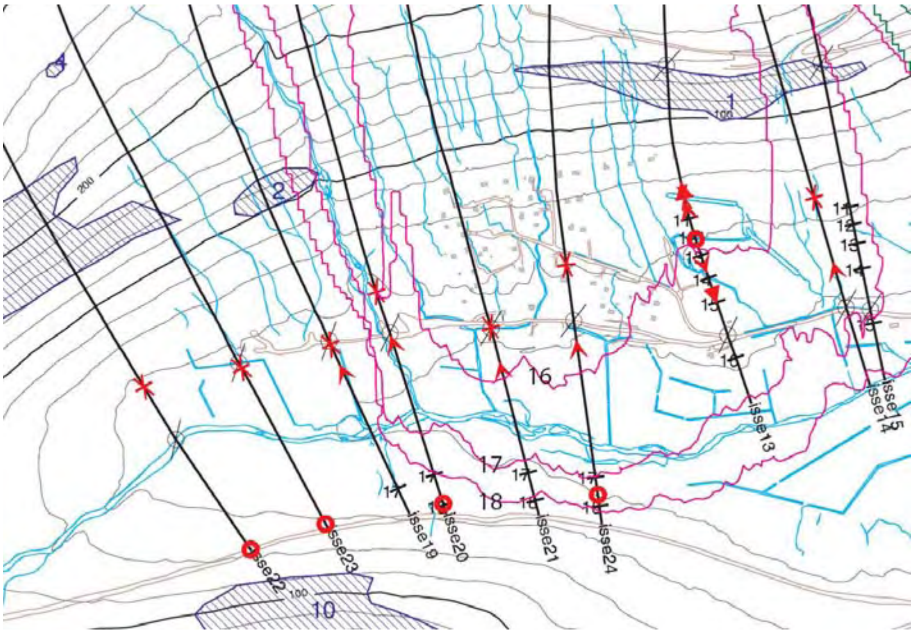

Figure 3 Comparison of 1D and 2D run-out indices based on simulations with a modified PCM flow-line model and samosAT, respectively.

As shown in Figure 3, the 1D and 2D run-out indices coincide in middle of the avalanche path of Seljalandsdalur/Tungudalur, N-W Iceland, where it is rather unconfined and the flow-lines are roughly parallel, whereas a difference is evident where the landscape is more complex. This information can be useful when hazard zones are delineated and make it possible to better consider the effect of ridges, gullies and curves in the path.

Hazard maps have already been issued for the most vulnerable villages of Iceland. The maps are constantly reviewed, especially in connection to the construction of defence structures. Furthermore, the avalanche hazard is yet to be assessed in many rural areas. Two-dimensional avalanche simulations and 2D run-out indices will be of good use in that process since two-dimensional avalanche models can provide a good overview and comparison of avalanche conditions from one place to another.

3.2 Hazard zoning of unsettled areas

The IMO is developing a methodology to be used for the hazard mapping of public ski areas in Iceland. Two-dimensional avalanche simulations will be important for this work and a first proposal of guidelines for systematic simulation for avalanche paths in Icelandic ski areas has been issued (Gíslason, 2007). This methodology could possibly apply for other recreational areas, roads and other places where more frequent avalanches are acceptable than around settlements. The hazard mapping process for ski areas is in many ways different from *e.g.* hazard mapping for settlements. Due to the proximity of avalanche starting zones to constructions and ski-paths, smaller release areas and more frequent events in known avalanche paths have to be considered. The primary result of exploratory simulations of small to medium-size Icelandic avalanches is that they can be simulated with reasonable realism with samosAT.

This approach is based on a classification of the release areas with respect to their physical properties such as inclination, aspect and shape. The release areas are assigned a single number referred to as the *starting zone index* and are thereby ranked by their likelihood of releasing an avalanche with a comparatively large run-out. It is not the goal to fully automate the hazard zoning process. The method is rather an attempt to provide some overview of the avalanche conditions of the area under scope and establish a basis for further analysis.

3.3 Design of deflecting dams

The effects of deflecting dams can by assessed with two-dimensional avalanche models by simulating the flow of an avalanche with given parameters using digital terrain model that includes the structure of consideration and compare it to equivalent simulation on untouched ground. The run-out index scale is useful to determine an appropriate design avalanche and to simulate the performance of the structure as the events gradually become larger.

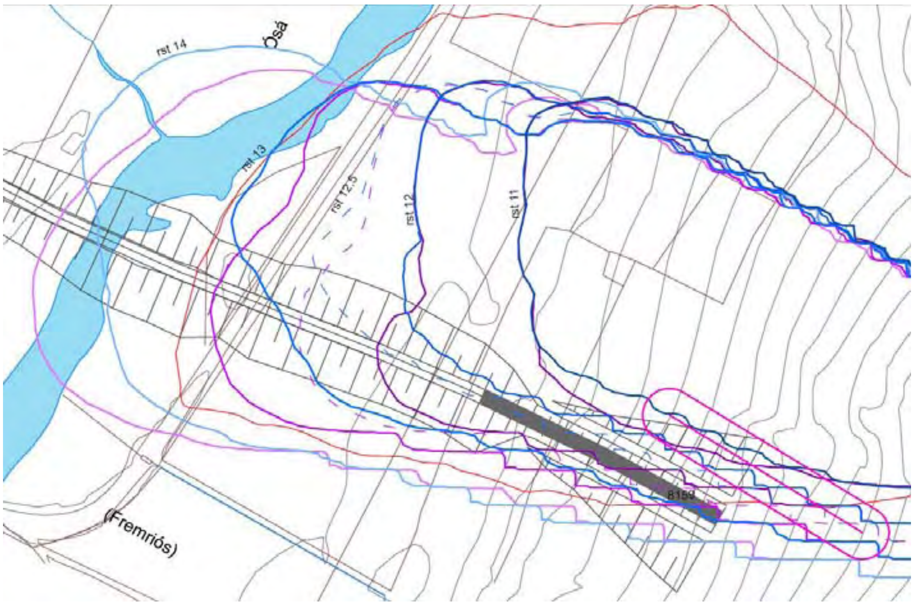

Figure 4 Distribution of 2D run-out indices around the opening of the Hnífsdalur-Bolungarvík tunnel with (blue curves) and without (purple curves) the deflecting dam. The extent of the January 2005 avalanche is shown as a red curve.

The samosAT has been run to constrain the design of a deflecting dam in relation to a construction of a road tunnel connecting Hnífsdalur and Bolungarvík in the northwestern part of Iceland. The planned location of one of the openings of the tunnel is in an area with well known history of avalanches. An avalanche recorded in January 2005 was chosen as a reference event. It reached the 2D run-out index 13 and has an estimated return period of approximately 15 years.

Figure 4 shows the effect of possible configuration of a deflecting dam on avalanches in the size-range from 11 to 14 on the 2D run-out index scale. According to these results, the dam provides protection for avalanches up to size 12.5 while avalanches of size 13, that is avalanches that are comparable in size to the January 2005 avalanche, still overflow the dam.

4. CONCLUSIONS

The experience accumulated at IMO indicates that two-dimensional avalanche models are a useful addition to other methods of studying avalanche motion. The samosAT model seems to simulate Icelandic avalanches with reasonable realism after an initial calibration and verification of the model. Avalanches that span a wide size range can be simulated by changing the bed-friction angle, δ, and the release snow depth, d, concurrently.

The development of the run-out index concept into two-dimensions, together with a definition of a single parameter axis, simplifies the work. Thereby, the motion of an avalanche, defined by standard parameters, can be simulated in multiple avalanche paths to estimate the run-out and other important features. Such simulation results are valuable in cases where records about avalanche activity are scarce.

Two-dimensional avalanche models have the potential to be an important tool for avalanche hazard mapping and to aid designers of protective structures.

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Hörður Þór Sigurðsson made the map in Figure 3. I thank Tómas Jóhannesson, Harpa Grímsdóttir and Sigurður Magnús Garðarson for inspiring enthusiasm, patience and guidance.

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Towers for snow avalanches in 420 kV transmission lines in Iceland

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ABSTRACT

This paper describes factors that influenced design and construction of two 420 kV transmission lines, Fljótsdalslína 3 and 4, in snow avalanche areas in the east part of Iceland. It presents a description of the snow avalanche loading, the structural solutions and how assembly and erection was carried out. A total of 83 towers are located in the avalanche prone areas and requirements to operational reliability of the two transmission lines are high since they are feeding an aluminium smelter.

1. INTRODUCTION

Landsnet completed the construction of Fljótsdalslína 3 and 4 (FL3 and FL4), two single circuit 420 kV overhead transmission lines (OHTL) by end of year 2006. The lines will be operating at 245 kV for the first years. The lines originate at substation Fljótsdalur, close to the powerhouse of hydropower plant Fljótsdalsstöð, and terminate at Alcoa Fjarðarál, an aluminium smelter in Reyðarfjörður. The total length of the lines is 102 km, of which FL3 is 49 km and FL4 is 53 km. The lines are located at an elevation of 20 – 620 m above sea level and lie parallel with 60 m spacing for appr. 80% of the line route. They pass through challenging areas for transmission lines and were designed for risk of; severe in-cloud icing, wet snow icing, high wind, snow avalanches, floods, frequent galloping *etc*. Requirements to the operational reliability of Fljótsdalslínur 3 and 4 are extremely high as they are the only transmission lines providing electricity for the aluminium smelter in Reyðarfjörður.

The lines contain a total of 326 towers, of which 83 are located in areas prone to avalanches. Of the 83 avalanche towers, 44 are parallel. The phase conductors consist mainly of duplex conductors 865-AL3/44-ST4 (dia. = 39 mm, rated strength = 312 kN). In sections with heavy in-cloud icing, these are for safety reasons replaced in FL3 by a simplex conductor 1288-AL3/183-ST4A (dia. = 49.9 mm, rated strength = 604 kN). Earth wires are only present close to substations and only 4 towers designed for avalanche carry earth wires.

Figure 1: Avalanche towers in FL3 in Hallsteinsdalur.

2. SNOW AVALANCHE LOADING

The risks of snow avalanches falling along the line route were extensively investigated by avalanche specialists through examination of the area, analysis of meteorological data, reviewing historical evidences of avalanches in the region, modelling snow drift and calculating runout distances and avalanche velocities see Jónsson and others (2005) and Margreth and Ammann (2004). Avalanche risk and loading was evaluated for each tower site.

The basic force at a given height on an obstacle caused by an avalanche can be expressed as:

$$F = p \cdot C_f \cdot A = (0{,}5 \cdot \rho \cdot V^2) \cdot C_f \cdot A$$

where C_f is a unit force coefficient, p is dynamic pressure, A is the projection of the obstacle area perpendicular to the avalanche load direction, ρ is density and V is avalanche velocity.

The avalanche loading is divided into three layers; a dense avalanche core, a saltation layer and a snow cloud. The saltation layer is an intermediate layer between the fairly rigidly flowing dense core and the turbulent snow cloud, physically representing the transition between the two. Rolling particles on top of the core can thus be found at the bottom of the saltation layer, whereas the lesser dense upper part of it more resembles a snow cloud. Density and flow velocity are the two variables that govern the avalanche pressure. Given a fixed velocity in all layers at a given site, the pressure becomes a function of density. Intuitively, the pressure reaches its highest value within the dense core and subsequently reduces with increased elevation. After accounting for the presence of snow layers and previous avalanches, the upper boundary of the avalanche core reached up to 5 – 8.5 m above ground level. The form of the pressure distribution diagram is shown in Figure 2. Figure 3 shows the distribution of towers in terms of avalanche core pressure, excluding form factor. The corresponding avalanche velocities lie in the range of 5 – 49 m/s for the towers in FL3 and FL4.

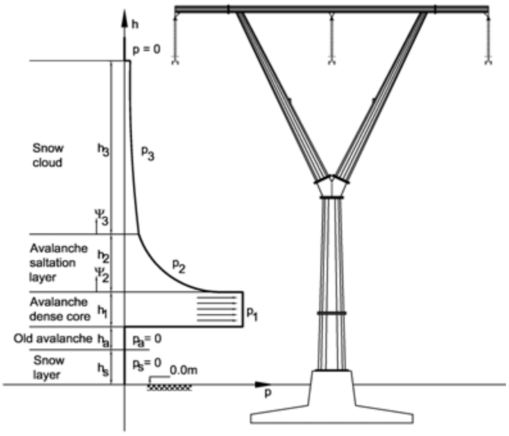


Figure 2: Definition of snow avalanche loading.

Following parameters were given for each tower site: thickness of existing snow layer and previous avalanche, thickness of avalanche core, thickness of snow cloud, avalanche velocity and direction. Same parameters were given for each span between towers. Some basic numbers defining the avalanche loading are as follows:

- Avalanche velocity (V): 5 – 49 m/s
- Density of dense core (ρ): 300 kg/m^3
- Thickness of core: 2 – 3 m
- Upper boundary of core (due to snow on ground and previous avalanches): 5 – 8.5 m
- Density at boundary between saltation layer and snow cloud: 15 kg/m^3
- Thickness of saltation layer: 0.10 sec. * V
- Finite pressure at top of snow cloud: 150 Pa
- Thickness of snow cloud = 15 – 35 m
- Unit force coefficient C_f = 1.5 for circular and elliptical tower shapes within the dense core and saltation layer, C_f = 1.2 in the snow cloud.

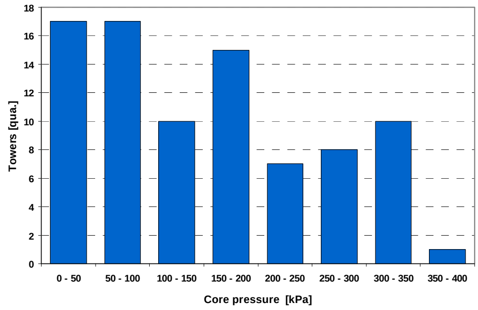


Figure 3: Distribution of core pressure.

Apart from the avalanche pressure, it was to be assumed that the towers could be hit by a stone carried by the tail of the avalanche. The diameter of the stone was defined as 50 cm and its velocity assumed to be 80% of the specified avalanche velocity.

Security load requirements were made to limit potential cascading failures. The longitudinal loading in all phases of suspension towers was taken equal to the every day stress of the conductor bundle, giving a force of 111–136 kN for each phase bundle, without considering pressure on tower.

3. DESIGN OF TOWERS IN AVALANCHE REGIONS

In Iceland, only a few towers in 33 – 132 kV transmission lines are located in snow avalanche regions, whereas no 245 kV or 420 kV lines cross such regions. Figures 4 and 5 show examples of simple protection measures, the former a pile of rocks within a plow shape timber structure and the latter an extra supporting pole with steel angle (plow).

Figure 4: Plow in front of a tower in a 132 kV line.

Figure 5: Avalanche tower in a 33 kV line.

A study of reliable and cost effective structural systems to withstand the avalanche loading was carried out, wherein three main types were studied:

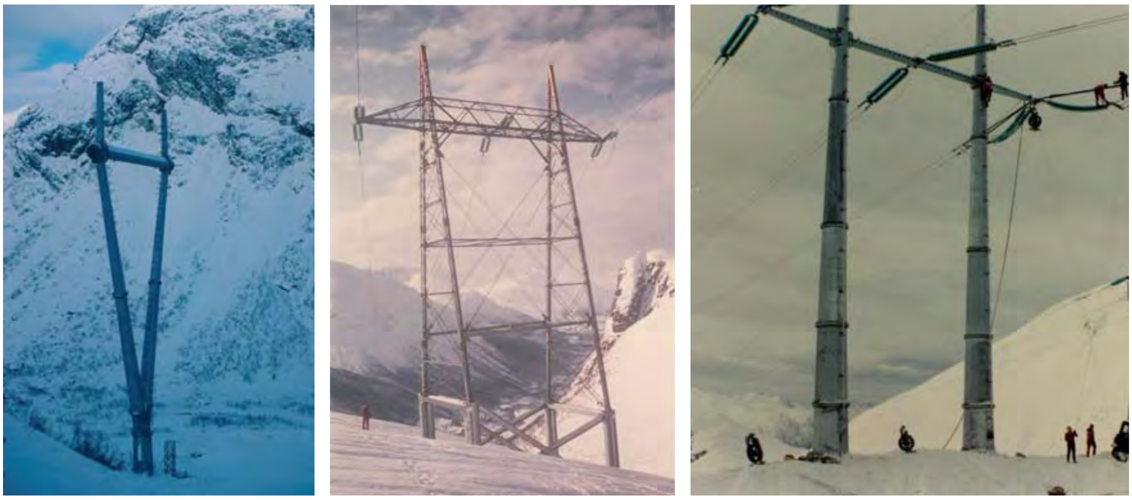
- (i) Lattice towers protected by separate uphill plow- or wedge shaped structures
- (ii) Lattice towers constructed on top of concrete columns/walls, which are in turn designed to resist avalanche forces and diverting the flow as much as possible
- (iii) Towers of tubular sections designed to resist the avalanche forces

Guyed tower solutions were rejected due to vulnerability of guys when subjected to avalanches. Figures 6–9 show examples of towers that are used in other countries in areas prone to avalanches.

Figure 6: Avalanche tower in Switzerland

Figure 7: Tower with concrete plow

Figure 8: Avalanche tower on concrete walls



a) at Ryggfonn test station *b) steel reinforced base section* *c) tubular shafts (Photo: NGI)*

Figure 9: Avalanche towers from Norway.

The study revealed that a singular, tubular steel shaft would be the best option in the impact zone of the avalanche core. Factors that influenced this result were:

- Foundation cost is high, thus it is important to minimize the foundation load and especially the overturning moment.
- All elements located within the impact zone of the avalanche core need to be compact and able to withstand high local pressure.
- Avalanche directional variability – Many towers may be subjected to snow avalanches from opposite hillsides of the valleys, in addition to directional variations in a flow from one hillside.
- It is more economical to build strong tower than to build separate protection structure uphill, *i.e.* plow- or wedge.
- Visual impact of transmission line towers is a matter of importance. Tubular shaft towers are believed to have a relatively consistent and good appearance.
- Relative ease of adopting design to variable avalanche loading between tower sites.

From the structural systems investigated during the tender design, a Y-shaped, tubular tower was selected as it appeared to minimize area exposed to the avalanche loading and thus reduce overturning moments. This in turn would result in savings for both towers and foundations. Brief cost comparisons also indicated economical advantages in having the concrete foundation column terminate just above the ground level, as opposed to extend the foundation up to and above the expected impact zone of the avalanche core. Factored herein was also the relative speed and simplicity of construction using tubular steel base sections as opposed to concrete.

Tower locations were carefully selected in order to minimize avalanche loading. This further resulted in having towers in the two lines located essentially side-by-side, as opposed to shifted along the line. It was therefore important to maintain sufficient spacing between the parallel lines such that a tower collapse in one line would not cause damage to the adjacent tower in the other line. Apart from having to fulfil required electrical clearances above ground, the height of the towers was also specified such that the average height of the conductor was maintained above the saltation layer.

Transmission lines in avalanche areas are at times designed with all towers as dead-end structures (*i.e.* no suspension tower) to minimize damage of adjacent towers if one tower fails.

Such examples are described by Anderson and Schauer. It should be noted that this only leads to a limited increase in operational reliability of the transmission line, as the main purpose is to reduce cascading failures, but not specifically guarantee continuous operational functionality of the OHTL. The cost associated with constructing all avalanche towers as dead-end towers, was considered to outweigh the limited increase in operational reliability.

4. DESCRIPTION OF AVALANCHE TOWERS IN FL3 AND FL4

4.1 Tubular Y towers

A total of 83 towers of type Y were built and 81 of them were to withstand avalanche loading. 70 towers are suspension towers and 13 towers are angle tension towers for line angles in range of 8 – 71 gone. The towers were detailed and supplied by Mitas in Turkey. Tubular tower shafts were produced by cold bending and welding of steel plates. A regular 12-sided polygonal cross-section was used for all towers, except the 11 suspension towers with the most extreme avalanche loads for which a semi-elliptical polygonal cross-section was used up to the Y connection. The aim for these towers was to increase the bending moment capacity, without increasing the area of sections subjected to avalanche loads. All towers were optimized with respect to the loading and different strength classes were used.

All shaft connections are bolted flange connections. Practical restrictions of widths, lengths and weights had to be considered in the design process with respect to production and transportation. Corrosion protection of towers was made by hot dip galvanizing where possible. Most tower base sections required different treatment, either because they exceeded dimensions of baths used in the galvanizing process, or were too heavy to handle. These larger sections were either partially galvanized, using metalizing and painting with duplex system for flanges, or wholly metalized and painted. All towers are equipped with a ladder system including rest platforms and safety lines. An inspection hole is provided close to the base of each tower to allow for visual inspection on the inside of the tower base.

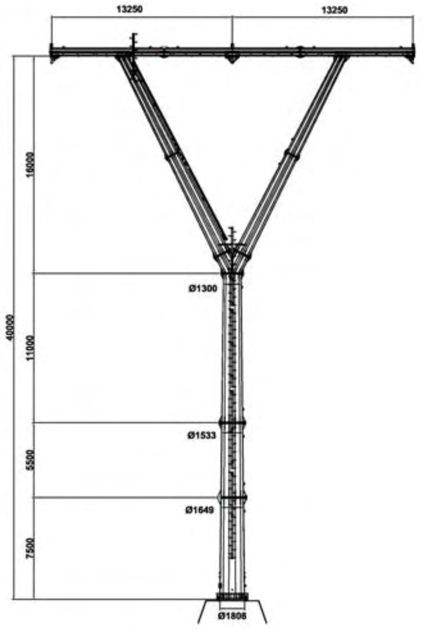


Figure 10: Main dimensions of 40m suspension tower. *Figure 11: Assembly of Y connection.*

Table 1 shows basic information of Y towers.

Table 1. Y towers. Main dimensions, material and loading

Tower Type			**Susp. Towers**	**Tension towers**
Quantity		[pcs.]	70	13
Average height		[m]	32	22,2
Height range		[m]	24 - 40	22 - 24
Weight of tower		[ton]	27 - 54	55 - 65
Line angle		[gone]	0	8 – 71
Base section	Material of steel plates	-	S355NL	S355NL
	Bottom dimension	[m]	1,4 - 1,8	2,1 - 2,65
	Thickness of steel	[mm]	16 - 20	20
	Flange bolt material	-	grade 8.8	grade 8.8
	Quantity of flange bolts	[pcs.]	24	24
	Size of flange bolts	-	M45 - M60	M64 - M68
Foundation connection	Material of anchor bolts	-	S355J2G3	S355J2G3
	Qua. of anchor bolts	[pcs.]	24 - 52	38 - 52
	Size of anchor bolts	-	M64	M64
Base loading at foundation connection	Max. overturning moment	MN·m	8 - 31,3	20 - 34,5
	Max. base shear force	MN	,3 - 4,1	1 - 3,4

Two types of suspension insulator strings are used in the avalanche area; 1x300 kN and 2x210 kN. Tension insulator strings consist of triple or quad tension strings with breaking strength of 3x400 kN or 4x400 kN.

Figure 12: Avalanche towers in Áreyjardalur, spacing between lines is 60m.

4.2 Terminal towers in Fljótsdalur

The two terminal towers at the substation in Fljótsdalur were designed for avalanche loading. They were also designed with a special emphasis on visual appearance, involving an architect. The detail design and production was carried out by PetitJean, France. The terminal towers are cold bent polygonal tubular steel, semi-elliptical sections with flange bolted connections similar to the other avalanche towers in FL3 and 4. One of the terminal towers is shown in Figure 13.

Figure 13: Terminal tower

4.3 Foundations

All avalanche tower foundations are cast-in-place concrete foundations with embedded foundation bolts/rods, M64, 28–52 pcs. depending on tower type and size. Rock bolt foundations were mostly used when depth to rock was within 4 m, but otherwise, concrete pads were used. The volume of concrete in foundations was in the range of 45 – 315 m^3, with an average of 124 m^3. The top of the foundation was cast with a special concrete shear "plug", positioned above the level of the tower base plate inside the tower base section. The aim is to transmit horizontal forces directly from the tower into the foundation through the shear plug instead of through the foundation bolts. To obtain tight fit after tower erection, the space between the concrete foundation and tower base section was filled with grout. See Figure 15.

Figure 14: Foundation of Y tower.

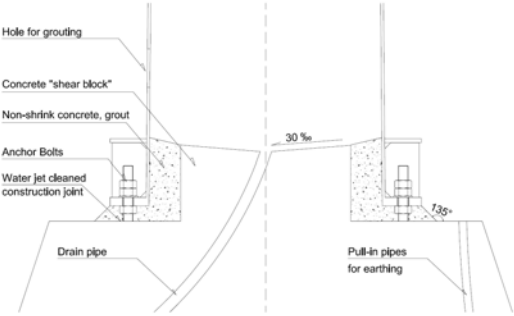


Figure 15: Shear plug in base connection.

5. ASSEMBLY AND ERECTION

The assembly and erection of all the towers in FL3 and FL4, including the avalanche towers, was carried out by Dalekovod (Croatia) and Elektrovod (Slovakia) through a joint venture. The relatively large dimensions of the avalanche tower sections required the use of heavy cranes. Sufficient access for the cranes was ensured during the site preparation phase by the construction of access roads and rectangular tower site planes, appr. 12x12m. Using the cranes, individual tower base sections were erected and assembled onto the anchor bolts. Lighter sections were preassembled on the ground and then lifted into place as shown in the figures below.

Figure 16. Assembly of upper part of tower by crane.

6. CONCLUSION

Due to the nature and severity of the avalanche loading for FL3 and FL4, dimensions of all structural elements, including towers and foundations, can be said to fall outside the norm in comparison to traditional transmission line structures. This poses a number of practical constraints on processes including material selection, fabrication and protective coating, transport, assembly and erection. In contrast to more traditional transmission line design, designing for avalanche loading of this magnitude thus requires extremely thorough preparations including extensive structural- and cost-benefit analyses of possible structural solutions for all components.

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Social effects of mitigative measures against snow avalanches in Neskaupstaður

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ABSTRACT

Research within the field of avalanche control and mitigative measures against snow avalanches has greatly increased in Iceland since the 1990s. This has been triggered in part by government policy after the catastrophes in 1995, when avalanches fell on both Flateyri and Súðavík. Studies into aspects concerning social effects of avalanche risk and avalanche control have been lacking. The following study is an exploratory qualitative inquiry aimed at producing suggestions for further research focusing on social aspects of avalanches. One aim of the study was to gain insight into the general effects of perceived danger, testing the hypothesis that inhabitants are significantly affected by the perils of avalanches. Another aim was to conclude about the effects avalanches and mitigative measures against avalanches have on the local real estate market, industry and commerce. During a week in February 2008, semi-structured interviews were conducted in Neskaupstaður. Findings suggest that inhabitants approach the avalanche threat with a sense of apathy.

1. INTRODUCTION

After the avalanches in 1995, two studies were conducted to assess prevalence of post-traumatic stress among inhabitants. Ásmundsson and Oddsson (2000) reported that 48% of people in Flateyri and 35% of people in Súðavík were diagnosed with post-traumatic stress disorder compared to 9% in a control group. Finnsdóttir and Elklit (2002) studied the post-traumatic sequelae for 104 adult inhabitants from the town of Flateyri. The study reported that 25% of the people in Flateyri, twice as many as in a control group, reached a level of psychiatric trauma, 10 weeks after an avalanche hit the town. Both of these studies used quantitative methods relying on standardized questionnaires. The advantage of quantitative studies is its breadth, whereas its problem is depth. Many social science studies into the effects of avalanches seem to be centered on trauma counseling and crisis intervention. This makes apparent the need for qualitative work to provide insight into wider social and psychological factors, however complex they may be (Flyvbjerg, 2006).

In comparison to the West fjords peninsula, on the North-West corner of Iceland, the climate on the East coast is milder, making the occurrences of avalanches less likely. Historical records of avalanches in Neskaupstaður date back to the late 19th century or around the time dense settlement began. Serious avalanches fell in 1885, killing three, in 1894, 1936 and in 1974, killing twelve people. Between 19th and 28th of December 1974, avalanches fell from most ravines above the town, in all 19 minor and major avalanches. The largest avalanches caused considerable private and industrial property damage in addition to taking lives. The catastrophes in 1974 are the ones contributing most strongly to a narrative of avalanches in Neskaupstaður, making them a fixed point of reference in all discussion about the topic. Investigating the types of stories people tell presents insights into the particular events described and the social framework within which the narrative is constructed. The purpose of this study was to assess the social effects avalanches and mitigative measures against avalanches through the use of these narratives.

2. METHODS

Central to this study is an exploratory approach. Exploratory research, within the social sciences, typically seeks to find out how people react to a setting under question, what meaning people give their actions or what issues most concern them. An exploratory method was thought to be appropriate since the purpose of this study is to assess the social effects of avalanches and literature on the subject was considered insufficient. A method most fitting this type of inquiry involves a qualitative method, in this case semi-structured interviews with people within the population frame. Semi-structured interviews facilitate understanding, they allow flexibility and tend to produce rich data (Smith and others, 1995). Interviews were conducted in Neskaupstaður during a week in early February 2008. Participants were in all 17 inhabitants selected with both purposive sampling as well as being identified by successive interviewees.

3. RESULTS AND DISCUSSION

Many of the respondents had witnessed at first hand the catastrophes in December 1974. A woman aged 42, eight years old at the time, lived in a house located between both of the bigger avalanches. She recalls this period: *The experience was horrific walking into town* [when evacuating her house], *we had to walk over the avalanche so I remember this very well, it's something you can't forget.* [We] *could not move back into the house for some time after. …when we moved back later we walked up the mountain side and saw the destruction. It was like everything had changed.* This respondent lost her friend and playmate in the avalanche and knew others that died. Another respondent, a man aged 62, lost his sister-in-law. He explains the events: *A day does not pass without me recalling the events.* When asked whether he now feels safe in his own home he replies: *I think I feel rather safe, but the fear is always there. There have been times we have evacuated without being called on to do so and you know I feel a lot safer today when my children have moved away from home.* This respondent, like many others, pointed out that there had been a dramatic change in weather in the last decades, resulting in less snow than before. *…I can't say we have had any real winter weather in the last years.*

All the interviewees, apart from one teenage boy, felt familiar with evacuation plans for the town. When asked if anything should be done to improve information about avalanche risk, the tendency of respondents was to confirm appreciation with the current implementation. People feel enough is being done with regards to monitoring risk. People also feel they can trust experts assigned to the task. More than one interviewee talked about the necessity of striking a balance between providing consistent information and causing unwarranted fear among inhabitants. A respondent, a 62 year old man, described this metaphorically in the following words: *It's a see saw. If* [authorities] *talk too much about avalanches people will be scared and that's something non-locals are sensitive to. This is the case, for example, in the West fjords. Many people from the capital would think twice before visiting* [respondent names a number of towns] *in the winter time. …*[B]*ut then again authorities can't ignore the threat because they are the ones that get the blame if things go wrong or if people die.*

Interviewees were asked whether avalanche risk has, to their knowledge, affected industrial development, commerce or jobs in Neskaupstaður. Only one respondent, a 50 year old general manager, held this to be true. More than one respondent thought avalanche risk likely to have an economic effect, referring to alleged problems regarding planning permission. Interviewees also answered questions regarding the effect avalanches have on population development, in- and out migration. Almost all respondents talked about a distinction of local attitudes, towards avalanche risk, as opposed to the attitude of non-locals. A woman aged 34 describes this in the following: *I noticed, because I have a friend that wasn't brought up here, that locals hardly ever discuss the possibility of an avalanche. She lives in* [a "safe part" of town] *…but is constantly talking about if it is safe or not, she is very nervous. I also know of people who have relatives* [in a nearby town] *…and they will call every time it snows just to make sure everything is fine.* Respondents were also asked what effect they thought mitigative measure has had on the local real estate market. The general perception was that the effect does not manifest itself in a difference in real estate prices within the town. One interviewee recalled "safe location" as being made a special selling point by a real estate agent, but also remembers it was rather frowned upon by locals. When asked if location with regards to avalanche risk would play part if they were to relocate within Neskaupstaður, only three interviewees said that location would not matter.

Interviewees were asked to describe how locals discussed the topic of avalanches. Respondents concurrently accounted a lack of dialogue and some even commenting on it as being rather peculiar. An answer given by an 18 year old male interviewed suggested a real sense of indifference. *I think I have never spoken to anyone worried about there being real danger here. I don't think people talk much about avalanches, with the exception of the one in nineteen seventy-something maybe.* A respondent, a woman aged 53, had moved to Neskaupstaður in 1976. She describes how people discuss the threat of avalanches: *Now people say we don't have to worry because the weather is so much better than before, and I agree, but you know when I came to Neskaupstaður in '76 people talked like this would never happen again. I think people believe Neskaupstaður has had it's avalanche, and you aren't really allowed to speak about it.*

4. CONCLUSION

People seem aware of evacuation plans and generally place great confidence in authorities who monitor conditions. At the same time respondents, knowledgeable about plans for further construction of mitigative measures, feel local authorities are not doing enough to push them through. Respondents talked about feeling a sense of unease regarding risk, but fear is too strong a word to describe the general sentiment. Thus it can be concluded that inhabitants are not significantly affected by the perils of avalanches. Interviewees recognized a difference between attitudes of locals and non-locals regarding avalanches, some describing the views of non-locals as being irrational. The effect mitigative measures have on the real estate market is, held to be, diminutive within the town and hard to weigh up against other factors within the region. When asked how locals discuss both avalanche risk and the mitigative measures, findings suggest a sense of apathy among inhabitants. Whether this apathy is warranted is not for this study to conclude upon. However, it is suggested that future research should focus on describing apathy among inhabitants living with avalanches risk. This is important because indifference among inhabitants may affect government policy and in turn delay construction of further mitigative measures against avalanches.

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Non-structural mitigation in areas of high snow avalanche frequencies in Iceland

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ABSTRACT

Mitigation is about action or an activity that attempts to eliminate or reduce human suffering and property damage from natural or man-made hazards. There are a number of different approaches to mitigation in emergency management. The focus of this discussion revolves around three themes relating to methods to mitigate risks

- The role of the Civil Protection in Iceland
- Mitigation in areas of high snow avalanche frequencies
- The collaboration of the Civil Protection, Meteorological Office, and other institutions on snow avalanche mitigation measures.

First, the objective of the Act on Civil Protection (No. 94/1962) in mitigation will be presented. Second, the non-structural mitigation methods in areas of high snow avalanche frequencies in Iceland will be addressed. Finally, the collaboration of the Icelandic Meteorological Office, the Civil Protection, and other organizations in the snow avalanche risk management process before and after 1995.

1. THE CIVIL PROTECTION IN ICELAND

When the Civil Protection Act (94/1962) first became effective, it was in the middle of the Cuban crisis and the key provision was the preparedness and prevention of a nuclear attack. The Civil Protection Unit (AVRIK) was governed by the state under the authority of the Ministry of Justice, but under control of the Civil Protection Council (until 2003 when the National Commissioner of the Icelandic Police took over the Civil Protection Affairs). The local communities (64) had their Civil Protection Committee and their administration was in the hands of the Chief of Police. The Civil Protection Unit monitored and gave advice to the otherwise independent Committees. The Minister of Health is responsible for medical service during disasters.

The Civil Protection responds according to two types of emergency plans: Generic Plans, that are core plans for mobilising staff and resources and apply to different kinds of emergencies, and Specific Plans – that apply to a specific hazard, site or location

In 1974, the Civil Protection made an agreement with volunteer organizations, the Icelandic Red Cross, and the Icelandic Association for Search and Rescue. This agreement defines their roles and tasks in the overall organization of Civil Protection in times of hazards and emergencies, training and education. This agreement is renewed on a regular basis.

The objective of the Civil Protection Act is to organize and implement actions for the preservation of life and human needs, protecting property in case of military action, natural disaster or other disaster. Amendments have been made to the Act regularly to correspond to changes in society, lessons learnt from crisis or new threats. There are now 28 Civil Protection Committees in the country in 15 districts but the plan is to have one Civil Protection Committee in each district.

A new and improved Civil Protection Act has been prepared and is under consideration in the Icelandic Parliament. The main objective of the Act is still the same as in the Act No. 94/1962.

2. THE SNOW AVALANCHE RISK AND NON-STRUCTURAL MITIGATION

Mitigation is about action or an activity that attempts to eliminate or reduce human suffering and property damage from natural or manmade hazards. There are a number of different approaches to snow avalanche mitigation measures, both structural and non-structural.

Structural mitigation: measures such as terrain modifications, supporting structures in the starting zone or deflecting structures like walls, barriers and fences. Structural mitigation is a lasting solution for inhabited areas, especially if relocation is not an option.

Non-structural mitigation: measures such as enforcing law and regulation, insurance, land-use planning, building codes, screening changes, education and awareness programs and public education.

In recent years, mitigation has been a mixture of both, but with increasing emphasis on the non-structural mitigation (Alexander, 2000; Thomas, 2006). Both the structural and non-structural mitigation methods need regular screening and monitoring. The approach of the Department of Civil Protection in the emergency management process includes non-structural mitigation.

2.1 Law and regulation.

Acts are passed by legislative bodies in order to protect the citizens and their properties and the executive authority is given power to enforce this law and regulation. Among legislation for this kind of protective and mitigative measures against natural hazards such as snow avalanches are:

The Civil Protection Act no 94/1962:

- Important changes were made in 1967 when a paragraph on preparedness and response to natural hazards was added to the Act´s objective in the prevention of damage to property and persons.
- Emergency and evacuation plans are made by the Civil Protection Authorities and also includes exercises. Tabletop exercises are performed each year in order to be better prepared for disasters. This is also done in snow avalanche areas in cooperation with the Meteorological Office.

Protective Measures against Avalanches and Landslides Act no 49/1997:

- The main objective is to prevent damage to property and persons resulting from avalanches and landslides.
- The Icelandic Meteorological Office collects and processes data on avalanches and avalanche danger and carries out measurements of snowpack properties and research on such with special regard to avalanche danger and issue warnings of such dangers.

2.2 Development and regulations.

Organized planning did not exist when the first town and villages around Iceland were developing, often around the harbours. Villages gradually spread out and historical knowledge about snow avalanche threat in some of these villages was almost nonexistent.

Land-use and planning in high snow avalanche risk areas is the collaboration of the Icelandic National Planning Agency and the Icelandic Meteorological Office in snow avalanche risk areas. Land-use changes and other measures are regularly evaluated such as hazard zoning, classification and utilization of hazard zones. New settlements have to be planned outside hazard zones with building codes and standards (Regulation 505/2000).

Snow monitoring and timely issuance of emergency warnings are vital for the public. The Meteorological Office and the Civil Protection Authorities co-operate and give warnings and risk information on imminent threat. The warnings must provide the information and motivation for people to take informed action. The Civil Protection works on three levels of emergency phases; Uncertainty Phase, Alert Phase and Distress Phase.

2.3 Public Insurance and Funding

- **The Act on Natural Catastrophe Insurance**. All property insured against fire is automatically insured against direct loss resulting from natural hazards. The Land Registry of Iceland is responsible for valuating property for taxation purposes as well as the valuation for the compulsory domestic fire insurance. (Act no 52/1975/513 and Act no 55/1992**).** Many houses in former disaster areas have been seriously undervalued (Annual Report SASS).
- **The Snow and Landslide Mitigation Fund. (Act no 49/1997)** The objective of the fund is to cover the cost of risk assessment in high risk areas, partially the cost of preparation and construction of defence structures and maintenance of defence and deflecting structures. Also assisting communities to purchase private residences in a high risk area and the relocation of persons concerned.

2.4 Information to the Public

- The dissemination of detailed information to communities on the risk of snow avalanches what to do in case of evacuation and where to go. Information leaflets have been distributed to all inhabitants in areas prone to frequent snow avalanches in Iceland. The Civil Protection website has three sub-sites in English, French and Polish on prevention preparedness and response during emergencies and the target groups are both tourists and immigrants.
- Raising awareness and community resilience with public education and outreach efforts. Empowering local groups by seminars and workshops on natural hazards. Training the local search and rescue teams in avalanche operation. Work with the media to raise awareness, since media is perhaps the most effective and important source of disaster information, and can influence how the public perceive disaster information. It also plays an important role in broadcasting and publishing warnings
- Risk perception. It is important to understand the public and the things that influence people's behaviour in an avalanche environment. There are other factors than objective calculation of risk that have to be identified in the risk management process and indicate how individuals or communities perceive the risks from natural hazard.

> The perception of risk by the public can determine the extent to which they will accept the planned level of the approach set by the authorities.

Society’s tolerance levels tend to fluctuate with the occurrence of disasters impacts. A serious catastrophe that causes widespread casualties and losses will create an upsurge of opinion in favour of renewed mitigation effects. It will thus reduce the tolerance level. But a long and peaceful period may allow other priorities to replace hazard mitigation and disaster preparedness, and thus increase the tolerance level (Alexander, 2000).

This tendency was clear during Parliamentary debate about snow avalanche disasters in Iceland, first in 1974, then in 1983, and again in 1994-5 (Parliamentary debate 1974/-1983/1994-5).

3. THE COLLABORATION OF CIVIL PROTECTION AND THE METEOROLOGICAL OFFICE

Following a snow avalanche disaster in the town of Neskaupstaður 1974, it was clear that increased work in avalanche risk research was an urgent requirement, and an amendment was needed in the legislation. Monitoring, risk assessments, data gathering and research were incomplete. Debate in the Parliament demands improvement. In 1978, the Prime Minister´s Office assigned the matter of snow avalanche prevention to the Ministry of Communication which gave the Meteorological Office the project. In 1979–80 a Parliament resolution proposed “that of all natural disasters in Iceland mitigation for snow avalanches could be the most successful of all because of their specific location and their meteorological nature that is easy to monitor” and “Mitigative measures are the only long lasting investment and the most profitable” (P.r. 1980-03-18). Still there was no permanent action taken by the Parliament. After a snow avalanche disaster in the village of Patreksfjordur in 1983, the government decided to form a snow avalanche expert committee to coordinate this work, and to try to prevent accidents due to snow avalanches and landslides. The committee proposed the strengthening of the work of the Meteorology Office and the Civil Protection Unit (AVRIK) and gave the local government increased authority. Then the work of the committee was terminated due to savings in the national economy. The only legislation until 1985 that stipulated preparedness and response to natural disaster was in the Civil Protection Act and the Act on Natural Catastrophe Insurance (52/1975 article 19). The legislation for the Meteorological Office 1958 stipulated warning against harmful weather in article 4. The first law on preventive measures against snow avalanches took effect in 1985.

One key provision in the 1985 legislation was the role of the Civil Protection in the risk assessment process, classification and utilization of hazard zones while the Meteorological Office focus was on monitoring, data gathering, research and warnings. Individual local government and the Civil Protection had to give the risk assessment their consent and then the Ministry of Social Affair made the final decision. Local governments could make recommendation for structural barriers and planning in their community but the Civil Protection and the Ministry of Social Affairs had to agree. The warning procedure became collaboration between the Icelandic Civil Protection, the Icelandic Meteorological Office and the Civil Protection Committees in each district (Hilmarsson, 1999).

Before the snow avalanche disasters in the villages of Súðavík and Flateyri in 1995, it was again clear that more effective measures in avalanche prevention preparedness and response were needed. Increased amendments were made; the snow avalanche preventive measures moved to The Ministry for the Environment and additional responsibility was given to the Meteorological Office.

Even though the objective of the Act on Civil Protection (No. 94/1962) is to protect human life and property from natural disaster the Parliament finally decided in 1997 that special legislation for avalanche measures was crucial since a substantial number of people in several Icelandic towns and villages had lost their lives in areas where avalanche risk is high and the economic loss is high. A total of 193 persons were killed during the period 1901 – 2000 in snow avalanches and landslides and the direct and operational loss from 1974 – 2000 is about 5.8 billion IKR (72 million USD) (about 3.3 billion (41 million USD) is direct economic loss due to avalanches and landslides) (Jóhannesson and Arnalds, 2001).

This new legislation became effective in 1997 (Act No. 49/1997). According to the new legislation the collaboration between the Civil Protection and the Meteorological Office was specified especially in Article 5, 6 and 7.

According to Article 5 the Icelandic Civil Protection shall prepare the emergency plans and the instruction and public education regarding the danger of snow and landslides. Also organize and carry out rescue and relief operation as a result of danger or damage from snow and landslides.

The Icelandic Meteorological Office issues a warning of localized avalanche danger, and declares a state of alert, and decides when the state of alert is terminated. This is all done in collaboration with the Icelandic Civil Protection.

According to Article 7, the Chief of Police may decide to evacuate houses in cooperation with the local Civil Protection Committee due to the risk of snow avalanche.

Response capabilities were improved as to facilitate the search and rescue of victims (Act 43/2003).

4. DISCUSSION AND CONCLUSION

Previous to the 1995 disasters and the Act on Protective Measures against Avalanches and Landslides (49/1997), the risk management process on prevention, preparedness and response was very complicated. The Ministry of Social Affairs, the Ministry of Health, the Ministry for the Environment, the Ministry of Justice, the Civil Protection Unit (AVRIK) and Council, the Meteorological Office, committees and local governments, all had their individual functions within the snow avalanche management process. All these different governmental bodies worked parallel, and each performing part of the puzzle without a holistic approach. Then, when disaster struck, the coordination between the different governmental bodies was incomplete.

Even though there was a political and Parliamentarian will for improvements in the avalanche preparedness, prevention and response, funding was lacking.

The mitigation planning process in emergencies is continuous and includes multitude of organizations. It needs a multidisciplinary perspective, research and coordination across agencies and at-risk communities, not in a parallel and with unconnected efforts, but with integrated work within these disciplines and organizations.

The goal of crisis management and crisis decision making process must be transparent with a holistic approach. By simplifying the management process in 1997, and entrusting increasing snow avalanche assignments to the Meteorological Office, a more effective procedure in the prevention and preparedness process was achieved.

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Environmental impact assessment of mitigative measures

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ABSTRACT

Out of 79 local authorities in Iceland 9 municipalities have 17 densely populated areas with hazard zoning confirmed by the Minister for the Environment. In a research survey by the Icelandic Meteorological Institute in 2006, 98 densely populated areas in addition were studied and 8 of them in 8 municipalities were pointed out to be better looked at to be able to define the risk of snow avalanches and landslides and the need for hazard zoning. This means that over 20% of the local authorities have to take hazard zoning and restrictions on land use that follows into consideration in the planning process. Dams and other protective structures have already been built above a few of the threatened settled areas and others are under preparation.

Risk for snow avalanches exists not only in densely populated areas but also in agricultural areas in valleys and near high mountains all around Iceland. The history of snow avalanches may be known in hills next to the existing farmhouses but when it comes to planning and building areas for summer houses, an increasing form of land use, questions have to asked about the safety for those who are going to be living in the houses because summer houses are in use all year round.

Laws and regulations to deal with planning and building of mitigative measures, such as dams and supporting structures, against snow avalanches are relatively recent in Iceland. There is a regulation from year 2000 on hazard zoning due to snow- and landslides, classification and utilisation of hazard zones and preparation of provisional hazard zoning. The Planning and Building Act nr. 73/1997 defines compulsory planning and the planning stages from national to local planning. According to the Act, every local authority has to prepare a municipal land use plan for all areas within the municipality. According to paragraph 21 in Annex 1 in the Environmental Impact Assessment Act no. 106/2000, quarries where planned extraction disturbs a surface area of 50,000 m^2 or more or amounts to 150,000 m^3 or more have to go through an EIA process. This includes building of dams to protect settled areas. In 2006, the Strategic Environmental Assessment Act no. 105/2006 was implemented in Iceland which means that every plan that includes a project listed in Annex 1 or Annex 2 in the EIA Act is subject to the SEA. Therefore, an environmental report has to be a part of the plan.

It is already evident that mitigative measures in the form of dams, walls and supporting structures can have a considerable impact on the environment. It is therefore of utmost importance that mitigative measures are well prepared and that the process of environmental impact assessment includes public participation. Environmental impacts can differ from site to site but when it comes to building, for example a colossal 15 m high and 600 m long dam in a hillside just above a densely populated area, it is clear that visual and social impacts are the most important and at the same time the most difficult environmental impacts to assess.

Avalanche protection – some aspects of design and construction

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ABSTRACT

Avalanches have posed a threat in Iceland. In the last decade a collective effort has been made to alleviate these threats. Deflection dams, barriers and splitters have been constructed at several locations. The material most commonly used for construction is scree material. Scree material can be difficult to handle and can be very sensitive to moisture. This sets some limitations on the utilization of the scree material. Other materials used for earth-fills include material from rockslide formations and blasted rock.

Barriers have been constructed using reinforced fills. Aspects like appearance and maintainability, as well as geotechnical factors, have to be considered carefully when selecting the appropriate reinforcing system. Two types of systems, geocells/geogrids and steel strips/-steelmesh, have been used successfully in Iceland.

To increase or maintain the stability of dams and barriers, it is vital to keep groundwater at the lowest possible levels. For that purpose drainage ditches are excavated to divert the water away from the constructions.

1. INTRODUCTION

Avalanches have posed a major threat in Iceland throughout the centuries. However, no large-scale protective countermeasures are known to have been taken until after the avalanches of 1995. Few mounds and a small barrier had been built at Flateyri but their size is dwarfed by the deflecting dams, later deemed necessary to protect the community. Prior to 1990, avalanche protection was studied at the Sudavik community using a computer software developed by Verkfræðistofa Siglufjarðar. It revealed the necessity of a large barrier in the mountainside above the town. A small community was in no position to build such an immense structure so no action was taken at that time (Jóhannesson, 2008). After the avalanches in 1995, a public decision was taken to protect communities subject to avalanche threat and the Avalanche and Landslide Fund came in with financial backing. The first major project was the construction of deflection dams at Flateyri. This was followed by projects at Siglufjörður, Neskaupstaður, Seyðisfjörður, Ísafjörður and this year construction will start on projects at Bolungarvík and Bíldudalur. Línuhönnun Consulting Engineers has had the opportunity to be involved from the beginning, participating in most of these projects, either during the design phase or the construction phase. In the decade that has passed since the completion of the Flateyri project Línuhönnun has gained valuable experience. In this paper some of the issues of design and construction will be addressed.

2. CONSTRUCTION MATERIAL

For construction of avalanche barriers and dams to be more economical than property procurement in threatened areas, construction materials must be available within the site. The geological conditions in lower part of Icelandic mountainsides consists of scree material (talus) of variable thickness overlying bedrock or various glacial or alluvial sediments. The scree can vary from being suitable for construction to being not suitable at all. It can be relatively coarse grained with low moisture content and thus quite suitable for construction of this kind. It can also be fine grained, with high fines and moisture content and very moisture sensitive, making it almost impossible to handle and process. The fines can vary from being a mixture of organic material to silty or clayey material. Figure 1 below shows a grain size distribution (<75mm) of material from Flateyri. The solid black line represents the average distribution (Línuhönnun, 1998).

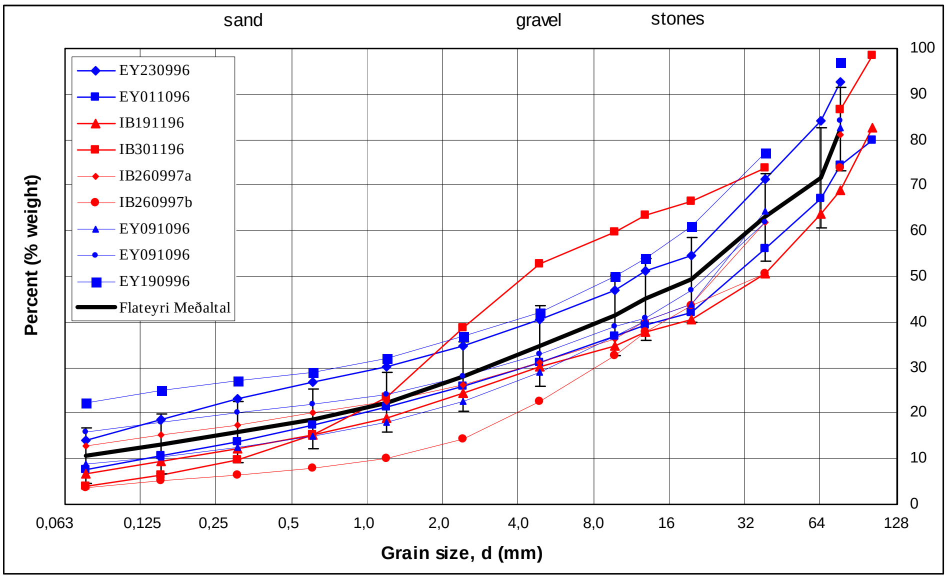

Figure 1: Grain size distribution of scree material from Flateyri.

What makes the scree material even more difficult to handle and process in construction is the non-uniformity of the material at the site. It is hardly in any recognizable layers, thus making it more difficult to separate the better material for construction. In most of the projects to date, a substantial amount of unsuitable material has been removed from sites in order to get to the more attractive material. With the involvement of landscape designers in the projects such materials has been put to good use, forming new landscape in harmony with the existing one and more often than not smoothing the slopes of the leeside making them more visually attractive.

Material from rock-slides is usually coarser than the conventional scree material, thus making it more suitable for fill material. At Siglufjörður, the deflection dams constructed 1998 – 1999 were partially made of such material from a rock-slide formation, Nautskálahólar, located within the construction site. That material was used to build up the slope 1:1.5 (vertical:horizontal) on the floodside of the dam (Línuhönnun, 1999a). The material, however, has fine and clayey particles that make it almost impossible to use during wet periods. When constructing the barriers at Siglufjörður 2003 – 2007 an attempt was made to process a similar material, coarse material with clayey submatrix. That experiment was futile as the clayey material stuck very much to the coarser fraction of the material so an actual separation was not possible. The following photographs show this type of material, both in-situ in the pit (left) and being unloaded at fill site on the barrier (right).

Coarse scree material in-situ, under an organic overburden, Siglufjörður 2006.

Same material unloaded at fill site on barrier, Siglufjörður 2006.

Where bedrock is encountered at shallow depths, blasted rock is the most logical material for use in dam or barrier construction. When forming a deflection dam floodpath or flood reservoir behind barriers, large cuts are made along the dams and barriers and that material is used for dam and barrier construction. Only at Ísafjörður and Neskaupstaður have geological conditions been such, that a large amount of rock had to be cut, to create the necessary volume. The rock cut accounted for all the required fill material in the floodside part of the dam and barrier. The overlaying material was then used on the leeside to lessen the visual impact and better adapt the slope to the existing terrain. At other projects bedrock has been encountered in some quantities but not nearly enough to account for all the fill material. In the case of a deflecting dam the blasted rock is usually hauled unprocessed straight to the dam. The photographs below are from the Ísafjörður deflection dam under construction. To the left, fill in dam and to right the cut in the bedrock in the flood path.

Rock fill material in deflection dam, Ísafjörður 2003.

Rock cut at Ísafjörður deflection dam, Ísafjörður 2003.

3. CONSTRUCTION – SCREE MATERIAL

The scree material has been investigated geotechnically for most of the projects to date. Usually a subsurface exploration is conducted and samples retrieved for testing. The tests run include tri-axial tests and compaction tests as well as grain size distribution and moisture tests. The results have been similar. An angle of internal friction for drained conditions is in the slightly above 40° and an optimum water content for compaction is 19-20% (VST, 1996; Björnsson, 1998; Verkfræðistofa Austurlands, 2000; Skúlason, 2007). The side slopes of the deflection dams at Flateyri were decided 1:1.25 on the floodside and 1:1.4 on the leeside, utilizing the friction angle to it's maximum extents. In other projects, the side slope on the floodside has not exceeded 1:1.5 unless using selected material.

The deciding factor in how well the scree material can be processed and handled is the moisture content. The material can not be compacted if the moisture content exceeds the optimum water content. At the Flateyri project the moisture content of the scree material planned for construction of the dams exceeded almost always the optimum water content. This was both due to very high natural moisture content and wet weather conditions in the fall of 1996. Figure 2 below shows an overview of the moisture and fines content of the Flateyri scree material, tested at site on material <19mm (Línuhönnun, 1998).

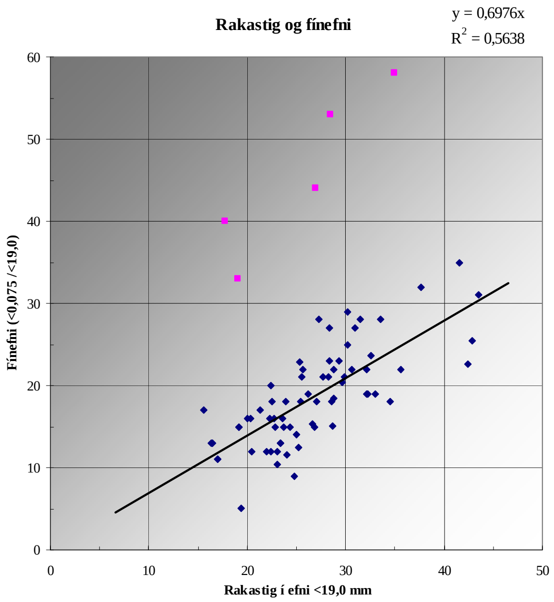

Figure 2. Overview of moisture and fines content of scree material at Flateyri. The pink points represent the material that was tested during the design phase.

As the material was not compacting properly it was almost impossible to maneuver equipment such as haul trucks, dozers and rollers on the fill. It can almost be stated that scree material is unusable, if the in-situ moisture content is high or during wet weather periods, unless there is some other material available that can be used for drainage layers in between. It is hardly realistic to attempt to dry out the scree material by piling it up in mounds, as has been suggested, because the moisture dissipates extremely slowly, due to the low permeability of the material. That can be restrictive to the typical time frame of projects like these. As an example only the outermost 0,5-1,0m of the deflection dam at Flateyri had drained out to any extent a year after construction ended. The remaining mass seemed to be in the same state as when it was laid out. Additionally, area needed for such stockpiling of material takes up valuable space within the usually sparse operational area made available for projects like these. Experience shows that in normal weather conditions in Iceland, thawing periods in late spring and rainy autumns, scree material can only be utilized effectively for 3 months every year during the summer, at least in the northern part of the country where all the projects have been taking place to date. It is therefore of vital importance to always have access to materials that are not as moisture sensitive, such as sand, gravel or blasted rock, to use as layers sandwiched between the scree material for drainage and to be able to maneuver equipment. Early in the construction phase at Flateyri, a large deposit of sand was encountered within the excavation site and a considerable amount of sand was used in the dams for the aforementioned purposes. The following photographs are from the Flateyri construction site (Línuhönnun, 1998).

Sand being laid out on top of scree material, Flateyri deflection dam, 1997.

Scree material being laid out, Flateyri deflection dam, 1996.

After the slopes have been constructed it is important to start the vegetation process as soon as possible. The vegetative layer minimizes surface erosion potential, dust pollution and gives the surface a far more appealing appearance.

4. CONSTRUCTION – REINFORCED FILLS

The first avalanche protection construction in Iceland using reinforced fill was a barrier constructed below Drangagil ravine at Neskaupstaður. That project also involved 13 splitters using same method. The barrier was 17m high with a reinforced part of 14m. The splitters were 10m high. Since then, both deflective dams and barriers have been constructed utilizing reinforced fills at Seyðisfjörður and Siglufjörður. Similar constructions are planned this summer at Bolungarvík and Bíldudalur.

The market offers a variety of types of systems to reinforce fill material. When choosing the most suitable system certain things need to be taken into consideration. It is important that the fill material has good compaction characteristics to minimize movements, since that will distort the front of the wall and the systems are not equally suitable to account for such distortions. The fill material has to be screened or processed in most cases, since the reinforcements require a certain maximum diameter and grain size distribution in order to maximize the friction between the fill and the reinforcement. Some other reasons also play a pivotal role when choosing the system. The walls are in some cases enormous and appearance obviously is important. Cost is another factor that always plays a major role. Maintenance and the ability to repair damages by avalanches or rock fall is also of importance.

When designing the barrier and the splitters at Neskaupstaður in 1999 an analysis of certain systems (geotextile/geogrid with two different fronts, gabions, steel strips/steel mesh front, anchored concrete units and a concrete wall) was performed in order to determine which was the most suitable for the project. The systems were analysed with respect to five factors. These were cost, appearance/aesthetics, durabilty/robustness, construction and maintainability. Each factor was given a certain value and ultimately a final grade calculated. The top scorers were the gabions and the steel strips system (Línuhönnun 1999b). It may be noted that these did not score highest on the aesthetic part. The client then made the decision to go with the steel strips system. The system consists of heavily galvanized steel mesh in the front and steel strips that are connected to the front and extend from the front into the barrier. The steel strips have ribs to increase frictional capacities. This system has since then been used successfully in two other projects with some modifications made to the initial manufacturer specification to accommodate for Icelandic conditions. For instance the maximum diameter of the frictional fill has been increased to up to 250mm from the initial 0/150 specifications. A pull-out test conducted at Neskaupstaður even indicated that using a blasted rockfill 0/350 with good grading was capable of creating the necessary frictional interaction with the steel strips. In addition the first two meters of the steel strips were painted with bitumastic paint to further minimize the corrosion risk. The photographs below show the barrier at Neskaupstaður under construction (left) and after completion (right).

Barrier built with steel mesh systems under construction, Neskaupstaður 2000..

Barrier built with steel mesh systems, after completion, Neskaupsstaður 2002

The construction of the barriers at Siglufjörður used a different approach. At Siglufjörður the vertical walls are a much lower portion of the total effective height, only 4-5,5m of a total effective height of 15m, with the rest of the barrier built with unreinforced fill to a 1:1.5 slope. The vertical walls are built up with so called geo-cells and geo-grids for forming the front and reinforcing the fill. A processed material is used for the cells and selected scree material is used around the geogrids. The filling of the geocells is mostly done with small construction equipment, bobcats and small vibratory plate rollers and with manual labor. The material needs to be hand-raked into the cells and a considerable manpower is necessary compared to the other solutions. The main advantage of the geocells is that the vertical walls can be vegetated and a green front can be created. The photographs below show the barriers at Siglufjörður under construction (left) and after completion (right).

Barrier built up with geo-cells, under construction, Siglufjörður 2006.

Barrier built up with geo-cells, after completion, Siglufjörður 2006

It is important to note that the top width must be sufficient to operate machinery, especially if the leeside slope is steep. The 3m usually allocated for the top width is very narrow. At least 6m are needed for trucks to maneuver one the top so usually the final two meters of fill are built up with an excavator.

5. GROUNDWATER

Groundwater levels in both cut and fill areas are very important. It is essential to lower the groundwater levels under the dams and barriers as much as possible to increase their stability and take some measures to maintain these levels and ensure that water has a safe passage out from under the constructions. For this purpose trenches have been excavated under the dams that have been filled with highly permeable material wrapped in geotextile. The most effective fill materials are stones that can be screened from the scree material. The final positioning of these trenches is best selected and adjusted to conditions encountered when construction has started, rather than specifying a grid of trenches. This will allow them to be positioned where water is actually flowing. The photographs below show typical trenches.

Drainage trench, Siglufjörður, 1999.

Drainage trench, Flateyri, 1997.

As mentioned earlier in this text, water and moisture plays a major role in the construction in projects like these. It is therefore very important to keep water away from the pits so an otherwise decent material is not made unsuitable for construction. Likewise, the fills in the dams must be kept in such a state that water always has a safe passage off the surfaces.

6. CONCLUSIONS

Several avalanche protection dams have been constructed in Iceland over the last decade. The main construction material so far is scree material. Scree material is extremly vulnerable and sensitive to moisture. It can not be compacted unless the moisture content is suitable for compaction. If that is not the case, access must be made to alternative fill material that can function as drainage layer and for construction traffic to operate on. Surface and ground water must be diverted away from the material both in pits and in the fill and trenches must be excavated to maintain safe ground water levels under the dam fills. Experience has shown that only during 3 months of summer construction with scree material is effective.

Reinforced fills have been utilized in avalanche protection in Iceland using two types of systems. When choosing the appropriate systems, factors like appearance and aesthetics as well as technical and geotechnical factors must be considered. Furthermore, compatibility between the front wall and the reinforcing system must be ensured. It is also important to allow sufficient width of top of dams.

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The role of landscape architects in the design team.

Why landscape architects are needed in the design team of large scale projects!

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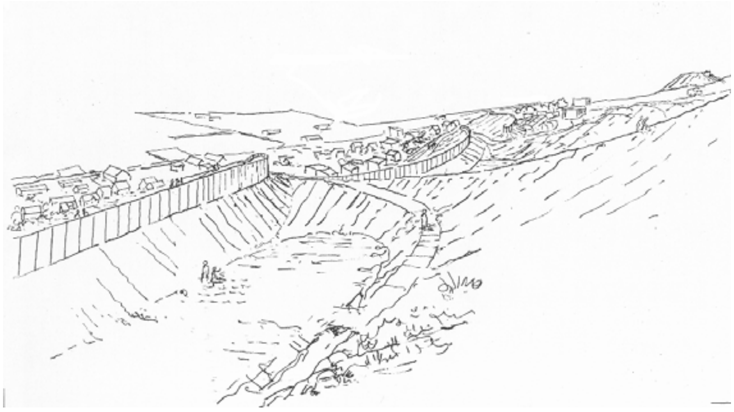
It is often assumed that architects and landscape architects have the tendency to turn simple projects into complicated ones for no apparent reasons. That view depends on how the designers identify the projects and define the problem formulation. The aim here is to explain the role of landscape architects in the design team of large scale projects, where engineers, geophysicist and other professionals play the main role.



Reynir Vilhjálmsson's sketch of a catching dam in Siglufjörður.

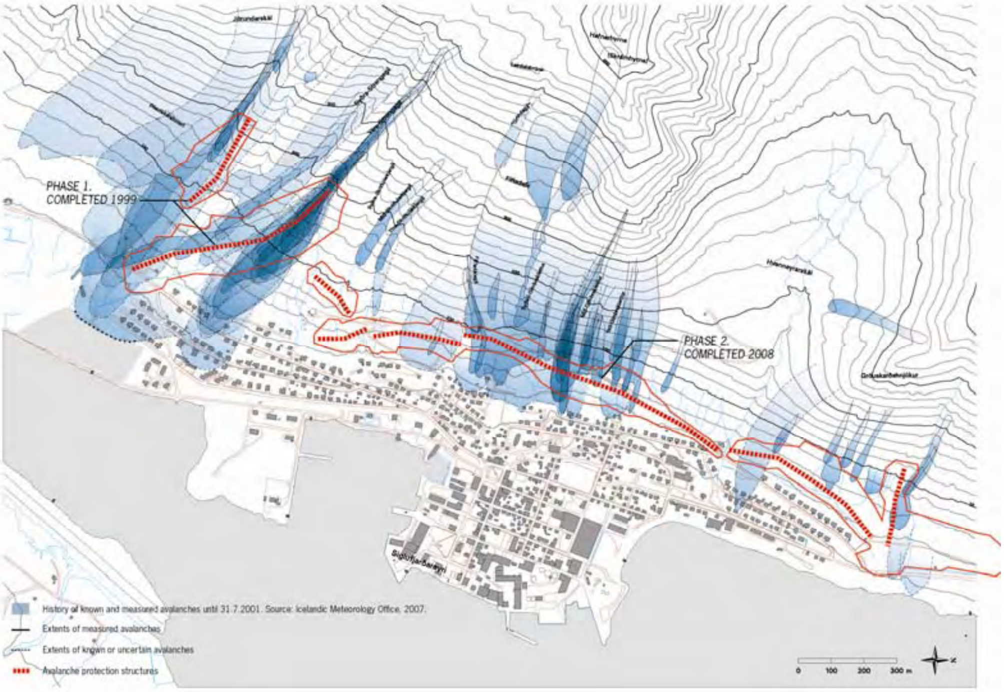
The landscape framing the area where people are living often has a great sentimental value. Thus even though large-scale projects such as hazard area projects are vital to the laypersons living in the area, the projects frequently meet heavy resistance. This is due to that it is challenging to adapt and integrate the new defence mechanism into the landscape while maintaining the functions of the protective structures.

Examples of large-scale projects are; avalanche defences, minimizing the visual impact of power plants, hydro or geothermal, large dams or reservoirs, roads and large-scale impact on the natural and man-made landscape. Here, avalanche defences are used as an example.

The main design process of avalanche protection projects are typically in the hands of engineers and geophysicist, thus the landscape architects role is to focus on different aspects in the project. The landscape architect works closely with the design team to minimize the visual and natural impacts of the project. Ultimately the aim of the landscape architect is to make the new defence structure socially acceptable. It is known that laypersons living in an area where such large-scale defence structures are built, can show strong resistance towards the change of the environment although it is acknowledged that these changes are vital for the area and the people who are living there. This is understandable when it comes to shaping a local mountain that is a large part of a town character and identifies an indistinguishable part of the town as a place. However, these psychological aspects of the projects are often dealt with by landscape architects. Consequently, landscape architects know that more has to be done than just build the defence structures. It is essential to create positive social motivation for new projects. This is done by softening the visual impacts and by creating a more acceptable landscape out of it. Landscape with a meaning – a place!

The best way to create a successful landscape out of the hazard area is to rethink the meaning of the project. This was the case in the project at Siglufjörður, northern Iceland, when the landscape architects proposed that the project should be seen as an opportunity to create something positive, such as in this case: a recreational area for the village.

At Siglufjörður, the design team was always aware of the fact that these gigantic structures could never be hidden, nor could they count on tall-growing trees to camouflage the large deflecting walls. Therefore, they choose to make an architectural statement or landmark out of the structures while adapting them to the shape of the mountain.



Map of Siglufjörður, northern Iceland. Known avalanches are shown in blue, defense structures in red. Building of the defense structures started in 1998 and some of them are still under construction (as of 2008).

During the construction process at Siglufjörður, new waterways started flowing as the machines cut through the bedrock and new landscapes emerged with new spaces that are all linked together with paths from the former construction roads and new built ones. The visual effect of the new defence structure is amplified with lush green vegetation where shrubs and trees and stabilize the soil at the same time.

Like middle-age towns that had walls to defend them against outside attacks, the avalanche structures at Siglufjörður are in principle build on the same idea; defending the town against the outside hazards. In some parts of the project, in order to avoid the deflecting walls from looking too dominating, their width varies thereby creating an organic form on one side of the wall, contrasting its steep dominating form on the other side.

The landscaping and final design of the structures was based on curved form in the landscape. While the dominating upper aspect of the dikes must be steep in order to deflect avalanches away from populated areas, their visual impact is offset by a smoother lower edge. Varying in width, this serves to give them an organic, ridged, yet undulating form. The end of the structures is formed like a sloping bastion with a public viewpoint at the top, giving the wall an architectural appearance near the town edge.

Deflecting dams, “Stóri-boli” and “Litli-boli”, near the southern end of the settlement.

In a place where the structures are close to the local community, it is sensible to integrate the two main functions of the area into one, natural hazards defence and outdoor recreation.

By binding these functions together and by focusing on visually blending the structure into to landscape, the local inhabitants see it as a positive input into their surroundings. Structure that fences the people away from the mountain and their long time neighbour often seem like a negative input rather that a positive one.

As an example of successful landscape creation base on hazard area is the avalanche defence structure at Siglufjörður. This became in fact the basis of a recreational facility in the area reaching up along the mountainside above the town. The area at the top is now a frequently used route for hikers going up to the mountain. The avalanche defence structures at Siglufjörður are well accepted by the community, as they are designed to protect without fencing the town away from the mountain. Furthermore, the avalanche defence structures have made a positive social impact during all seasons. Simultaneously planting an abundance of vegetation has been started which in decades to come will see the natural vegetation of the area reclaimed and inhabit the mountainside once again.

It is concluded that it is necessary to work with the formation of the avalanche structures and to visualize them before the construction take place. It is not the main thing to minimize that structure but more crucial to blend it into the surroundings. That is done by mimicking natural forms that are found in the surrounding natural settings and by using natural local materials. Every place has its character and landscape architects do their best to retain that character.

“Stóri boli” deflecting dam in winter – A well designed extension of the mountain to protect the nearby village of Siglufjörður. This dam has already deflected several avalanches away from the settlement.

Local communities are often more willing to accept large scale projects and changes like this if they get more out of it than an isolated defence structure, built to follow the “Act on Protective Measures Against Avalanches and Landslides”, even if it is present for their own safety as an act to increase their own safety. It is necessary to rethink the environmental hazard as a place of opportunities.

The design of avalanche protection dams. Recent practical and theoretical developments

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ABSTRACT

Recent experimental and theoretical studies of the flow of avalanches against obstructions have been used, in combination with traditional design guidelines, to formulate recommendations for the design of dams and other protection measures in the run-out zones of wet- and dry-snow avalanches. These recommendations deal with the design height of dams, geometry and layout of braking mounds and impact forces on walls and other obstacles. In addition, laws and regulations regarding hazard zoning below avalanche protection measures in different European countries are described. The main new features of this procedure to dimension dams are:

- The dam design is based on a *consistent dynamic description* of the interaction of shallow granular flow and an obstruction.
- *Shock dynamics* are used to derive run-up heights on dams, which determine the design dam height under some conditions.
- The necessary dam height to prevent *supercritical overflow* is also used to derive run-up heights on dams, which determines the design-dam height under other conditions.
- A *maximum allowable deflecting angle,* derived from shock dynamics, limits the range of possible deflecting angles of deflecting dams.
- *Momentum loss in the impact with a dam* is calculated from the component of the velocity normal to the dam in the same way for both catching and deflecting dams.
- Avalanche flow along deflecting dams becomes canalised, which may lead to a substantial *increase in run-out* in the direction of the canalised flow.
- A consistent dynamic framework makes it possible to account for the *slope of the terrain* where a dam is located and a *curvature of the dam axis* in the dam design.

1. INTRODUCTION

Dams in the run-out areas of snow avalanches are widely used as protection measure against wet- and dry-snow avalanches (Figure 1). Several methods have been used to design avalanche dams, based either on simple point mass considerations, widely used in Alpine countries, a description of the dynamics of the leading edge of the avalanche or on numerical computations of the trajectory of a point mass on the upstream facing sloping side of the dam. A fundamental problem with the point mass view of the impact of an avalanche with a deflecting dam is caused by the transverse width of the avalanche, which is ignored in the point mass description. As a consequence of this simplification, the lateral and longitudinal interactions between different parts of the avalanche are ignored. Point mass trajectories corresponding to different lateral parts of an avalanche that is deflected by a deflecting dam must intersect as already deflected material on its way down the dam side collides with material heading towards the dam farther downstream.

Similarly, it is clearly not realistic to consider the flow of snow in the interior of an avalanche that hits a catching dam without taking into account the snow near the front that has already been stopped by the dam. The effect of this interaction on the run-up cannot be studied based on point mass considerations and a more complete physical description of lateral and longitudinal interactions within the avalanche body during impact with an obstacle must be developed.

Figure 1 A catching dam at Brún in Bjólfur in Seyðisfjörður, eastern Iceland. An avalanche that fell on the 9th of February 2008 and stopped on the dam face can be seen. The dam is 20 m high with a 10 m high very steep upper part. (Photo: Emil Tómasson.)

2. DAM HEIGHT DETERMINATION

New dam height criteria have been developed based on the concepts of *supercritical overflow* and *flow depth downstream of a shock* (Hákonardóttir, 2004; Hákonardóttir and Hogg, 2005; Jóhannesson and others, 2008a,b). A dry-snow avalanche will typically flow towards a dam in a supercritical state, that is with a Froude number greater than 1 (or perhaps greater than some other limit larger than 1, depending on the rheology). The first determining factor for the height of both catching and deflecting dams is, that uninterrupted, *supercritical flow over the dam must be prevented*. If supercritical overflow is impossible, shallow fluid dynamics predicts the formation of a shock upstream of the dam. This theoretical prediction has been confirmed for fluid and granular flow in several chute experiments, and may have been observed in natural snow avalanches. The second criterium for the design height of avalanche dams is, that the *flow depth downstream of the shock* must be smaller than the dam height. These two requirements in combination constitute the main part of the new design requirements. Furthermore, the estimated snow depth at the location of the dam is to be added to the dam height. Figure 2 shows the dam height as determined from the new dam design procedure for a dam with side slope 1:1.5, corresponding to loose materials.

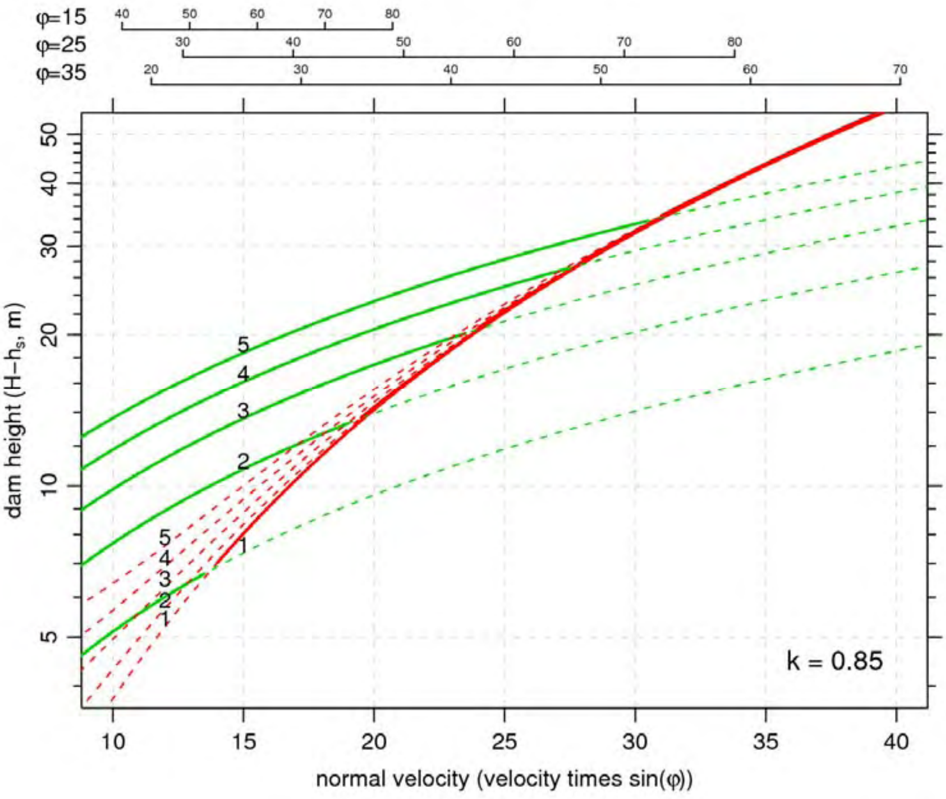

Figure 2 The design dam height *H* above the snow cover depth h_s as a function of the component of the velocity normal to the dam axis, u_1 sinφ, where u_1 is velocity upstream of the dam and φ is the deflecting angle (φ = 90° for catching dams), for several different values of the depth of the oncoming flow h_1. A momentum loss factor, $k = 0.85$, corresponding to a dam built from loose materials, is assumed in the impact with the dam. The figure shows curves derived from both supercritical overflow (red) and shock dynamics (green) labelled with the flow depth h_1. The design dam height should be picked from the higher of the two curves corresponding to the estimated design flow depth. The part of each family of curves corresponding to the higher dam is drawn with solid, thick curves. The labelled axes at the top of the figures show velocity corresponding to the deflecting angles φ = 15, 25 and 35°. The dam height is measured in the direction normal to the terrain and needs to be transformed to vertical dam height for dams on sloping terrain. (Note the logarihmic scale on the *y*-axis.)

The dam height determined according to the new criteria is generally similar to dam height determined from traditional criteria. Slightly lower dams are recommended in some cases but considerably higher dams are required for low deflecting angles. As an example, deflecting dams with φ = 10–20° corresponding to typical Froude numbers need to be built approximately one third higher according to the new criteria compared with the traditional formulae. This is, however, not as significant a change as it seems at first sight, because the run-up component of the dam height is much smaller in this case than for larger deflecting angles. The difference between the new and old criteria may, for example, lead to an increase in run-up, above the snow cover from 6–8 m to 9–10 m.

3. VALIDATION

There is considerable uncertainty about the effectiveness of dams to deflect and, in particular, to stop, snow avalanches. The new dam height criteria have been compared to a data set of run-up marks on man-made dams and natural obstacles from Norway (Harbitz and Domaas, 2006), Iceland and France. The run-up data can only be partially reconciled with the theoretically predicted run-up ranges as the run-up marks are in some cases substantially higher than the predictions (Jóhannesson and others, 2008b). However, the validation shows that the run-up marks of several medium-sized and large avalanches are in rough agreement with the proposed criteria, and that the overall variation of the run-up with normal velocity is in general agreement with the new criteria. The high observed run-up of some of the avalanches indicates a large uncertainty in the estimated velocity or some run-up mechanism that is not accounted for in the theoretical analysis. Some of the highest run-up marks may be caused by the impact of the saltation or powder components of the avalanches, which may, for example, damage forest considerably higher up than the highest point reached by the dense core. Pressure from the saltation or powder layers can, however, not account for the complete overflow of dense-flow avalanches over obstacles as has been observed in at least one case with high run-up.

An analysis of overrun of avalanches at the Ryggfonn test site in Norway (Gauer and others, 2005) also indicates that avalanches are in some cases able to overrun dams, in particular catching dams, more easily than the dam design criteria predict. These observations need to be taken as reminders of the still imperfect dynamic basis of the proposed run-up criteria, in spite of the advances that have recently been made, indicating that natural avalanches are perhaps of several different types, which are not adequately described by a single dynamic framework.

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The snow avalanches in Neskaupstaður in 1974. The reaction after the accident and the organisation and administration of safety measures for the village for the more than 30 years since the accident occurred

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1. THE SNOW AVALANCHES IN 1974

Neskaupstaður was hit by several destructive avalanches in 1974 causing 12 casualties. The avalanches caught the inhabitants by surprise. There had hardly been any avalanche discussion in the community for many decades. Small avalanches had fallen from gullies in the mountainside above the village, some terminating close to the settlement, but it had not crossed my mind that avalanches might cause any damage in the town. The 1974 avalanches not only caused casualties but also considerable damage to the town´s main industrial companies; the herring rendering facility and the freezing plant.

2. THE RESPONSE AFTER THE ACCIDENT

Following recovery from the catastrophe and during the build-up phase it was interesting to observe how people were divided as to how to tackle the avalanche danger. It appeared that the older inhabitants wanted to forget the catastrophic events and tended to minimise any imminent avalanche danger while the younger generation was calling for appraisal studies of avalanche hazard as well as ideas for avalanche protection for the community. A hazard assessment was carried out and proposals for avalanche protection were presented but these proposals were not realised due to lack of funds in the community and a disinterested state government; this despite vociferous proclamations from the politicians.

3. HAZARD ASSESSMENT

A hazard assessment for Neskaupstaður was confirmed in 1992. It came as a bit of a shock to the inhabitants to see that the majority of the houses in the town were situated in red hazard zones, although the inhabitants were traditionally used to be associated with the red colour in a political sense. The ensuing media coverage was definitely disheartening to people who wanted to move to eastern Iceland and were considering to settle in Neskaupstaður.

4. THE EFFECT OF THE AVALANCHE ACCIDENTS IN THE WESTFJORDS IN 1995

The disastrous avalanches in Súðavík and Flateyri in 1995 served as a wake-up call for the authorities; it was clearly necessary to respond to the avalanche danger. A radical change came with the 1997 legislation act on protective measures against avalanches and landslides and the 2000 regulation on hazard zoning. A clear legislative framework was set and funds for the construction of avalanche protection measures were guaranteed. 90% of expenses were to be paid by the state and 10% by the municipality.

5. PROTECTION MEASURES

Shortly after the accidents in 1995, preparations for protection measures for the settlement below Drangagil in Neskaupstaður were started. The proposed catching dam and braking mounds were the first of their kind in Iceland and there was considerable debate in the community regarding their environmental impact. In 1998, the Neskaupstaður municipal government initiated a survey among the inhabitants regarding the construction of a catching dam below the Drangagil gully following a public introduction of the prospective avalanche defences. The survey showed that 55% of those who had familiarised themselves with the proposals were in favour of the defences but 35% were against. However, the survey also revealed that more than half of the respondents were not familiar with the defence proposals which was surprising in view of the fact that less than 3 years had elapsed since the catastrophic avalanches in Western Iceland and despite the thorough introductions in Neskaupstaður. One wonders whether the introductions were unsuccessful. A flyer was distributed to every household in Neskaupstaður, a public meeting with avalanche experts, engineer and landscape architects was held as well as an open house for two days at the community centre, where the specialists were present to explain and elaborate on the proposals.

The catching dam, braking mounds and supporting structures in the starting zone were constructed and formally inducted in 2002. Prior to the construction and during the planning stage there was some opposition to the plans. Articles appeared in the local paper but these did not affect the process and after the defences were erected there have been no voices of dissent and not even the people who wrote the articles objecting to the defences will now admit to any opposition! The defences fit admirably into the environment and the area is very popular both for recreational activities by the local population as well as an attraction to visitors.

The 17 m high catching dam and two rows of 10 m high braking mounds above the settlement in Neskaupstaður.

6. RELOCATION VERSUS PROTECTION MEASURES

It was decided, due to excessive cost of protection measures, that the municipality would buy 5 houses in the western part of the town that were outside the main residential area instead of constructing defences in that area. There were some difficulties, mostly concerning the right prices for the houses, although the owners were unanimous that the houses should be bought. It should be noted that at the time a real estate market in Neskaupstaður was virtually non-existent, hardly any new houses were being built and real estate prices were very low. None of the previously mentioned houses would have been sold on the open market but it is a fact that real estate owners will demand unrealistic prices when dealing with public officials. However, the matter was resolved satisfactorily and the houses were bought. Four of the five families bought houses in other parts of Neskaupstaður and one moved away. As proprietor of the 5 houses, the municipality made the mistake of selling four of them with the stipulation that the buyers could use them as residence from May to October. It is the consensus today that these houses should have been demolished, in part because two of them have been used as guesthouses during the summer. In some people's opinion this has constituted an unfair competition for other guesthouses in the town as the municipality sold these houses at a very low price due to the limitations on the period when they may be used. Apart from that there is always the chance that the houses are used outside the stipulated period. This has, however, not been a problem in Súðavík were the old part of town is a residential area for tourists during the summer.

7. FURTHER BUILD-UP OF PROTECTION MEASURES

The next steps regarding avalanche defences in Neskaupstaður are defence measures for the western part of town in the Tröllagil and Miðstrandargil areas. Despite the fact that defences were slightly more expensive than buying the residences, both the municipal authorities and the Icelandic Avalanche and Landslide Fund agreed on the defence option. It was not considered practical to buy all the houses because of the radical change in the layout and organisation of the town. It is interesting to note that at the time the value of the houses in question was low, but it has since increased by almost 200% making the defences a less expensive option in a relative sense!

It is some source of worry that construction of the Tröllagil defences has not yet begun. According to the 2000 risk assessment regulation all houses in avalanche hazard zone C should be protected no later than 2010. However, due to an overheating in the Icelandic economy it was decided by the state government in 2003 to postpone the construction of new avalanche defences until 2007, thereby nullifying the 2010 deadline. Regarding Neskaupstaður, we should be thankful if the regulation objective will be reached before 2020. I think that despite possible economic side effects, avalanche defences should remain a priority and we must not forget the impending danger and possible devastation of avalanches, although more than a decade has passed since the fatal accidents Western Iceland. A positive sign is the fact that even though construction of defences has been postponed, the revenue of the Avalanche Fund has not been reduced so the funds for the construction of the defences are available when the government decides to restart the build-up.

8. SNOW OBSERVERS

The position of a snow observer was established in Neskaupstaður following the 1974 avalanches. This step was seen as a positive one by the inhabitants and they have depended on the snow observer regarding measurements of snow conditions and assessment of impending avalanche danger.

Many are of the opinion that a reduction in surveillance is not acceptable despite the construction of avalanche defences. The defences do not offer 100% protection against avalanches and the functionality of the defence structures in the run-out zone may, furthermore, be reduced, following an avalanche, until the snow has melted or been removed. There may be as much as several hundred thousand cubic meters of rock-hard snow deposits adjacent to the avalanche dam following a large avalanche so it is a huge task to attempt to remove it. Should an avalanche strike under these circumstances the dam’s effectiveness is considerably impaired. It is, therefore, necessary that a snow observer be employed on a permanent basis in the future as in the past so that the person may gain experience and knowledge to be able to assess possible avalanche hazard with any degree of certainty. It takes a long time to gain experience as a snow observer and to become familiar with avalanche conditions in a certain area, both geographical conditions as well as meteorological.

The point has been raised among snow observers that monitoring may be reduced with the build-up of avalanche defences although the national authorities have made assurances to the contrary. In fact there has been an added emphasis on monitoring and research in the past years and that policy should continue in the future. There are still some towns without avalanche protection, and it should be noted that dams and/or supporting structures are mainly constructed to defend densely populated, residential districts. The monitoring of avalanche danger also needs, however, to be considered for industrial and commercial buildings, roads, skiing areas, rural districts.

9. DIVISION OF COST BETWEEN THE STATE AND THE LOCAL MUNICIPALITIES

As previously mentioned, the construction cost of avalanche defences is divided between the state (90%) and the relevant municipality (10%). The municipality may receive a loan from the Avalanche and Landslide Fund corresponding to their 10% share of the cost and then reimburse the loan in 15 years according to predetermined rules. This division of cost between the state and municipality makes it possible financially for the local authorities to undertake these projects. It is, however, clear that these are added expenses for the communities in Iceland facing avalanche hazard and in the interest of equality, avalanche defences should be solely the financial responsibility of the state. It should be noted that the maintenance cost for the defences is divided 60-40 between the state and relevant municipality. This cost can become considerable as time passes necessitating talks between the state and municipalities on these issues.

10. EFFECT OF AVALANCHE DANGER ON THE DEVELOPMENT OF THE ENDANGERED COMMUNITITES

It is clear that media coverage regarding avalanche danger has a negative impact on the respective communities. Notices on evacuations carried out and announcements declaring an end to the state of emergency due to avalanche danger are extremely negative for the communities in question. Although there is limited research into the effects that avalanche danger may have on regional development, it is not unlikely that the long-term effects on the development of the settlements in question are quite negative. An overview of population development in communities in Iceland facing avalanche danger that has recently been made does, however, not show a clear distinction between these communities and other communities of a similar size in the same parts of the country.

11. CONCLUSIONS

The response of the state government and local municipalities to the avalanche accidents in the Westfjords in 1995 has been very different from the response to the accident in Neskaupstaður in 1974. The laws and regulations regarding hazard zoning and protection measures have been completely rewritten since 1995 and an expensive programme of a large-scale build-up of protection measures is ongoing based on an allocated source of governmental funding. Although the build-up of protection measures since 1995 has been slower than initially planned and many problems have been encountered, the state and local authorities are committed by law to complete the build-up of protection measures within a “reasonable” time. This stands in sharp contrast to the response to the accident in 1974, which led to some revision of hazard zoning, but very little action to improve the safety of the endangered villages.

An avalanche index for roads

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ABSTRACT

Several methods have been introduced through the years to evaluate avalanche risk along road sections. In 1988, Peter Schaerer introduced Avalanche Hazard Index, a numerical expression of damage and loss as the result of an interaction between snow avalanches and vehicles on a road. Later works by different authors have developed the methodology for risk management and winter road opening of high alpine pass roads.

This project is a spin-off of a project conducted by ORION Consulting for the Icelandic Road Authority. This project describes a simple method to evaluate possible consequences of an avalanche hitting a passing vehicle on a road section. Besides the size, intensity and frequency of avalanches, the severity of the consequences is related to several environmental factors such as the distance from the road body to potentially dangerous terrain features. Such factors may include cliffs and steep banks along fjords, as well as steep slopes above the road. In addition, the consequences of an encounter between a vehicle and an avalanche may depend on the probability of a speedy rescue.

The factors used are quantified on a scale from 0–5, where the lower values are given the worse case and higher values the more favourable.

Test results show that this procedure gives other results than a preliminary assessment suggests in some cases. At a specific avalanche threatened stretch of road site in northern Iceland, a different avalanche path received a higher index value than the one that initially was considered the worst.

1. INTRODUCTION

At present, neither guidelines nor other instructions are available for the road authority in Iceland to evaluate the avalanche threat to the road traffic or to prioritize necessary measures. In 2000, the Ministry of Environment published regulations for populated areas. The safety requirements are related to individual risk, defined as the probability of a fatal injury of an individual living (with occupancy of 75% of the time) in an un-reinforced house. The actual risk can be estimated by considering the probability of an individual staying at home, the avalanche frequency and intensity, and the strength of the building.

Risk-based methods based on encounter probability and average values for mortality have been used before, *i.e.* in the Avalanche Index Method (Schaerer, 1989). However it is possible to extend these methods by introducing several environmental factors that can affect the survival of avalanche victims. For instance, a small avalanche that hits a car in an unfavourable or a remote area can have disastrous consequences for those in the car. On the other hand, if conditions were more favourable the travellers might do well. Thus, the encounter probability alone does not always show the whole risk picture.

The endeavour of this paper is to point out some factors, that may affect the survivability of victims that are hit by an avalanche on a road and to introduce a simple tool for prioritizing protective measures.

2. PROBLEM APPROACH AND LIMITATIONS

The avalanche threat to a road section is limited in time. Also, in Iceland, the annual variability can be great, from no avalanche cycles at all to several weeks. Different roads also have different traffic or traffic characteristics. Some avalanche-prone roads may be the only road connection to villages while other villages have a second access road. School buses may travel the road every day and busses full of tourists may travel the road in case of some events in the villages in the wintertime.

3. THE INDEXING METHOD

The method is based on assigning values to various factors that are related to avalanches, avalanche paths, the surroundings *etc*. Those factors can be the recurrence of avalanches, the slope inclination of distal side, the distance to life threatening object on distal side and distance to the nearest rescue station, *etc*. The factors could as well be the probable effect of protective measures, aspect of the starting zone. The alternative detours, the length and the susceptibility of these to hazards can also be considered. The scale ranges from 0–5. Every factor is then weighted from 0–1.0 and the sum of all the weighted numbers is called the index for the avalanche path. The lower the index is the more urgent it is to protect the traffic, either by moving the road or by protecting it.

4. DATA COLLECTION

4.1 Avalanche history and frequency

The Icelandic Road Authority (IRA) logs every avalanche that hits the road system and files them into their database. IRA also reports all avalanches to the Icelandic Meteorological Office (IMO), where they are stored in their central avalanche database.

The frequency of known avalanches that hit the road is estimated from the current data set. It is of interest to consider different size classes of avalanches, but the 10–20 year avalanches are here considered to be the “normal” design avalanches for roads. From this frequency estimate based on the data set, a maximum value is set to 0 and minimum value set to 5.

4.2 Inclination of distal side of the road

Cars are often thrown or pushed off the road, down the distal side when hit by an avalanche. The approach here is to relate the severity of such an incident to the inclination of the distal side; the steeper the slope, the more severe the accident. The first 50 m of the distal side, from the road, is considered to be the most important one. Inclination is divided into 5° steps, ranging from 0 to 25° or larger. It is rated from 5 to 0, see Table 1.

Table 1. The Inclination of the distal side of the road.

Inclination	Scale
>25°	0
20°-25°	1
15°-20°	2
10°-15°	3
5°-10°	4
0°-5°	5

Table 2. The distance to a cliff or a life-threatening object.

Distance at distal side	Scale
0-25 m	0
25-150 m	1
50-75 m	2
75-100 m	2
100-125 m	4
>125 m	5

Table 3. The width of the avalanche track at roadside.

The width	Scale
>125 m	0
100-125 m	1
75-100 m	2
50-75 m	3
25-50 m	4
0-25 m	5

4.3 Distance to a cliff or a life threatening object

Many avalanche-prone road sections are on coastal areas in Iceland; the sea is on one side and the mountain on the other side. This is similar to many Norwegian road sections, but different from the typical Alpine road sections.

The distance to the shoreline, a cliff or any other dangerous obstacle at the distal side is important when the survivability of a driver and/or passengers is considered. The grouping is done in 25 m steps from 0 m to 125 m. If the distance is greater than 125 m it is considered a "good" site and is graded 5. The classification is shown in Table 2.

4.4 The width of the avalanche

The encounter probability is dependent on avalanche width and the probability of a vehicle being present. The speed of the vehicle can be considered constant. The avalanche width depends on the avalanche size. When historical data exist they are used; is cases where no data exist, an assessment has to be made. If an avalanche width from an "unknown"[1] avalanche path is used in combination with the known width of avalanches it can be considered to grade it higher[2] by one step to compensate for the uncertainty. When new road alignment is planned, the width of all avalanches is estimated so it is not necessary to grade them higher. Each step is 25 m, ranging from 0 to 125 or more, see Table 3. The speed of a vehicle is considered constant.

4.5 Rescue operation

ICAR (The International Commission on Alpine Rescue) has kept records[3] of avalanche victims over the last years. Their records, from winter 2004/2005 to the winter 2006/2007, show

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[1] Avalanches that hit the road have not been reported but calculation and site investigation indicate that avalanches can hit the road.

[2] If no avalanches are observed it would be inappropriate to grade it the same as known avalanche. Lower grade means more severity.

[3] Backcountry skiing or snowboarding, free ride (off piste), on ski runs, alpinists, on roads, in buildings, on snow mobiles, and others.

that 1631 persons have been caught by an avalanche; of those, 949 were rescued alive or about 60%. In a Swiss study (Margreth and others, 2003), the probability of death of an individual in a vehicle caught by an avalanche is found to be 18%. In a Norwegian report, Kristensen and others (2003) estimate that the risk is somewhat higher in a remote area in Norway, about 40%. The reason for higher number is thought to be linked to adverse high mountain conditions, topographic characteristics and longer rescue time. The authors do not know it if any research on survival chances in vehicles has been carried out in Iceland. Avalanches hitting vehicles are very few, significantly less than a one per year on average. There are, however, many similarities between Iceland and Norway; the climate, remote areas and terrain features. Therefore, it seems reasonable to assume similar numbers as the Norwegians do; here we propose slightly a lower survival chance or 30–40%, mainly because of harsher weather.

Falk and Brugger (1994) have studied the survival chance of avalanche victims in the backcountry. Their result show that the survival chance drops to about 65% in 20 minutes and to 35% after 30 minutes. The importance of short distances (and quick responses) for rescue personnel or police to reach the avalanche site is therefore important. In Iceland, as well as in Norway, the voluntary avalanche rescue groups are the main resources in avalanche accidents. For an organized voluntary rescue team a response time of 15–20 minutes is quite normal, *i.e.* to prepare for the mission at the rescue station. The travel time to the avalanche site is a variable, depending on the distance, travel speed, conditions of the road surface (snow or ice) and the weather. Here we assume that the travel speed is 50 km/h. This speed might seem to be relatively low but taking into account that most of avalanches in Iceland occur in bad weather, higher speed does not seem to be reasonable and not advisable for a rescue group.

When comparing avalanche paths, the distance from the rescue centre to the path is important. Comparison can be performed between paths at two or three different sites like north, east and west Iceland. Only the distance counts. The longest distance will have the lowest (0) while the shortest distance the highest (5).

If an avalanche hits a vehicle it is most likely that the nearest voluntary rescue team will be asked for help. It can take voluntary teams 15–20 minutes to be ready at their rescue station and several minutes to drive to the avalanche site. For an avalanche prone road section, where avalanche tracks are in close proximity, the time difference between tracks is not that important but if different road sections are compared the respond and travel time might be important. The longest time to reach the avalanche site is here rated 5 and shorter distances are rated correspondingly.

4.6 Traffic volume

Traffic volume (WDT[4]) is one of the important factors when comparing two different road sections. WDT has no effect when comparing paths at the same road sections. Here a logarithmic scale is used to grade the traffic volume (5-log(WDT)). This method can be questioned for very low traffic volume but can be considered to be reasonable for larger volumes, WDT >10 vehicle/day.

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[4] Winter Daly Traffic.

5. APPLICATION OF THE METHOD

The indexing system has been tested on few of the avalanche paths in an avalanche prone area in northern Iceland between Dalvík village and Ólafsfjörður village. At the moment only few categories have been tested, more will be done later.

Table 4 The table shows an example of how this method can be applied. Few of the paths are compared here for the road section.

Path#	Distance to rescue base			Inclination of distal side	Distance to an obstacle or a cliff	Width of path		Number of avalanches			WDT 2008		Sum Index	Rank
								25	Frequency					
		Weight#	0,2	0,15	0,2		0,1			0,2		0,15	1,00	
	[Km]	[Min.]	Grade	Grade	Grade	[m]	Grade	[n/25Year]	[t]	Grade	[veh/day]	Grade		
05BF01	6,0	22,0	2,3	2,0	5,0	170	0,0	15	0,6	2,9	480	2,3	2,7	10
05BF02	6,1	22,0	2,3	3,0	5,0	170	0,0	15	0,6	2,9	480	2,3	2,8	12
05BF03	6,2	22,1	2,2	3,0	5,0	0	5,0	0	0,0	5,0	480	2,3	3,7	16
05BF04	6,3	22,1	2,2	2,0	5,0	0	5,0	0	0,0	5,0	480	2,3	3,6	15
05BF05	6,4	22,1	2,1	2,0	2,0	70	3,0	21	0,8	2,1	480	2,3	2,2	6
05BF06	6,4	22,1	2,1	2,0	2,0	70	3,0	21	0,8	2,1	480	2,3	2,2	6
05BF07	6,5	22,2	2,1	2,0	3,0	70	3,0	35	1,4	0,1	480	2,3	2,0	4
05BF08	6,8	22,3	1,9	2,0	3,0	70	3,0	36	1,4	0,0	480	2,3	1,9	2
05BF09	6,8	22,3	1,9	2,0	3,0	70	3,0	36	1,4	0,0	480	2,3	1,9	2
05BF10	6,9	22,3	1,9	3,0	3,0	50	2,0	9	0,4	3,8	480	2,3	2,7	11
05BF11	7,0	22,3	1,8	4,0	2,0	50	2,0	9	0,4	3,8	480	2,3	2,7	9
05DF02	9,5	23,2	0,7	1,0	1,0	70	3,0	9	0,4	3,8	480	2,3	1,9	1
05EF01	10,5	23,5	0,3	4,0	5,0	80	3,0	8	0,3	3,9	480	2,3	3,1	13
05EF02	10,9	23,6	0,1	2,0	5,0	0	5,0	0	0,0	5,0	480	2,3	3,2	14
05EF03	11,1	23,7	0,0	2,0	3,0	130	0,0	9	0,4	3,8	480	2,3	2,0	5
05EF04	11,1	23,7	0,0	4,0	4,0	130	0,0	9	0,4	3,8	480	2,3	2,5	8

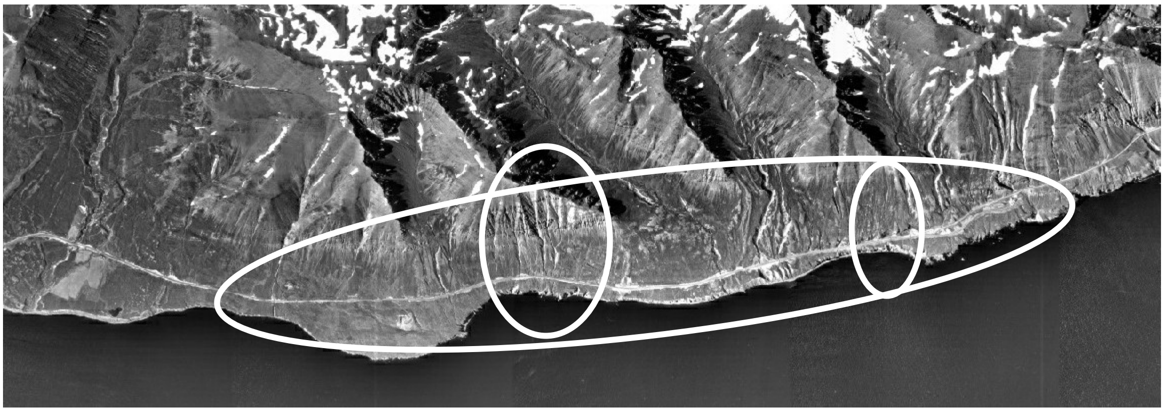

Figure 1. This aerial photo shows the observation area, inside the large ellipse, on the Ólafsfjarðarvegur road stretch between Dalvík and Ólafsfjörður villages north of Akureyri, Iceland. The vertical ellipse on the left depicts the initially “worst” site and the one on the right depicts the “new worst” site. Aerial photo: Iceland Geodetic Survey.

6. RESULTS AND DISCUSSION

This method was tested in one project carried out by ORION Consulting for the Icelandic Road Authority. The avalanche site is along the main highway from the village Dalvik to the village Ólafsfjörður in northern Iceland. Avalanches hit the road quite frequently; see report by ORION (Jónsson, 2007). The report describes the frequency of avalanches at known and “unknown” tracks and the individual risk for road users as a result of an avalanche encounter.

It also describes the worst avalanche track according to the method used in the report. After applying this indexing method a different avalanche track was considered to be the worst and the former worst was considered to be the second worst. The reason for this is that even though avalanches are not that frequent the consequences were not taken into account. This “new” worst site is only within 25 m from a cliff and the sea but the former worst is around 100 m from a cliff.

This method is in its early stage, further discussion and comments are welcome.

7. CONCLUSION

Limited tools are available for the road authorities to quantify the severity of an avalanche accident on the road network. The proposed avalanche indexing method for roads aims first of all to help the road authorities to be able to quantify the need for measures in small or large avalanche areas. It is a simple method but it gives good information on avalanche paths on the road network that need to be protected from avalanches.

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