Veðurstofa Íslands
Internal Report

Tómas Jóhannesson

# A description of the sites that will be considered in an overview study of the need for avalanche defences in Iceland

VÍ-G96018-ÚR18
Reykjavík
April 1996

## 1. INTRODUCTION

The purpose of the study is to make an overview of the need for avalanche defenses in Iceland. Catastrophic avalanches in Súðavík and Flateyri in 1995, which killed a total of 34 people and caused extensive damage in the two villages, have totally changed the view regarding avalanche safety in Iceland. These avalanches made it clear that a substantial number of people in several Icelandic villages live in areas where avalanche risk is unacceptable. Although extensive evacuations may be used to reduce this risk to some extent, they can only be viewed as a temporary measure and avalanche defenses or land use changes are necessary for a permanent solution to this problem.

The overview will provide governmental agencies responsible for avalanche safety in Iceland with a rough estimate of the likely cost of proper avalanche defenses for the villages threatened by avalanches in the most important avalanche regions in Iceland. This cost will be compared to an estimate of the value of buildings and infrastructure in the respective areas. A crude prioritization of the areas in need of defenses will also be made.

## 2. TASK

The overview will encompass the following villages: Ísafjörður and Hnífsdalur, Bolungarvík, Patreksfjörður and Bíldudalur, Neskaupstaður, Seyðisfjörður and Siglufjörður. Avalanche defenses for Flateyri and Súðavík have already been considered in separate appraisals. They will therefore not be considered in the overview study, except that the main results of the appraisals will be included in the overview report. For each village, a number of sites will be considered, where avalanche danger may be unacceptable according to the current judgement of the IMO. The sites are briefly described in separate sections below. An overview of meteorological conditions and the results of the scattered snow depth measurements that exist are given in separate sections.

Each site will be visited in May and in June 1996 by a work group of 5-6 people. They are Frode Sandersen or Karstein Lied from NGI, Stefan Margreth from EISL, two scientists from IMO, an Icelandic engineer and the local avalanche observer. The study will make a proposal for a suitable defense type for each site, *i.e.* supporting structures in the starting zones, deflectors or dams, and make a rough cost estimate for the building of the proposed defenses.

It is clear that the planning and installation of avalanche defenses in order to bring avalanche risk in Iceland to an acceptable level is a long term project. IMO is presently working on a revision of the procedures for risk mapping in areas threatened by avalanches. Previous hazard zone maps are considered outdated and cannot be used as a basis for decisions about avalanche defenses. It is of course outside the scope of this study to define new risk zoning for the threatened areas, but a crude classification of the danger will be attempted in order to provide guidance for the next effort in the planning of defenses and the focusing of research over the next few years.

It is also clear that a full appraisal or pre-design of the proposed defenses for all the sites considered, is impossible within the time frame of the study. Rather, the study will propose defenses that are on a scale that is judged appropriate for the sites under consideration and determine the relevant lengths, heights *etc.* that are necessary for a rough cost estimate. A realistic dimensioning of the defenses is a task that will be attempted at a later point in time during the appraisal phase in the design of defenses for each site.

A report with the results of the work group will be written by the IMO in cooperation with other members of the work group. This report will be ready in the beginning of August 1996.

## 3. PREPARATIONS

As a part of the preparations for the visits to each site the following material has been collected and will be studied by the work group before the visits (except item 9 which will be compiled by the local authorities of each village at a later stage).

1. Maps with registered avalanches.
2. Runout model calculations ($\alpha/\beta$-model, PCM-model).
3. Evacuation maps.
4. Aerial photographs. Photographs of winter conditions where they exist.
5. Overview of existing measurements of snow depths in starting zones (very little data exist).
6. Rough overview of meteorological conditions.
7. Geotechnical conditions (evaluation of the quality of loose materials that might be used for deflectors or dams).
8. Overview of previously proposed defenses (very few exist, if several proposals have been made for the same area only the most recent one is summarized).
9. Rough estimate of the value of buildings and infrastructure which will be protected by the proposed defenses.

Test pits will be dug in loose material deposits at some of the relevant sites and the grain size distribution in samples from the pits measured before the visits to the villages.

Items number 1, 2, 3, 5 and 8 will be studied to some extent by the work group members before the foreign participants come to Iceland. The material will as a whole will be reviewed by the work group in work meetings before the visits to the sites.

## 4. EVACUATION MAPS

Evacuation maps have been prepared for the villages that will considered in the study, except Bíldudalur. The maps outline areas where evacuations are planned when local avalanche observations and weather forecasts indicate impending avalanche danger. Evacuation zones are divided into three classes:

I. Zones in the immediate neighbourhood of known avalanche tracks where avalanches can reach at times of *moderate* snow accumulation in starting zones or otherwise moderately bad conditions. The zones may be smaller than indicated by the runout of the longest recorded avalanches in the corresponding tracks if these avalanches fell under extreme conditions. Relatively few residential houses are located in these zones and most of them have been evacuated very often in recent years. The level of danger for people living in these zones is so high that one must consider the use of houses there as a temporary condition while the local authorities decide how to discontinue their use during wintertime (or build appropriate defenses).

II. Zones which are defined mostly on the basis of the runout of the longest recorded avalanches, and neighbouring areas which are considered equivalent with respect to avalanche danger. The zones will be evacuated during times of *high* snow accumulation in starting zones or otherwise bad conditions.

III. Zones where avalanche modelling indicates that avalanches can reach under *extreme* conditions. Avalanche records do not need to contain avalanches that reach these areas, but expert judgement of the conditions in the slope above the area must indicate that there is a potential for dangerous snow accumulation. Some areas, where heavy snow accumulation is considered very unlikely according to the local meteorological conditions, but where houses are located so close to the foot of the slope that avalanche are bound to reach them if they are released at all, are also classified in this class. The avalanches are in this case considered extreme with respect to the local conditions although they are perhaps not extreme according to a topographical model for the corresponding slope.

The heavy vertical borderlines on the evacuation maps indicate a division of the villages into areas that become dangerous at the same time, *i.e.* similar aspect and snow loading conditions, *etc.* These lines are identified with triangular symbols at the ends.

The horizontal borderlines of the evacuation zones are labelled with the roman numerals I, II and III which indicate the class of the zone immediately above the line according to the above list.

Each tile defined by the vertical and horizontal borderlines on the evacuation maps defines an area that will be evacuated as one unit during times of impending avalanche danger.

In addition to the evacuation zoning displayed on the maps, the maps show the most important, but not all, recorded avalanches in the villages. The maps also show short, straight, vertical lines in each slope with several different symbols and numbers along the lines that indicate the results of avalanche modeling which was carried out in connection with the preparation of the maps. The symbols show the location of the 10°-$\beta$-point, the results of an $\alpha/\beta$-model which has been calibrated for Icelandic avalanches, and the numbers show the results of several runs of a PCM-model along the profile indicated by the straight vertical line. The symbols and the numbers have the same meaning as described below in the section on avalanche modelling results.

The evacuation maps were prepared in some haste earlier this year in order to organize evacuations which the IMO is responsible for according to a recent change in the law from the Icelandic parliament. Luckily the weather conditions since November this winter have been favorable so that we have not needed to issue evacuation orders. The maps will certainly change as we do more work in the villages and they do not delineate areas where avalanche danger is above some well defined criteria, *i.e.* they do not define avalanche danger zones that will be used in land use planning or decisions about avalanche defenses. We hope the maps include some class III zones which will later be judged "safe" or "acceptable" after additional work has been done as we have tried to err on this side. The maps nevertheless indicate our best current judgement of the avalanche situation in the respective villages.

Almost all class I and II zones and many or most of the class III zones certainly define areas where avalanche danger is not acceptable according to any reasonable definition of the term "acceptable", unless some evacuation or defensive measures are taken. Due to uncertainty in avalanche forecasts, it appears unlikely that evacuation measures will provide an acceptable lowering of risk in class I and II zones, according to our judgement and the judgement of others that we have consulted in this matter. The current situation, where the safety of people living in the class I and II areas hinges on the effectiveness of the evacuation plan, must therefore be considered temporary while other measures are taken to ensure the safety of the people. The same applies to a significant part of the class III areas.

Each vertical zone in each village is further described in a separate section below. The maps are labelled with the section number of the corresponding section to identify the zone (using a blue pen).

The maps are in the scale 1:5000 (or 1:7500 if the size has been reduced in copying).

## 5. MAPS SHOWING AVALANCHE MODEL RESULTS

The evacuation maps were partly based on the results of avalanche modelling, which are shown on a sequence of maps in the same scale as the evacuation maps. The maps show several profiles down the slopes above each village. Contour lines drawn across the profiles more or less perpendicular to the slope of the hill show results of a sequence of PCM-model runs along the profiles. The contours, which are labelled with numbers in the range 10 to 20, show the runout length or the stopping position of a model run with parameters according to the following table.

| Label | $\mu$ | M/D |
|---|---|---|
| 10 | 0.35 | 80 |
| 11 | 0.32 | 180 |
| 12 | 0.29 | 270 |
| 13 | 0.25 | 360 |
| 14 | 0.22 | 460 |
| 15 | 0.19 | 550 |
| 16 | 0.16 | 650 |
| 17 | 0.13 | 730 |
| 18 | 0.11 | 790 |
| 19 | 0.09 | 840 |
| 20 | 0.08 | 880 |

The numbers or runout indexes in the first column of the table may be interpreted as the runout in units of 100 m in a parabolic shaped slope of height 700 m and horizontal length 1600 m. About 5% of avalanches in

data-sets of long Icelandic and Norwegian avalanches have a runout index higher than 17 and about 13% of the long avalanches in the same data-sets have a runout index higher than 16.

Graphs of the modelled speed along each profile were plotted for the different runout positions identified on the maps of the model results. These graphs will be considered at work meetings before and after the visits to the villages.

There are several symbols plotted along each profile. The star symbols show the location of the 10°-$\beta$-point, and the results of an $\alpha/\beta$-model, which has been calibrated for Icelandic avalanches, are shown with circles, arrows and boxes. The $\alpha/\beta$-model is defined by $\alpha = 0.92\beta$ with a standard deviation of 2.6°. The meaning of the symbols is given in the following table.

| Symbol | Meaning |
|---|---|
| star | 10°-$\beta$-point |
| filled up arrow | Location of $\alpha + 2\sigma$-point |
| up arrow | Location of $\alpha + \sigma$-point |
| circle | Location of $\alpha$-point |
| down arrow | Location of $\alpha - \sigma$-point |
| filled down arrow | Location of $\alpha - 2\sigma$-point |
| filled box | Location of $\alpha - 3\sigma$-point |

The profiles were drawn along all the slopes above the villages without respect to the conditions for snow accumulation in each slope. The results were interpreted on the basis of our subjective judgement of snow accumulation conditions in the respective starting zones.

## 6. DESCRIPTION OF THE SITES

The sites, which will be considered in each village, are briefly described in separate sections below. The evacuation maps show several of the longest avalanches at each site and the description of the site starts with a sentence that summarizes the avalanche situation as recorded in the avalanche archive of the IMO. The description of each site also specifies the present use of the area (residential or industrial buildings), the approximate width of the area, existing proposals for avalanche defenses for the area (if any), and how we at IMO judge the need for defenses. The need for defenses is specified in one of three different ways.

1. Some defenses or change in land use are necessary.
2. Some defenses or change in land use are probably necessary.
3. The need for defenses is uncertain.

The first possibility means that we consider the situation intolerable and that something must almost certainly be done to reduce the avalanche danger if present lands use is to be continued.

The second possibility means that we consider the situation dangerous and that it is likely that a part of buildings in the area will be inside a future hazard zone when a revision of the hazard zoning in Iceland is carried out.

The third possibility means that future research must decide the level of avalanche danger in the area, but existing data indicates that the danger is much lower than for the two other possibilities.

The sections below describe 34 sites or areas in the 8 villages. Some defenses or change in land use are necessary for 16 of the sites, some defenses are probably necessary for 6 sites and the need for defenses is uncertain for 12 sites according to the preliminary classification described above.

## 7. ÍSAFJÖRÐUR

Ísafjörður is located in the fjord Skutulsfjörður in Ísafjarðardjúp in Vestfirðir in North-Western Iceland.

### 7.1 Holtahverfi

There is a danger of avalanches under certain weather conditions (SA wind with heavy snowfall), which are relatively rare in the area. Avalanches reaching to the present location of the uppermost buildings in the area are recorded and it is possible that an avalanche reached 50-100 m into what is now a populated area back in 1963.

The width of the area is about 650 m.

There are many residential buildings in the area.

A low relatively short and low catchment dam above the highest houses was built around 1988.

Some additional defenses are probably necessary.

### 7.2 The area around and to the west of Seljaland

Several avalanches are recorded, one of them reaching almost all the way to the sea.

A comprehensive avalanche defense appraisal has been carried out by HNIT hf. and NGI and the area will therefore not be considered in the overview study.

### 7.3 Seljalandshlíð

Avalanches are frequent and some reach all the way to sea. Evacuations and road closures are frequent.

The width of the area is about 1 km.

There is some industrial activity in the area, but no residential buildings.

No defenses have been proposed to date.

Some defenses or change in land use are necessary.

### 7.4 Gleiðarhjalli

Avalanche risk is considered low, but the area will be considered in the overview study because a large number of residential buildings is located very near the foot of the slope. A large flat shelf, Gleiðarhjalli, between 400 and 500 m a.s.l. in the mountain above the area is believed to protect the upper part of the slope from a dangerous accumulation of snow. The size of the shelf is approximately 1500x400 m.

The width of the area is about 1.5 km.

A large number of residential and other buildings are located in the area.

No defenses have been proposed to date.

Safety below the eastern and western ends of the flat shelf in the mountain needs to be considered. The need for defenses is uncertain.

### 7.5 Eyrarhlíð

Avalanches are very frequent and lead to frequent closure of a road along the coast.

The width of the area is about 2.5 km.

There are no buildings in the area, but a road along the coast connects Hnífsdalur and the main part of the town of Ísafjörður.

No defenses have been proposed to date.

Some defenses that reduce the risk facing traffic on the road may be necessary.

## 8. HNÍFSDALUR

Hnífsdalur is located near Ísafjörður in Ísafjarðardjúp in Vestfirðir in North-Western Iceland. It is a part of the Ísafjörður community.

### 8.1 Southern part

There is some danger of avalanches under certain weather conditions (SA wind with heavy snowfall), which are relatively rare in the area. The slope usually collects much less snow snow than the slope above the northern part of the village. An avalanche touching the uppermost buildings in the area is recorded.

The width of the area is about 650 m.

There are many residential and some industrial buildings in the area.

No defenses have been proposed to date.

The need for defenses is uncertain.

### 8.2 Northern part

Avalanches are very frequent and evacuations of several buildings may occur many times in some winters. Catastrophic avalanches with many fatalities occurred in the last century and early in this century in Búðargil in an area which is presently without residential buildings, although some residential buildings are close to this area. Stables are currently located in the dangerous area below Búðargil.

The width of the area is about 400 m.

There are many residential and some other buildings in the area.

Defenses consisting of deflectors (heights 12-17 m and 7-17 m, lengths 350 m and 130 m) have been proposed (VST, 1994a). Representatives from EI in France have considered the installation of avalanche nets in the starting zones and the some of the combinations of defenses proposed by VST included about 300 m of nets in the starting zones. Residential buildings closes to the Traðargil avalanche track have been purchased by the government in order to guarantee that they are not used during the winter.

Defenses for several buildings outside the area where buildings were purchased by the government are necessary.

## 9. BOLUNGARVÍK

Bolungarvík is located relatively close to Ísafjörður and Hnífsdalur in Ísafjarðardjúp in Vestfirðir in North-Western Iceland.

### 9.1 Gullies in the western part of the village

There is some avalanche danger, but the avalanche records are very short so it is difficult to estimate the avalanche frequency.

The width of the area is about 300 m.

There are several residential buildings in the area.

No defenses have been proposed to date.

Some defenses or change in land use are probably necessary.

### 9.2 Ufsir

The avalanche danger is believed to be low, but the avalanche records are very short so it is difficult to estimate avalanche frequency. The mountain slope above this area usually collects little snow.

The width of the area is about 600 m.

There are many residential and other buildings in the area.

No defenses have been proposed to date.

The need for defenses is uncertain.

### 9.3 Ernir

Several avalanches are recorded from a gully near the northeastern end of the mountain Ernir, some reaching far beyond the present location of buildings in the area.

Stables and buildings owned by the Vestfirðir Power Company are located at the foot of the slope. The buildings of the Power Company are somewhat to the side of the main avalanche track. The buildings of the Vestfirðir Power Company often need to be occupied 24 hours a day during times of bad weather when avalanche danger may be very high.

The width of the area is about 200 m.

No defenses have been proposed to date.

Some defenses or change in land use are necessary.

## 10. PATREKSFJÖRÐUR

Patreksfjörður is located in the southern part of Vestfirðir in North-Western Iceland.

### 10.1 Vatneyri

Avalanches in the avalanche track above the present harbor are frequent and have caused damage to several houses in the area. The avalanches are most frequent in a 150 m wide track in the middle of the area, but there is some danger outside of this track.

The width of the area is about 700 m.

There are many residential and industrial buildings in the area.

Defenses consisting of deflectors (heights 9-10 m and 8 m, lengths 170 m and 250 m) have been proposed (VST, 1994b).

Some defenses or change in land use are necessary.

### 10.2 Klif

The avalanche danger is believed to be low. The mountain slope above this area usually collects little snow, but buildings are located very close to the foot of the slope.

The width of the area is about 650 m.

There are several residential and other buildings in the area.

No defenses have been proposed to date.

The need for defenses is uncertain.

### 10.3 Stekkagil

A slush flow from the gully caused 3 fatalities in 1983. There is also a danger of dry snow avalanches from cornices or drift snow that accumulates in the upper part of the gully. There are records of slush flows from Stekkagil around 1948 and 1966/7, in addition to the catastrophic event in 1983, and some indications of additional slush flows before 1948.

The width of the area below the gully is about 300 m, but the gully is much narrower.

There are several residential and other buildings in the area.

Avalanche nets at about 80-150 m a.s.l. in the gully (4 rows, total length 250 m) have been proposed (VST, 1994b). The effectiveness of nets for containing the slush that accumulates in the lower part of the gully and immediately below it needs to be considered.

Some defenses or change in land use are necessary.

### 10.4 Litladalsá

A slush flow along the path of the river caused 1 fatality in 1983.

The width of the area is difficult to define but it is about 150 m.

There are several residential and other buildings in the area.

An appraisal of avalanche defenses for Patreksfjörður (VST, 1994b) discusses the possibility of dams to contain wet avalanches or slush flows, but explicit proposals for defenses are not made.

Some defenses or change in land use are necessary.

### 10.5 Sigtún area

The avalanche danger is believed to be low, but two relatively thin avalanches are recorded from the winter of 1994/95 when there was exceptionally much snow in this part of the country. The mountain slope above this area usually collects little snow, but buildings are located very close to the foot of the slope.

The width of the area is about 450 m.

There are many residential and some other buildings in the area.

No defenses have been proposed to date.

The need for defenses is uncertain.

## 11. BÍLDUDALUR

Bíldudalur is located somewhat north of Patreksfjörður in the southern part of Vestfirðir in North-Western Iceland. It is a part of the same community as Patreksfjörður.

A report on the avalanche hazard in Bíldudalur and a discussion of possible defenses was written some years ago (Stuðull, 1990), but no defenses have been built yet according to these proposals. The proposed defenses were deflecting dams near the main slush and mud flow tracks in gullies Búðargil and Gilsbakkagil and below the slope between the two gullies. Some relatively low deflecting dams that are intended to control slush and mud flows have been constructed in the area.

### 11.1 Búðargil

Several avalanches, slush flows, mud flows and floods from the large gully are recorded.

The width of the area is 4-500 m.

There are several residential and other buildings the area.

Deflecting dams to control slush and mud flows have been proposed (Stuðull, 1990).

Some defenses or change in land use are necessary.

### 11.2 Kaldabakki

Several mud flows from small ravines in the hill are recorded.

The width of the area is about 400 m.

There are several residential and some other buildings in the area.

Deflecting dams to control slush and mud flows have been proposed (Stuðull, 1990).

The need for defenses is uncertain.

### 11.3 Gilsbakkagil

Several mud flows running over a talus fan below the gully are known, but no avalanches from the gully are recorded.

The width of the area is about 400 m.

There are several residential buildings in the area.

Deflecting dams to control slush and mud flows have been proposed (Stuðull, 1990).

The need for defenses is uncertain.

## 12. NESKAUPSTAÐUR

Neskaupstaður is located in the fjord Norðfjörður in the middle of Austfirðir in Eastern Iceland.

The avalanche danger in Neskaupstaður is greatest below distinct gullies in the mountain above the village, but there is also a potential for the release of avalanches in the slopes between the gullies. There are some reports that a major area in the innermost part of the mountain was released in one large avalanche before the beginning of this century (the area to the west of Tröllagil which is mentioned below and indicated on the evacuation map). Several reported avalanches reached far into what is now a populated area and some all the way to the sea as shown on the evacuation maps. Catastrophic avalanches in 1974 killed 12 people in the village.

The length of the coastline where most of the residential buildings in the village are located is about 2.7 km. There are some industrial buildings located further to the west.

It is likely that initial construction of avalanche defenses in Neskaupstaður would be targeted to the release areas in and above the abovementioned gullies. Presumably, some additional effort would later have to be made in the areas between the gullies.

Snow depth in the slopes above Neskaupstaður has been monitored for several years. The snow depth is 2-3 m over wide areas in the starting zones in "ordinary" years (*i.e.* every other year or so) and more than 3 m in relatively "bad" years (*i.e.* every 5-10 years or so). Data on the snow depth measurements will be reviewed in work meetings before the visit to Neskaupstaður.

Avalanche defenses for Neskaupstaður have been considered by Jónsson (1987) and VST (1995c). The defenses proposed by Jónsson consisted dams and walls with heights ranging from approximately 10 to 20 m, in addition to several direct protecting structures upstream from individual buildings. The defenses proposed by VST consist of more than 5 km of avalanche nets in the starting zones of the avalanches combined with extensive retaining mounds above the uppermost buildings in the village. Defenses consisting of retaining dams were also briefly discussed. The defenses proposed by VST are further describe below.

The main zones of the evacuation map are described below. The need for defenses in each individual area is not described, since this has already been mentioned in general terms above. It is clear that major defenses or changes in land use must are necessary Neskaupstaður in order to lower the avalanche risk to acceptable levels.

### 12.1 Miðstrandarskarðssvæði

Several avalanches have reached to the sea in this area.

The width of the area is about 1600 m.

Many industrial buildings and some residential buildings are located in the area.

Defenses consisting of avalanche nets (3 and 4 rows, total length 1800 m), combined with retaining mounds above the uppermost buildings and purchasing of some buildings where defenses are uneconomic have been proposed (VST, 1995c).

### 12.2 Tröllagil

An avalanche reaching the sea in this area is recorded and several other avalanches have reached to or almost to the uppermost houses.

The width of the area is about 600 m.

There are many residential and other buildings in the area.

Defenses consisting of avalanche nets (4 to 11 rows depending on configuration, total length at least 2000 m), combined with retaining mounds above the uppermost buildings have been proposed (VST, 1995c).

### 12.3 The area immediately to the east of Tröllagil

The avalanche danger is considered lower than in the adjacent areas.

The width of the area is about 250 m.

There are many residential buildings in the area.

No defenses have been proposed to date.

### 12.4 Drangaskarð

Avalanches reaching into the currently populated area are recorded.

The width of the area is about 750 m.

There are many residential and other buildings in the area.

Defenses consisting of avalanche nets (4 and 5 rows, total length about 1600 m) combined with retaining mounds above the uppermost buildings have been proposed (VST, 1995c).

### 12.5 Bakkasvæði

Avalanches reaching near the uppermost buildings are recorded.

The width of the area is about 700 m.

There are many residential and other buildings in the area.

Defenses consisting of retaining mounds above the uppermost buildings have been proposed (VST, 1995c).

### 12.6 Stóralækjarsvæði

The avalanche danger is considered lower than further to the west.

The width of the area is about 400 m.

There are many residential buildings in the area.

No defenses have been proposed to date.

## 13. SEYÐISFJÖRÐUR

Seyðisfjörður is located somewhat north of Neskaupstaður in the middle of Austfirðir in Eastern Iceland.

### 13.1 Öxl

Avalanches are very frequent. Several avalanches reaching all the way to the sea are recorded. Wet avalanches and mud flows are also recorded.

The width of the area is about 750 m.

There are several industrial buildings in the area, but no residential buildings.

No defenses have been proposed to date.

Some defenses or change in land use are necessary.

### 13.2 Bjólfur

Catastrophic avalanches reaching all the way to the sea in the last century in a part of the area are recorded, one killing 24 people. Several dangerous wet avalanches and mud flows are also recorded.

The width of the area is about 1200 m.

There are many residential and other buildings in the area.

A deflecting wall (height about 12 m, length about 200 m) above the area crossed by an avalanche in 1885 has been proposed (Verkfræðistofa Siglufjarðar s.f. and Verkfræðistofa Austurlands h.f., 1992). Other dams and walls ranging in height from approximately 10 to 18 m have also been proposed in this area and somewhat further to the east. Defenses in the starting zone in the uppermost area of the slope have been considered (Tækniskóli Íslands, 1995) and consisted of 2800 m of 3 m high nets.

Some defenses or change in land use are necessary.

### 13.3 Botnar

Avalanche risk is considered low, but the area will be considered in the overview study because a large number of residential buildings is located very near the foot of the slope.

The width of the area is about 1300 m.

There are many residential and other buildings in the area.

No defenses have been proposed to date.

The need for defenses is uncertain.

### 13.4 Strandatindur

Avalanches are frequent. Wet avalanches and mud flows are also recorded.

The width of the area is about 1300 m.

There are many industrial buildings in the area, but no residential buildings.

No defenses have been proposed to date.

Some defenses or change in land use are necessary.

## 14. SIGLUFJÖRÐUR

Siglufjörður is located in a small fjord somewhat west of the fjord Eyjafjörður in Northern Iceland.

### 14.1 Jörundarskál/Strengsgil

Avalanches are very frequent and evacuations of several buildings may occur many times in some winters. Several avalanches reaching all the way to the sea before the buildings in the area were built are recorded.

The width of the area is about 400 m.

There are many residential buildings in the area.

No defenses have been proposed to date.

Some defenses or change in land use are necessary.

### 14.2 Fífladalasvæði, southern part

Few avalanches are recorded in the area. There is some potential for a dangerous snow accumulation of show in the upper part of the hill in N-NV-ly wind directions, although this potential is considered much lower than in the adjacent area to the north. Although no very long avalanches are recorded, there may be a possibility for the release of a catastrophic avalanche in this area, but it is very difficult to quantify the probability of such an event.

The width of the area is about 500 m.

There are many residential and some other buildings in the area.

No defenses have been proposed to date.

The need for defenses is uncertain.

### 14.3 Fífladalasvæði, northern part

Many avalanches have reached the uppermost houses in the area. There is a potential for a dangerous accumulation of show in the upper part of the hill in N-NV-ly wind directions. Although no very long avalanches are recorded, there appears to be a possibility for the release of a catastrophic avalanche in this area.

The width of the area is about 450 m.

There are many residential and other buildings in the area.

No defenses have been proposed to date.

Some defenses are probably necessary.

### 14.4 Gimbraklettar

Many avalanches have reached the uppermost houses in the southern part of the area. The hill is comparatively low in the northern part and the higher southern part does not collect much snow due to its convex shape. The potential for the release of an extreme avalanche is therefore considered low, but the uppermost houses are endangered by avalanches that are released in the lower part of the hill.

The width of the area is about 500 m.

There are many residential and other buildings in the area.

No defenses have been proposed to date.

Some defenses for the uppermost buildings are probably necessary.

### 14.5 Gróuskarðshnjúkur, southern part

An avalanche reached into the middle of the area in 1963, but no other avalanches are recorded.

The width of the area is about 350 m.

There are many residential and some other buildings in the area.

No defenses have been proposed to date.

Some defenses are probably necessary.

### 14.6 Gróuskarðshnjúkur, northern part

The avalanche danger is considered low. The mountain slope above this area usually collects little snow, but buildings are located very close to the foot of the slope.

The width of the area is about 250 m.

There are many residential and some other buildings in the area.

No defenses have been proposed to date.

The need for defenses is uncertain.

## 15. METEOROLOGICAL CONDITIONS

Meteorological conditions that lead to avalanches in Iceland have not been extensively studied to date. A paper by Björnsson (1980) gives a general outline of avalanche conditions in Iceland and includes a brief discussion of the meteorological conditions associated with the major avalanche cycles of this century. A report has been written about the weather in Vestfirðir during the most important avalanche cycles in the last 46 years (Jóhannesson and Jónsson, 1996, included with this report). It is found that the most dangerous avalanche cycles are associated with intense lows that direct strong N- or NE-ly winds to the Vestfirðir region. Accumulation of drifting snow in the starting zones in the very high winds is a an important component in conditions that lead to most dangerous avalanche cycles (wind speeds in excess of 90 knots have been observed in the mountains under these conditions).

The meteorological conditions associated with the largest avalanches in N- and E-Iceland appear to less violent than in Vestfirðir, *i.e.* the longest avalanches have often fallen after prolonged periods of intense snowfall, not necessarily combined with violent storms although winds in the mountains tend to be strong during the days immediately before the avalanches fall.

Return periods of the weather conditions that have lead to the worst avalanche incidents have not been much studied, but are briefly discussed in Jóhannesson and Jónsson (1996). Return periods for avalanches in specific avalanche paths have not been studied much either. Return periods of avalanches in the Skollahvilft avalanche track on Flateyri in Vestfirðir are analyzed in Jóhannesson (1996) who also summarizes some other related work.

## 16. SNOW DEPTH IN STARTING ZONES

Little direct measurements of snow depth in starting zones of avalanches in Iceland exist except for the monitoring of snow depth in Neskaupstaður which was mentioned in the section about Neskaupstaður, where snow depth is measured to be more than 2-3 m over wide areas in the starting zones in "ordinary" years and more than 3 m in relatively "bad" years, and the measurements near Ísafjörður described below.

Measurements of snow depth at 600 m a.s.l. in Seljalandsdalur west of Ísafjörður since 1989 show that the snow dèpth there ranges from approximately 2 to 5 m in a relatively open slope.

Indirect evidence from the catastrophic avalanche in Flateyri 26. October 1995 indicates that the snow depth in the starting zone was on the order of 3-4 m over extensive areas and the maximum snow thickness in the rupture zone was measured to be 3.9 m.

## 17. REFERENCES

Björnsson, H. 1980. Avalanche activity in Iceland, climatic conditions, and terrain features. Journal of Glaciology, 26(94), 13-23.

Jóhannesson, T. 1996. Return period for avalanches on Flateyri. Icelandic Meteorological Office, Internal report VÍ-G96014-ÚR14.

Jóhannesson, T. and T. Jónsson. 1996. Weather in Vestfirðir before and during several avalanche cycles in the period 1949 to 1995. Icelandic Meteorological Office, Internal report VÍ-G96015-ÚR15.

Jónsson, Á. 1987. Avalanche defences in Neskaupstaður, Iceland (thesis in Icelandic). Stockholm, Kungl. Tekniska Högskolan.

Stuðull. 1990. Bíldudalur. Skriðuföll og skriðuvarnir (report in Icelandic). Reykjavík, Stuðull, Verkfræði og jarðfræðiþjónusta.

Tækniskóli Íslands. 1995. Snjóflóðavarnir fyrir Seyðisfjörð (thesis). Reykjavík. Tækniskóli Íslands.

Verkfræðistofa Siglufjarðar s.f. and Verkfræðistofa Austurlands h.f. 1992. Seyðisfjarðarkaupstaður, varnargarður vegna snjóflóða, 1. áfangi -- hafnarsvæði, frumáætlun (avalanche defense appraisal in Icelandic). Siglufjörður, Verkfræðistofa Siglufjarðar s.f.

VST, 1994a. Snjóflóðavarnir í Hnífsdal (tender documents in Icelandic). Reykjavík, Verkfræðiskrifstofa Sigurðar Thoroddsen hf.

VST, 1994b. Snjóflóðavarnir fyrir Patreksfjörð, forathugun (avalanche defense appraisal in Icelandic). Reykjavík, Verkfræðiskrifstofa Sigurðar Thoroddsen hf.

VST, 1995c. Snjóflóðavarnir í Neskaupstað, forathugun (avalanche defense appraisal in Icelandic). Reykjavík, Verkfræðiskrifstofa Sigurðar Thoroddsen hf.