The importance of the Icelandic Avalanche and Landslide Fund for avalanche-prone areas in Iceland

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ABSTRACT

The Avalanche and Landslide Fund has played an important role in increasing the safety of the inhabitants of avalanche-prone municipalities in Iceland. This has been accomplished by establishing the safety criteria for avalanche and landslide hazard mapping and for the design of protection measures as well as by providing for over 90% of the actual cost of such measures undertaken in local municipalities in Iceland since 1995. After two catastrophic avalanches in two small towns in the north-west of Iceland in the year 1995, the Icelandic Government reorganised its support and at the same time increased public funding to local municipalities for dealing with the threat from avalanches and landslides. The Icelandic Meteorological Office was designated as the expert advisory body and the Government established an Avalanche and Landslide Fund to provide funding for local municipalities to implement the necessary measures.

1. INTRODUCTION

Catastrophic avalanches in the small towns of Súðavík and Flateyri in 1995 caused 34 fatalities and extensive economic damage in areas considered to be outside avalanche hazard zones. The public and political opinion on avalanche safety in Iceland was instantly changed by these tragic events. Hence, the prime minister established a committee in the fall of 1995 to review the legal framework for all aspects of risk assessment, hazard evaluation and protective measures against avalanches and landslides. Furthermore, the administration in this field needed to be strengthened and an improved scientific and technical approach was needed.

This work resulted a complete and radical change in the administration and involvement of the government in the field of avalanches and landslides protection, i.e.:

- Requirements to municipalities to secure protection from avalanches and landslides.
- The administration in the field of avalanches and landslides was transferred from the Ministry of Social Affairs to the Ministry for the Environment.
- Research and advice on preventive measures and responsibility for hazard zoning, regular snow observations and hazard monitoring was given to the Icelandic Meteorological Office (IMO), an institute under the Ministry for the Environment.
- A new Avalanche and Landslide Committee was established under the Ministry for the Environment.

2. THE AVALANCHE AND LANDSLIDE COMMITTEE

An act on protective measures against avalanches and landslides was approved by the parliament (Althing) in 1997 (no. 49/1997). Public meetings were organized 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. Comprehensive plans on monitoring and evacuation schemes were developed for all the communities in question and it was informed that the implementation of permanent protection structures would take several years.

The main thrust of the legislation on protective measures against avalanches and landslides was to aim for permanent structures unless cost–benefit analysis showed that it would be considerably less costly to purchase the buildings in the respective 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 which amounts to around 2.5 billion ISK (ca. 21 million €) in 2019. However, the actual expenditure from the Avalanche and Landslide Fund is determined annually by the Icelandic Parliament, Alþingi. The key role of the fund is to assist municipalities to deal with protective measures for existing populated areas within towns and villages, mainly the domestic rather than the industrial areas.

The new act also established an Avalanche and Landslide Committee. The role of the committee is to decide on proposals from municipalities for 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 monitoring 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.

The act on protective measures against avalanches and landslides was modified in 2014 and again in 2017 allowing the use of funds for hazard zoning regarding other natural hazards than snow avalanches and landslides, i.e. eruptions and river and ocean floods (see Figure 1 for an overview of the different natural hazards that need to be considered in Iceland). Extensive research under the direction of IMO is ongoing in the fields of these new tasks. A further modification of the act occurred in 2018, stipulating that the annual fee levied on all property will no longer go to the Avalanche and Landslide fund and that government funding in this field will be the determined directly by the Icelandic Parliament each year.

3. 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, in particular from Norway, Switzerland, France and Austria. Several international research projects supported by the European Commission have also been important in the build-up of expertise in avalanche science in Iceland. An experiment on supporting structures under Icelandic conditions was carried out in Siglufjörður at an early stage of the preparations. This experiment was primarily intended to study the loading and foundation conditions for supporting structures in typical Icelandic environmental conditions. Important lessons were learned from this experiment, such as regarding snow load, wind load, corrosion and installation of the struc-

tures. The experience gained through the experiment was formalised into an Icelandic annex to the Swiss Guidelines for Supporting Structures to be applied when designing such structures for Icelandic circumstances.

An implementation plan for protection measures was drawn up by the Avalanche and Landslide Committee in consultation with the local municipalities in 1996 and 1997. According to this original plan, the most urgent tasks were to be finished before 2010. However, this plan was revised, and the target year changed to 2020. The plan now needs to be revised again with a new target to be set. The prioritization took into consideration the estimated hazard level in the different threatened settlements, the wishes of the municipalities, different local circumstances and the 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. The actual implementation of the protection measures has largely been according to this plan with some deviations due to practical circumstances. The plan with its detailed prioritization has proved to be a valuable tool for organizing the various tasks and for distributing the available funding between the various municipalities.

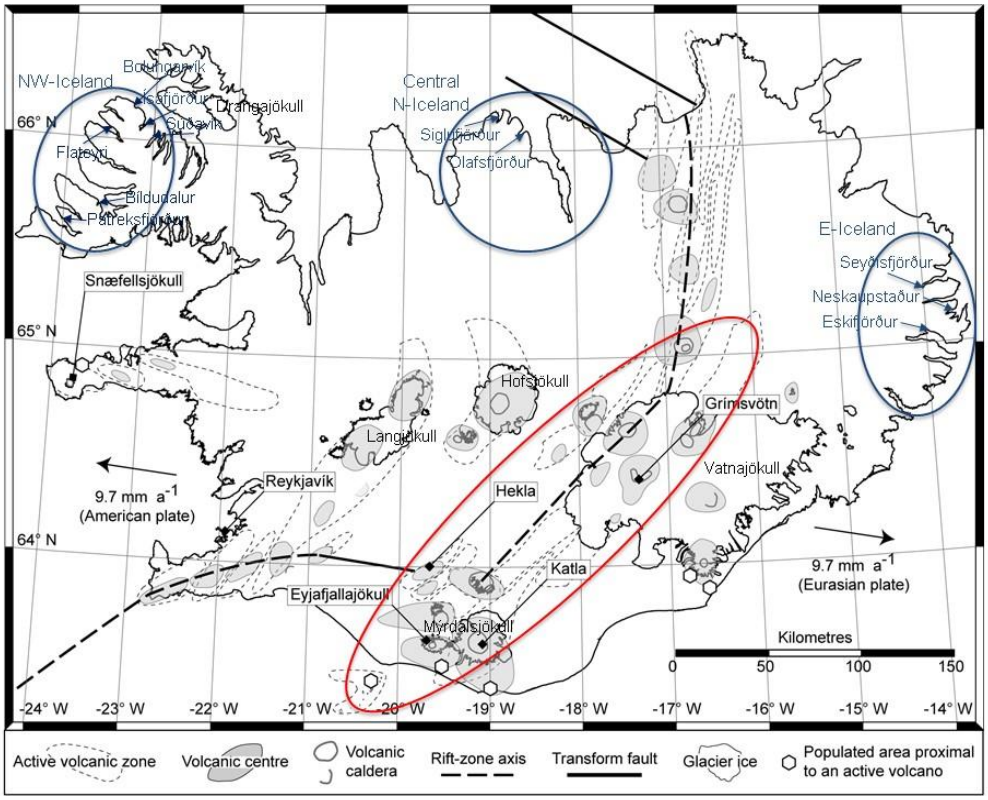

Figure 1 Geological characteristics of Iceland that determine natural hazards in different areas of the country. The map shows transform faults in SW-Iceland and central N-Iceland (earthquakes), the central volcanic zone that strikes across Iceland from SW to NE (volcanic eruptions, the most active volcanic area is indicated with an oblique, red ellipsoid), the glaciers (jökulhlaups) and the mountainous regions in NW-, central N- and E-Iceland (snow avalanches and landslides, dark blue oval areas). The main villages threatened by snow avalanches and landslides are shown with dark blue labels. (Map from the Icelandic Meteorological Office.)

4. ACCEPTABLE RISK AND HAZARD ZONING

A definition of acceptable risk from avalanches and landslides for living quarters in towns and villages was needed before permanent protective structures could be designed for the areas in question. This required the involvement of several experts and eventually a political decision.

The regulation no. 505/2000 on hazard zoning due to avalanches and landslides, classification and utilization of hazard zones defines acceptable risk.

> "Local risk to humans in residential dwellings, schools, day-care centres, hospitals, community centres and similar locations is considered acceptable if it is less than 0.3×10^{-4} annually. For commercial buildings where there is steady activity, the risk is acceptable if local risk is less than 1×10^{-4} annually. For recreational homes, risk is acceptable if local risk is less than 5×10^{-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, except for schools and day-care centres."

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	0.3×10^{-4}	1.0×10^{-4}
Hazard zone B	1.0×10^{-4}	3.0×10^{-4}
Hazard zone C	3.0×10^{-4}	–

The term "local risk" is defined as the "annual probability of death because 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 is not in accordance with the hazard map must be revised. Disputes regarding revised plans can be referred to the Ruling Committee for Environment and Natural Resources.

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

Ólafsvík	Hnífsdalur	Tálknafjörður
Patreksfjörður	Súðavík	Drangsnes
Bíldudalur	Siglufjörður	Akureyri
Þingeyri	Ólafsfjörður	Kirkjubæjarklaustur
Flateyri	Seyðisfjörður	Vík
Suðureyri	Neskaupstaður	Mosfellsbær
Bolungarvík	Eskifjörður	Reykjavík
Ísafjörður	Fáskrúðsfjörður	

Hazard zoning is currently in preparation for the village of Stöðvarfjörður in E-Iceland.

When the present efforts to improve safety due to avalanches and landslides were initiated, it was generally considered that mainly 8–10 local communities were threatened by avalanches or landslides in Iceland. However, the total number of local communities that are now considered endangered to some degree is 24 after further evaluation.

5. PROTECTIVE MEASURES

According to the *regulation no. 505/2000 on hazard zoning due to avalanches and landslides, classification and utilization of hazard zones*, 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 must make an action plan to ensure safety of people in residential 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, the 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. This task was approved in the fall of 1995 and mostly completed in the spring of 1997. A total of 55 new residential units were built in a safe area and a few houses were relocated in the process.

6. CONSTRUCTION OF PROTECTION STRUCTURES

The first permanent protection structures were built in Flateyri and completed in 1998. The Avalanche and Landslide Fund has since then supported the construction of protection structures at more than thirty locations in fifteen municipalities. Several of those structures have been hit by avalanches and hence have already proven 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 two deflecting dams and a catching dam was completed in 1998.
- Ísafjörður:
    - construction of a deflecting dam for Seljaland area was completed in 2004.
    - construction of a catching dam for the Kubbi area was completed in 2013.
    - construction of catching dams for the Gleiðarhjalli area was completed in 2017.
    - construction of supporting structures for the Kubbi area was completed in 2018.
- Hnífsdalur – purchase of houses and demolition completed in 2007.
- Siglufjörður:
    - construction of deflecting dams for the Strengsgil area was completed in 1999.
    - construction of supporting structures for the Gróuskarðshnjúkur area (phase 1) was completed in 2004.
    - construction of several catching dams above the entire town north of Strengsgil was completed in 2007.
    - construction of supporting structures for the Hafnarhyrna area (phase 2) was completed in 2015.
    - construction of supporting structures for the N-Fífladalir area (phase 3) was completed in 2018.
- Seyðisfjörður – construction of a catching and a deflecting dam in the shelf Brún the Bjólfur mountain was completed in 2004.
- Neskaupstaður:

    - construction of a deflecting dam, braking mounds and supporting structures for the Drangagil area was completed in 2001.
    - construction of supporting structures for the Tröllagil area was completed in 2012.
    - construction of a deflecting dam, a catching dam and braking mounds for the Tröllagil area was completed in 2015.
- Ólafsvík – construction of supporting structures, a small dam as well as landscaping was completed in 2009.
- Eyjafjarðarsveit – construction of a small deflecting dam for Grænahlíð was completed in 2009.
- Bíldudalur – construction of a deflecting dam in the Búðargil area was completed in 2009.
- Bolungarvík – construction of catching dams and braking mounds was completed in 2012.
- Ólafsfjörður – construction of a deflecting dam was completed in 2010.
- Patreksfjörður:
    - construction of a catching dam for the Klif area was completed in 2015.
    - construction of protection measures for a river Litladalsá were completed in 2015.
    - construction of experimental snow fences above the Urðir, Hólar and Mýrar area was completed in 2017.
- Eskifjörður:
    - construction of protection measures for the river Bleiksá were completed in 2015.
    - construction of protection measures for the river Hlíðarendaá were completed in 2016.
    - construction of protection measures for the river Ljósá were completed in 2018.
- Fáskrúðsfjörður – construction of a catching dam and a low deflecting dam in Nýjabæjarlækur was completed in 2014.

Protection structures are under preparation in the following towns:

- Patreksfjörður – design of deflecting and catching dams in the Urðir, Hólar and Mýrar area will be completed in 2019.
- Patreksfjörður – preparation of the construction of additional snow fences above the Urðir, Hólar and Mýrar area.
- Neskaupstaður – construction of catching dams in under Urðarbotnar will start in 2019.
- Siglufjörður – preparation of the construction of supporting structures for the Hafnarhyrna area (phase 4).
- Neskaupstaður – preparation of the construction of additional supporting structures in Drangagil.
- Eskifjörður – design of protection measures in the river Lambeyrará will be completed in 2019.
- Eskifjörður – design of protection measures in the river Grjótá will be completed in 2020.
- Seyðisfjörður – design of deflecting and catching dams for the Aldan and Bakkahverfi area will be completed in 2020.

Protection structures in a preliminary stage of preparation:

- Ólafsvík – preparation of the construction of snow fences.
- Patreksfjörður – protection measures in the Geirseyrargil and Sigtún area.
- Bíldudalur – protection measures in the Gilsbakkagil and Milligil area.
- Tálknafjörður – protection measures in the Geitárhorn area.
- Hnífsdalur – protection measures in the Bakkahyrna area.
- Siglufjörður – supporting structures (phase 5).

- Seyðisfjörður – protection measures in the Þófar and Botnar area.
- Neskaupstaður – catching dam in the Nes- and Bakkagil area.

The completion of the construction of protection structures for residential settlements in the C-zone in the various municipalities will take around 30 years if the current annual expenditure is not increased. This delay is partly because that more towns and villages are threatened by avalanches or landslides than was initially realised and partly because the government decided to slow down the construction in the years 2004 to 2007 due to general economic expansion and again after the economic crisis in 2008. The estimated cost of the remaining effort now appears to be around 19 billion ISK (140 million €) whereas the total accumulated cost of protection measures, relocation of settlements and other mitigation measures since 1995 is 21 billion ISK (150 million €). Figure 2 shows an example of the revised hazard zoning at Seljalandshverfi in Ísafjörður, NW-Iceland, after the construction of a deflecting dam.

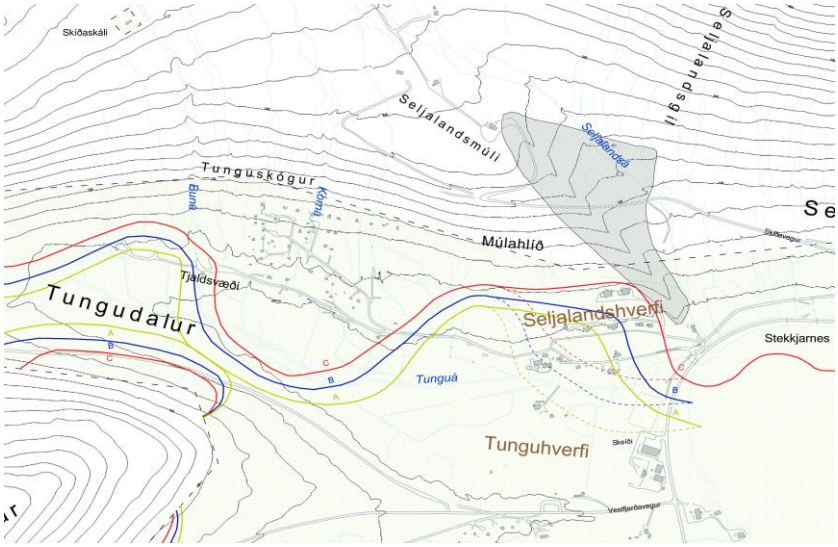

Figure 2 Snow avalanche hazard zones for Seljalandshlíð in Ísafjörður, NW-Iceland. The solid lines show the boundaries of the A (yellow), B (blue) and C (red) zones of the Icelandic hazard zoning regulation. The dashed lines show the zones before the construction of a deflecting dam at Seljalandsmúli, seen as kinks in the contour lines in the shadow area on the map. (Map from the Icelandic Meteorological Office.)

7. CONCLUSIONS

The establishment of the Icelandic Avalanche and Landslide Fund for avalanche-prone areas has proven to be of vital importance for the safety of the inhabitants of the concerned municipalities. Substantial improvements have been made in safety against avalanches and landslides for the communities that were endangered by snow avalanches and landslides in Iceland by the actions taken during the past two decades. Invaluable knowledge on hazard zoning, design of permanent structures and construction of the same has been gained, awareness has been raised at the municipal level and with the public at large. Permanent protection structures have already been established in almost all the affected communities and several have already proven their value. The local municipalities would never have had the resources to deal with the threat of avalanches and landslides without the support of the Icelandic Avalanche and Landslide fund.