The avalanche situation in Neskaupstaður, Iceland. A preliminary defensive plan

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ABSTRACT.

The avalanche situation in the town of Neskaupstaður is rather unique and in many respects more difficult than in any other place in Iceland. The avalanche risk is high in a large portion of the 2,7 km long residential area, with similar snow accumulation conditions throughout the entire area. Additionally, conditions for the construction of avalanche defences are rather difficult. The avalanche starting zones are extensive and many of these have difficult geological conditions. The uppermost houses are located close to the mountain, with limited space to construct avalanche defences above them, especially in the western part of the town.

After the avalanche accidents in Súðavík and Flateyri in 1995 the Icelandic government has set a long term goal for the acceptable risk to people living in avalanche prone areas. To fulfil this goal, a risk analysis has to be made in connection with avalanche defence planning. The risk analysis for Neskaupstaður indicates that the risk level is far above the acceptable limits in certain parts of the town. To improve the situation, a preliminary protection plan has been set up for the whole town. The plan is based on a combination of supporting structures, deflecting dams, catching dams and breaking mounds.

INTRODUCTION

Urbanization started in Iceland in the last part of the 19th century by the formation of many fishing villages around the country at trading places, natural harbours or in the vicinity of good fishing grounds. In these years, and in fact until quite recently, snow avalanches were not recorded or even remembered unless they caused damage to property or loss of life. The oldest snow avalanche records in these towns are therefore about a century old, except were older records exist due to the existance of a farm dating further back. And the records of snow avalanches tend to be quite limited, as the residential areas were at first relatively small and in general located close to the shoreline.

In this century, and in particular in the last few decades, many of these fishing towns have expanded considerably, with the boundaries of the residential areas moving away from the shoreline and towards the mountain. The lack of avalanche records and respect for the avalanche danger, together with a relatively mild climate and consequently few avalanches in the second half of this century, has caused expansion of some of these fishing towns into avalanche prone areas.

Icelandic society was severely reminded of this fact by two catastrophic avalanche accidents in 1995, when avalanches ran far into residential areas in the fishing towns of Súðavík and Flateyri in the Vestfirðir peninsula in western Iceland, killing 34 people alltogether. These accidents have caused a total change of view regarding avalanche safety in the country, both within the general public and within the Icelandic government.

The government responded by increasing the funding of avalanche research at the Icelandic Meteorological Office (IMO), where avalanche research is conducted in Iceland, as well as reestablishing their role with regard to avalanche control and avalanche safety. As a short term solution, evacuation plans were prepared for those towns that were considered at greatest risk, and IMO was given the authority to order evacuations in times of avalanche danger. An overview of the need for avalanche protection in the country was made by the Ministry for the Environment (Johannesson et al., 1996b) and a special tax was put on all property in the country to pay for the protection measures. The long term goal of the protection plan is to reduce the risk due to avalanches to $0{,}2\text{-}0{,}5 \cdot 10^{-4}$ per year within all residential areas. For comparision, this level is somewhat lower than the average risk due to traffic accidents in Iceland, which is around $1{,}0 \cdot 10^{-4}$ per year.

One of these avalanche prone areas is Neskaupstaður, a fishing town on the east coast of Iceland. The avalanche

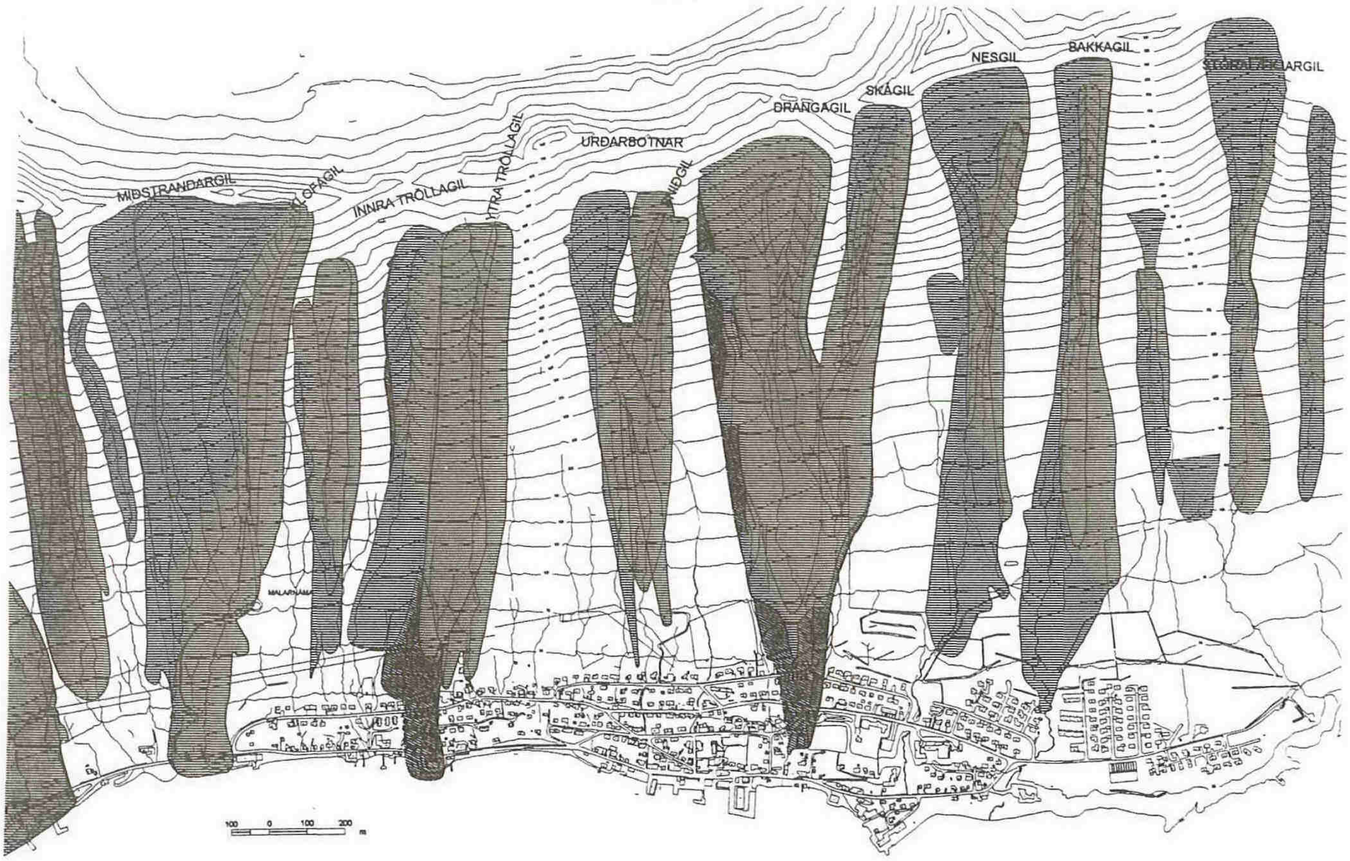

Fig. 1. The total cover of historical snow avalanches over the residential area of Neskaupstaður.

situation there is rather unique and in many respect more difficult than at any other place in Iceland. The exceptionally difficult conditions in Neskaupstaður are fully recognised by the Icelandic authorities, who in the summer of 1997 organised a closed international workshop to discuss possible defences for the town. The Neskaupstaður avalanche situation is described in the following paper, together with a preliminary defensive plan for the town, perpared in co-operation by VST Consulting Engineers in Iceland and Cemagref in France (VST & Cemagref, 1998).

AVALANCHE HAZARD IN NESKAUPSTAÐUR

The town of Neskaupstaður is located on the northern side of Norðfjörður, one of the eastern fjords of Iceland. In the last part of the 19th century a village formed around the local fisheries and expanded throughout this century to the present population of around 1600 people. Today, the town may be separated into two parts, an industrial part to the west in a very avalanche prone area, and a residential part to the east with considerable avalanche hazard over a large portion of its area. Above the town the mountain rises to an elevation of around 700 m a.s.l., formed as a narrow ridge with Alpine characteristics. The shape of the mountain side is quite regular, with conditions for snow accumulation quite uniform over the entire area, but influenced by gullies and bowls formed above many of the gullies.

The climate of the eastern fjords of Iceland is relatively mild as compared with that in many of the other avalanche prone areas in Iceland. The average temperature is above freezing throughout the winter months and weather situations causing serious avalanche cycles are less frequent here. Accumulation of snow by snow drift is also less pronounced here because there are no large flat plateaus at the mountain tops.

From the second half of the 19th century, when avalanches were first recorded in Neskaupstaður, the area has been hit by numerous avalanches as well as debris flows, mudflows and possibly slushflows. A characteristic of the avalanche activity is that avalanches tend to fall in relatively infrequent, but large cycles. This may be attributed to a combination of several factors. The topography of the mountain side and the mountain ridge above Neskaupstaður is quite homogeneous. All the starting zones face approximately the same direction and snow accumulation conditions are very similar throughout the entire area. Secondly, the slope angle in the starting zones is relatively small and close to the lower limit for avalanche starting zones (30°-35°). Consequently, avalanches tend to be large, but infrequent, as relatively large snowdepths are required for avalanches to be released. Thirdly, the climate of the east coast is relatively mild, resulting in lower frequency of avalanche cycles.

In December of 1974 Neskaupstaður was hit by a number of avalanches that are a good example of such an avalanche cycle. It is also the only cycle that is well recorded, with two large avalanches reaching the shoreline within the industrial area, killing twelve people, and more or less all the paths above the residential area spilling avalanches towards the uppermost houses. In earlier cycles, only those avalanches that caused property damage or killed people were recorded. Avalanche cycles in the years 1885, 1894 and 1936 may thus have been comparable or even

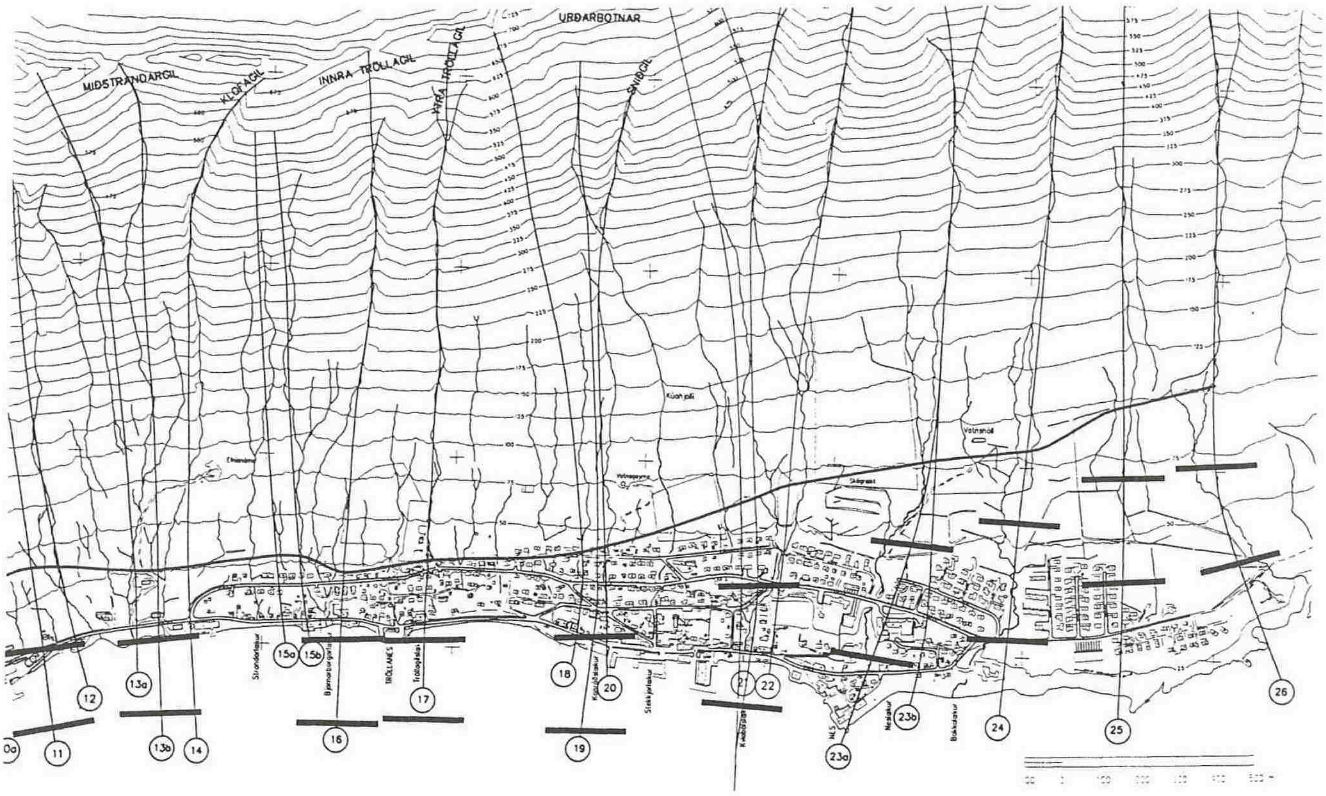

Fig 2. Runout lengths corresponding to results of the statistical topographical model for Icelandic avalanches. The uppermost line indicates the location of the β point, whereas the two lower lines indicate the runout length corresponding the the averege α angle and one standard deviation beyond the average α angle.

larger than that of 1974, especially the ones in the last century. In these years the population lived mainly on a narrow strip along the shoreline and thus further away from the mountain than the present population. Avalanches were therefore less likely to be recorded, even though these may have been considerably large.

The avalanche danger in the Neskaupstaður residential area may be attributed to seven main avalanche paths. They are, ordered from west to east, Miðstrandargil/Klofagil, Tröllagil (Innra-Tröllagil and Ytra-Tröllagil), Urðarbotnar/ Sniðgil, Drangagil/Skágil, Nesgil, Bakkagil and Stóralækjargil. The extent of historical avalanches in and above the residential area of the town is shown in figure 1, based on information gathered by the Icelandic Meteorological Office (Haraldsdóttir, 1997). Most of these avalanches came down in the avalanche cycle of December 1974, but two of them that extend well into the present residential area came down in 1894.

RISK ANALYSIS

The evaluation of risk in an avalanche prone area may be divided into two parts, an estimate of the return period of avalanches with a given runout length, and an estimate of the risk to people in the case that residential houses are hit by an avalanche.

Figure 2 shows the results of a statistical topographical model for Icelandic avalanches (Johannesson et al., 1996a). The model is based on the Norwegian α/β model (Lied & Bakkehøi, 1980), with parameters derived from a database on long Icelandic avalanches, resulting in $\alpha=0{,}92\beta$ with the standard deviation in α equal to 2,55°. The angle α is defined as the average slope of the avalanche path from the fracture line to the outer end of the avalanche deposit, while the angle β is the average slope of the avalanche path to the foot of the slope where the terrain slope angle is equal to 10°. It may be seen that the avalanche danger is greatest in the westernmost part of the residential area where the houses are located closest to the mountain, but in general decreasing when moving eastward through the residential area.

The main assumption behind our estimate of the return period of avalanches in Neskaupstaður is that the avalanche situation is more or less the same along the entire mountain above the residential area, except in the Urðarbotnar/Sniðgil area, where historical avalanches seem to be smaller and less frequent than in the other paths. The topography of this starting zone is different from that in the other areas, with a large step below the uppermost part of the starting zone that influences the starting conditions of avalanches. Historical avalanches from Miðstrandargil/Klofagil, Tröllagil, Drangagil/Skágil and Bakkagil have probably all reached a runout of around 0,5 standard deviations beyond the α-point (α-0,5 SD) (The exact runout of the avalanches reaching the ocean is uncertain). Although recorded avalanches from Nesgil have a somewhat shorter runout length, there is in our view no reason to believe it to be less dangerous than the other paths. The reason for the smaller recorded avalanches there may be that the residential areas in Nesgil and the paths to the east of it are further away from the mountain than in the other paths. This was especially true in the older days. Thus, avalanches in the tracks east of Drangagil were less likely to be recorded, since only those causing damage or killing people were recorded. Additionally, Stóralækjargil is at the outskirts of the town and has up to now been given much less attention than the other paths, although it does not seem to have any lesser potential of large avalanches.

Based on the above assumptions we have estimated the frequency of avalanches in the residential area of Neskaupstaður. Our method consists of measuring the runout length of each historical avalanche using results of the statistical topographical model for Icelandic avalanches presented above. As this work was being finalised, the above model was revised based on a new and revised database for long Icelandic avalanche, and new parameters obtained, resulting in the model $\alpha = 0{,}85\beta$ with SD = 2,2° (Johannesson, 1998). Although the new model parameters differ substantially from the earlier ones, the older model is quite satisfactory for the present study, as its only purpose is to provide a consistent scale to measure and normalise avalanche runout lengths in different avalanche paths. By using this method, all historical avalanches may be pooled into one data set and Gumbel statistics used to estimate the frequency of an avalanche of certain runout length falling anywhere in the area. The frequency for each individual avalanche track is then one sixth of the above frequency. The results of this analysis are given in the following table.

Table 1: Estimated return period of avalanches in each of the six main avalanche tracks above the residential part of Neskaupstaður

Return period	**Runout length measured by the old Icelandic α/β model**
500 years	α - 0,6 SD
1000 years	α - 1,0 SD
2000 years	α - 1,25 SD

The above estimate must of course be taken with some precautions, given the limited data available and the uncertainties involved in all avalanche frequency studies.

The size of the design avalanche depends on the safety required in the populated area below the defensive structures Our analysis indicates that the present risk level may be up to two orders of magnitude larger than the acceptable risk level in certain places within the residential area of Neskaupstaður.

To translate this risk value into an appropriate return period for the design avalanche, the effects of the defensive structures on the flow of an avalanche have to be evaluated, and in particular the flow of avalanches larger than the design avalanche over the defensive structures. This is obviously a very difficult task, given the present understanding of the flow of avalanches and the effect of defensive structures on it. In this evaluation the following methods and assumptions have been used:

- The estimate of return periods and runout lengths presented above.
- An estimate of the speed and mass of avalanche snow that will overflow a catching dam when it is hit by an avalanche larger than the design avalanche.
- Modelling the speed and runout of the overflowing avalanche mass as it travells down the leeward side of the dam and towards the uppermost houses.
- Data on the probability of being killed in a typical Icelandic house when hit by an avalanche at a certain speed. This data has been compiled from experience in the Flateyri and Súðavík accidents [Kristján Jónasson, IMO, personal communication].

The results of this analysis are that for a design avalanche with a return period of 1000-2000 years, the risk in the uppermost houses approximately 100 m from the top of a catching dam, is within the acceptable level.

A PRELIMINARY DEFENSIVE PLAN

Conditions for avalanche defenses in Neskaupstaður are rather difficult for several reasons. The starting zones are in general large, with irregular landscape and questionable foundation conditions in certain areas. Conditions in the runout runout zone to set up defenses are not favourable as the uppermost houses are located quite close to the mountain and the material on the site is questionable as fill material in dams.

Use of deflecting dams is out of the question over most of the area except if channels would be made through the present residential area to carry avalanches towards the shoreline. Such a solution would have an enormouns impact on the town due to the number of houses that would have to be sacrificed and the consequent segregation of the town. The cost would also be high due to the number of houses involved.

A solution with supporting structures only is not considered feasible. Experience with supporting structures is quite limited in Iceland and conditions are different from the Alpine conditions, where supporting structures have been used most extensively. Little data is available on snow depths and the effect of snow drift is uncertain. Corrosion due to the ocean climate is likely to be a problem and foundation conditions are questionable in some areas. The landscape in the Neskaupstaður starting zones is irregular in certain places with possible rockfall and difficult foundation conditions. Even if supporting structures were technically feasible in Neskaupstaður, the cost would be very high due to the large area of the starting zones.

The general idea of the overall protection plan for Neskaupstaður is to use a combination of different defensive measures to obtain the required safety, including deflecting dams, catching dams, breaking mounds and supporting structures. A schematic view of the plan is presented in figure 3. The advantage of combining supporting structures in the starting zone with dams and breaking mounds in the runout zone is that the dimensions of the dam and breaking mounds and the extension of the necessary disturbance of the area just above the houses become smaller. This of great interest to the local people who fear the environmental impact associated with defensive measures built in the runout zone along the entire residential area. It may also be very difficult to fulfil the safety requirements with defensive measures in the runout zone only, due to the little space and consequently limited

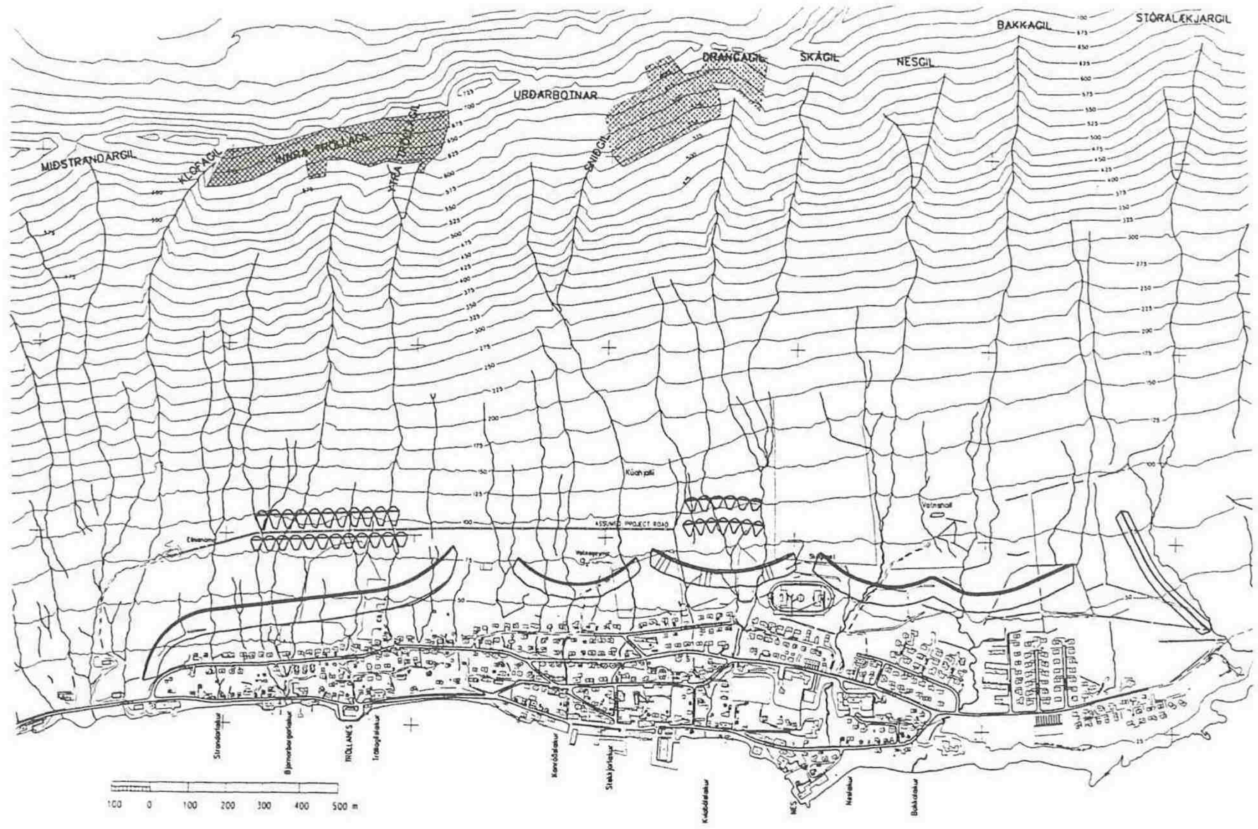

Fig. 3. An overview of the proposed protection measures for the residential area of Neskaupstaður. The hatched areas are regions where supporting structures would possibly be set up.

dimensions of the structures. This applies in particular to the western most part of the area.

To fulfil the safety requirement in the residential areas below the defensive structures, they have to be designed and dimensioned to stop an avalanche of the size determined in the previous section , i.e. with a return period of 1000-2000 years and a runout length corresponding to 1,0-1,25 standard deviations beyond the α-value. The runout length of such an avalanche extends well into the ocean over all of the western part of the residential area.

DISCUSSION

An avalanche protection plan has been set up for the town of Neskaupstaður. The avalanche risk within the residential areas of the town has been determined and compared with the required safety level set by the Icelandic government. To obtain the required safety, it has been estimated that the avalanche protection measures should be dimensioned for an avalanche with a return period of 1000 to 2000 years and a runout length well into the ocean over a large portion of the town.

The accuracy of the above analysis is of course somewhat limited, given the short historical records of avalanches in the area and the present status of avalanche risk assessment in general. However, it is certain that avalanche defences based on the above criteria will, if built, improve the avalanche situation in Neskaupstaður considerably.

The first part of this plan, i.e. defensive measures in the Drangagil/Skágil area, are currently going through the appraisal phase. The estimated cost of the project is US$ 7-8 million, 90% of which will be paid for by the Icelandic government. The final decision regarding the construction of the avalanche defences will be in the hands of the local authorities in Neskaupstaður.

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