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. Given a specific level of probability of failure for both the lines less than approximately 6.5×10^{-4} per year, a total sum of 82 masts might be hit by 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. For each mast, the risk level must be considerable lower than for the transmission lines, and this question has been treated statistically in this paper. In order to achieve the best possible 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.

KEYWORDS: Avalanches, Avalanche risk, Fljótsdalslínur, Landsvirkjun (National Power Company), Landsnet (Icegrid), Transmission lines, Design load.

1. INTRODUCTION

Landsnet (Icegrid) is now building two 420-kV transmission lines from proposed switchgear in Fljótsdalur valley to the aluminum smelter proposed by Alcoa at Hraun, Reyðar-fjörður fjord, Iceland. The transmission lines will run parallel from Fljótsdalur over the ridge Hallormsstaðaháls and into the valley of Skriðdalur. From there, Fljótsdalur Line 3 (FL3) will pass through Hallsteinsdalur and over to Áreyjadalur, while

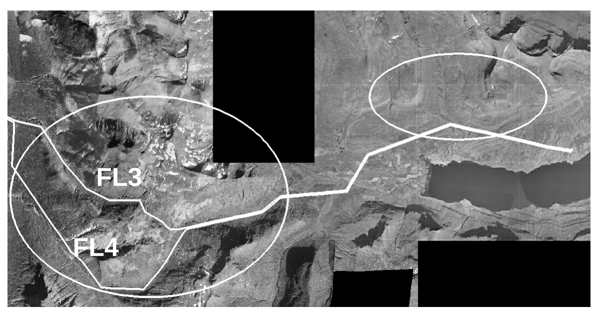

Figure 1. Aerial photo of the main avalanche sites. Ellipses show the snow avalanche areas and lines show the transmission line routes.

Fljótsdalur Line 4 (FL4) will run via Þórudalur, Brúðardalur and Þórdalsheiði down into

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Áreyjadalur. After that the transmission lines will run parallel through Áreyjadalur valley and toward the coast along Reyðarfjörður to the aluminum smelter. The length of the line route is about 30 km. Due to the risk of snow avalanches and landslides at several places, Landsnet requested that this hazard might be investigated, making it possible to design the lines in accordance with an acceptable risk.

The studies of snow avalanche hazards was initiated in the autumn of 2001. The basis for the authors' methodology is similar to that applied in work on civil defence proposals for Icelandic communities. The authors have endeavoured to obtain the best possible information on conditions in the area examined by taking field trips and interviewing those who are familiar with the localities, in addition to utilizing Norwegian experience of such projects.

A draft of this work was reviewed by a number of people, among them Stefan Margreth from SLF (Swiss Snow and Avalanche Research Institute) Davos Switzerland.

Additional information about snow and weather conditions in the area has been gathered and the results are presented in different reports, see references at page 45. The present report has been revised in accordance with above mentioned information.

2. TOPOGRAPHY

Most part of the lines in the observation area run northwest to southeast and west to east. Hallsteinsdalur, which is the northernmost valley, is narrow and sheltered on the north side by mountains with elevation ranges from 400 m above sea level to almost 1000 m above sea level. The south side of this valley is considerably lower. Avalanches from the north side are considered to pass the river at the valley bottom and reach the line on the south side at most of the paths. At the east part of this valley the line passes a pass at elevation of 600 m above sea level. At this pass avalanches are not the real threat to the line but the climatic force from heavy wind and atmospheric icing.

The valley Þórudalur runs northwest to southeast while Brúðardalur valley runs west to east and Þórdalsheiði pass runs northeast to southwest. Avalanches can run from both sides of these valleys and pass. Avalanches from Hallbjarnarstaðatindur mountain, which is on the south side of Þórudalur valley, are considered to be extremely powerful and have long runout distances. Vertical drop of avalanches from this mountain is more than 1000 m.

The lines, FL3 and FL4, run parallel from Þórdalsheiði pass down to Áreyjadalur valley, through it and out to the plains east of it. Áreyjadalur valley is sheltered by steep mountains that reach more than 1000 m. Avalanche risk is considerable in the valley.

The line route passes the village Búðareyri in the fjord Reyðarfjörður. The route is above the village on a relatively flat area below two steep mountains. Avalanches from these mountains are considered to be powerful enough to reach the line routes on several locations.

3. CLIMATE AND SNOW CONDITIONS

Meteorological data from Egilsstaðir, which is a town roughly 20 km north of the site, was used to compile statistics for wind direction and snow fall in the mountains above the lines. The data indicates that approximately 60% of the situations are accompanied by wind from north-northeast while winds from south-southwest directions cover approximately 6%. This implies that south-southwest facing slopes are about 10 times more likely to release avalanche than north-northeast facing sides. The line FL3 in Hallsteinsdalur valley is on the south side of the valley to minimize the risk of being hit by an avalanche. The line FL4 is on the northern side of Þórudalur valley even though avalanches are considered to be more frequent than on the south side. The vertical drop on the north side is much lower than on the south side. During extreme conditions avalanches from Hallbjarnarstaðar-tindur mountain on the south side are expected to reach the line on the north side.

A detailed simulation on a large scale with MM5 simulation software was carried out for weather data from the area which spanned 50 years. The result of the simulation confirmed our conclusions concerning snow and precipitation in the area. A more detailed simulation on small scale was carried out for the starting zones and along the transmission lines. Drifting snow and snow accumulation can be interpreted from the gradient in the wind.

4. CALCULATION OF RUNOUT DISTANCES AND VELOCITY

An Icelandic topographical runout-distance model ($\alpha\beta$-model) (Jóhannesson, 1998), build on an Icelandic dataset, was used as well as PCM (Perla, et.al. 1980) and NIS (Norem, et.al. 1987) which is built on results from Ryggfonn in Norway.

The Icelandic $\alpha\beta$-model provides an approximation for runout distances with annual probabilities of about 1×10^{-2}. Standard deviation or a ratio of it is added to the runout according to the circumstances like aspect, area above the starting zone etc.

The μ and M/D parameters of the PCM model were adjusted more or less to the design runout distance of the $\alpha\beta$-model.

The number of parameters of the NIS model is greater than of the PCM model. The value of adjustable parameters was set somewhat higher/lower than the values commonly used 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.

5. SECURITY FOR THE TRANSMISSION LINES

The two transmission lines pass basically four different avalanche areas from the power plant to the aluminum smelter. Three of them, were the lines run parallel; near the power plant, in Áreyjadalur and above Reyðarfjörður village, are assumed to have the same acceptable probability of damage of an individual tower 0.5×10^{-4} pr. year. The fourth area, between Skriðdalur and Áreyjadalur, is assumed to have the probability of 1.0×10^{-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: 0.75×10^{-4} for the first area, 2.5×10^{-4} for the second area and 2.25×10^{-4} for the third area. The fourth area, were the lines run in two different valleys, the probability is calculated to 1.0×10^{-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 6.5×10^{-4}

6. DETERMINATION OF DESIGN LOAD

6.1 Snow avalanches

The owner of these transmission lines made very high demands for the security of the lines to minimize the probability that snow avalanches will interrupt transmission through both lines simultaneously in Áreyjadalur valley.

Design load from the snow avalanche was calculated for the towers and the conductors. It was assumed that the load acted on the conductor in the middle of the towers. 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:

$$F = C \times p \times A \qquad (1)$$

where:
- *F*: force (N),
- *A*: projected frontal area of an obstacle (m²),
- *C*: unit less 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.

$$p_1 = \frac{r_1 \times v_d^2}{2} \qquad (2)$$

Icelandic Meteorological Office (IMO) has compiled information on snow depths and snow density over 50 years. From their data and other information on snow density in Iceland it was considered that density of 300 kg/m³ would describe best the actual density of the dense core of maritime avalanche.

It is proposed that the saltation layer load be computed according to the following equations. Equation (3) gives the height of the saltation layer, equation (4) gives the DPOFSF at the bottom of the layer, equations (5) and (6) give the DPOFSF at the top of the layer and equation (7) gives the distribution of DPOFSF in the layer.

$$h_2 = v_d \times \Delta t \tag{3}$$

$$p_2(0) = p_1 \qquad p_2(0) \geq 4{,}2kPa \tag{4}$$

$$p_2(h_2) = p_3(0) = \frac{r_3(0) \times v_d^2}{2} \tag{5}$$

$$r_3(0) = 15 kg / m^3 \tag{6}$$

$$p_2(y_2) = p_2(0) + \left[p_2(h_2) - p_2(0)\right] \times \left(\frac{y_2}{h_2}\right)^{0,25} \tag{7}$$

where:

- *?t:* 0.10 s,
- *h:* height of layer (m),
- *r:* density (kg/m³),
- *p:* DPOFSF (N/m² or Pa),
- v_d*:* design velocity of the avalanche (m/s),
- y_2*:* distance from bottom of layer (*0*=y_2=h_2).

The subscript $_1$ refers to the core of the avalanche, $_2$ refers to the saltation layer and $_3$ refers to the powder layer.

Little knowledge is here in Iceland about snow clouds in avalanches as it is hard to observe the cloud in naturally released avalanches due to weather conditions. We therefore looked at Norwegian experience as we believe that our maritime snow is similar to their maritime snow. The lower limit of the snow cloud height was set to 15 m as values less than 15 m are not thought to be in accordance to the high security demands. The highest value calculated was 35 m.

Following equations were used to calculate the force:

$$p_3(h_3) = 0{,}15kPa \tag{8}$$

$$p_3(y_3) = p_3(0) + \left[p_3(h_3) - p_3(0)\right] \times \left(\frac{y_3}{h_3}\right)^3 \tag{9}$$

Equation (8) gives the DPOFSF at the top of the snow cloud and equation (9) gives the distributon of DPOFSF in the snow cloud.

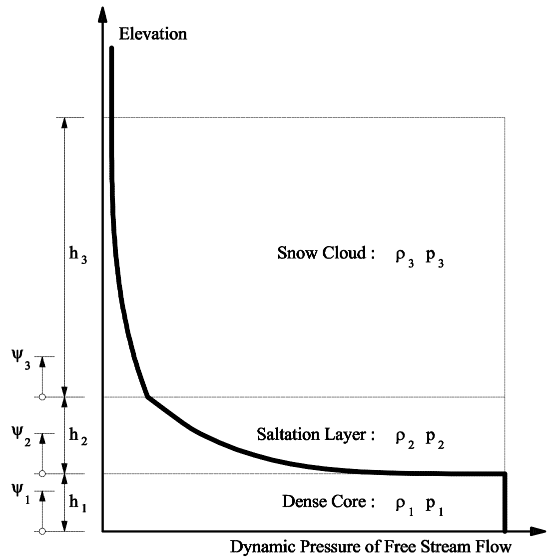

Figure 2. Schematic diagram of the DPOFSF distribution in a snow avalanche.

6.2 *Point load*

It is well known that avalanches often bring with them a lot of other material than snow. Logs are still not any problem in Iceland but boulders and earth material can be. The two catastrophic avalanches in 1995 in West fjords Iceland brought a lot of earth material down and in the village Súðavík two boulders of several cubic meters were found roughly 200 m above the buildings. It was therefore obvious that stones and boulders must be taken into account. However it is almost impossible to estimate the size of stones that could be carried by snow avalanches. The authors however found it reasonable to calculate the load due to stones at least 50 cm in diameter. It is 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. The ? coefficient was defined as the reduction factor for the speed of material at the tail of an avalanche. Here the value was set to ?=0.8.

6.3 Drag coefficient

The drag coefficient C describes the total load acting on a structure and it varies in relation to the shape of the structure and kind of material striking. The drag coefficient is not very well known for avalanches but by back calculating the coefficient from previously studied avalanches it is being improved. It has been noted (Norem, 1990) that the Reynolds number (Re) can vary a lot depending on the avalanche itself; when it is coming to halt Re can be in the range 0.1 to 4 but it can also be in the range of 4 to 1000. It is expected to lie in the range of 4 to 1000 for the transmission lines and the drag coefficient will then lie in the range of C=1 to 4. At the moment of impact, the C coefficient for the core is at least 2. Research at Ryggfonn in Norway indicates that the C coefficient is close to 2 for the dense core of avalanches. Concerning the load on conductors from the dust cloud, the coefficient is somewhat lower. The authors have chosen C=2.0 for rectangular form and C=1.5 for circular form for dense core and for powder- and saltation layer wind standards should be used.

6. HEIGHT OF SNOW COVER AND AVALANCHES

According to IMO the 200 year height of snow is in the range 0.90 to 1.70 m at the nearest weather stations. The height of snow cover in the mountains is higher and the authors estimate it 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 is assumed to be in the range 1.0 to 2.0 m.

The thickness of the avalanche that hit the village Flateyri in 1995 indicates that the height of the dense core was less than 3 m. Research from Ryggfonn Norway indicates that the height can be in the range from 1.8 to 3.7 m. Here we assumed that the height 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.

7. EPILOG

The building of foundations and erection of the towers (except avalanche towers) started in 2005. At present the plan is to raise the avalanche towers (Y-tower) the fall 2006 and the winter 2006-2007.

Figure 3. Foundation of one of the Y-towers in Áreyjadalur. The view is up the valley; the foundations of other towers in both of the lines can be seen. The kid leaning at the foundation is about 1.1 m tall. Photo: Árni Jónsson 16/7 2006.

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