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Avalanche risk along a 420 kV transmission line in Iceland

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ABSTRACT

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

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

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

1. INTRODUCTION

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

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

2. CALCULATION OF RISK AND DESIGN LOAD

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

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

2.1 Climate and snow conditions

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

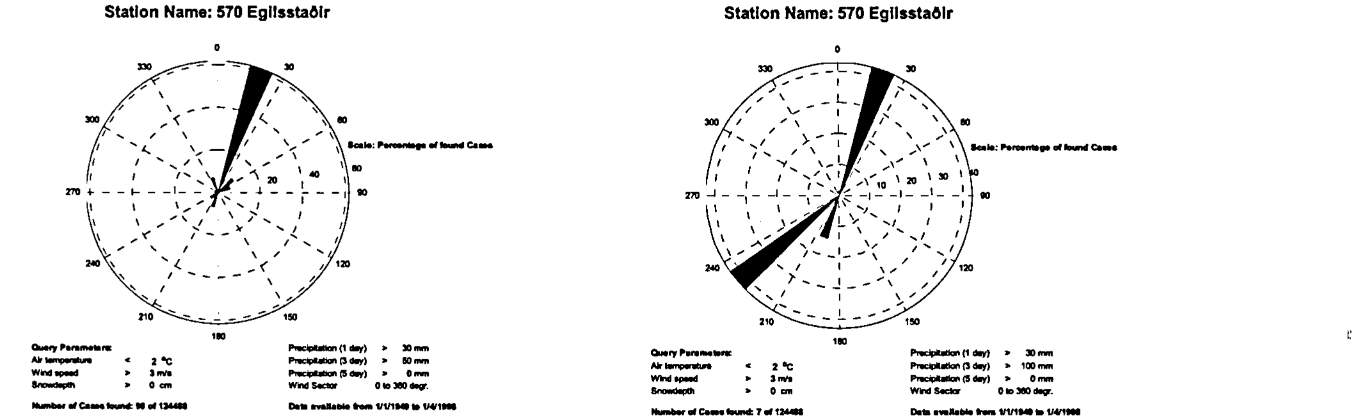
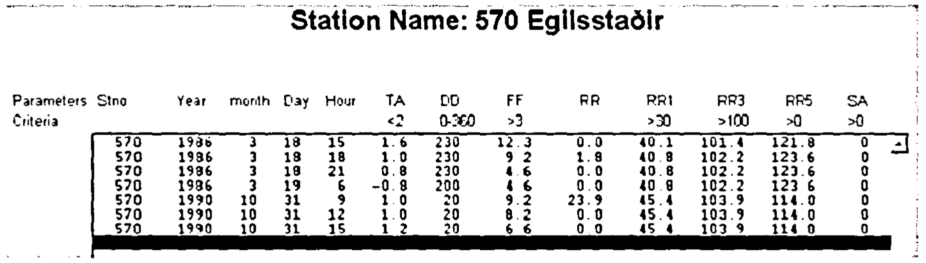


Figure 2. Left drawing gives wind dominating directions during snowfall in the mountains, right drawing gives wind directions with extreme snowfall in the mountains; meteorological statistics for Egilsstaðir during the period 1949–1998, data from the Icelandic Meteorological Office (IMO).

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

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



Station Name: 570 Egilsstaðir

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

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

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

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

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

2.2 Calculation of runout distances and velocity

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

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

2.3 Security for the transmission lines

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

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

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

2.4 Determination of design load

Snow avalanches

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

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

where:

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

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

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

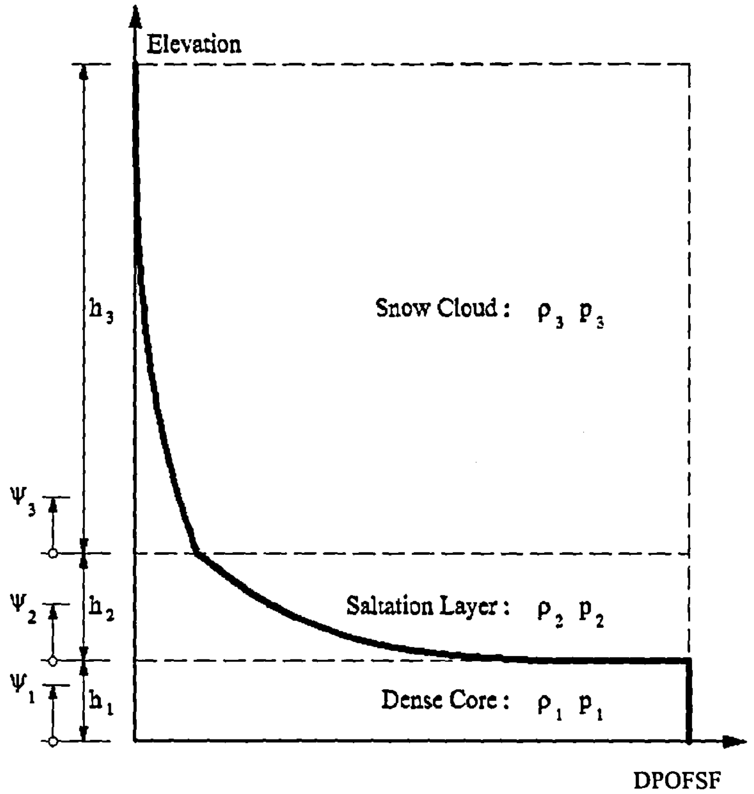


Figure 4. Schematic diagram of the DPOFSF distribution in a snow avalanche.

2.4.1 Drag coefficient and point load

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

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

2.4.2 Snow thickness on ground

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

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

3. CONCLUSIONS

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

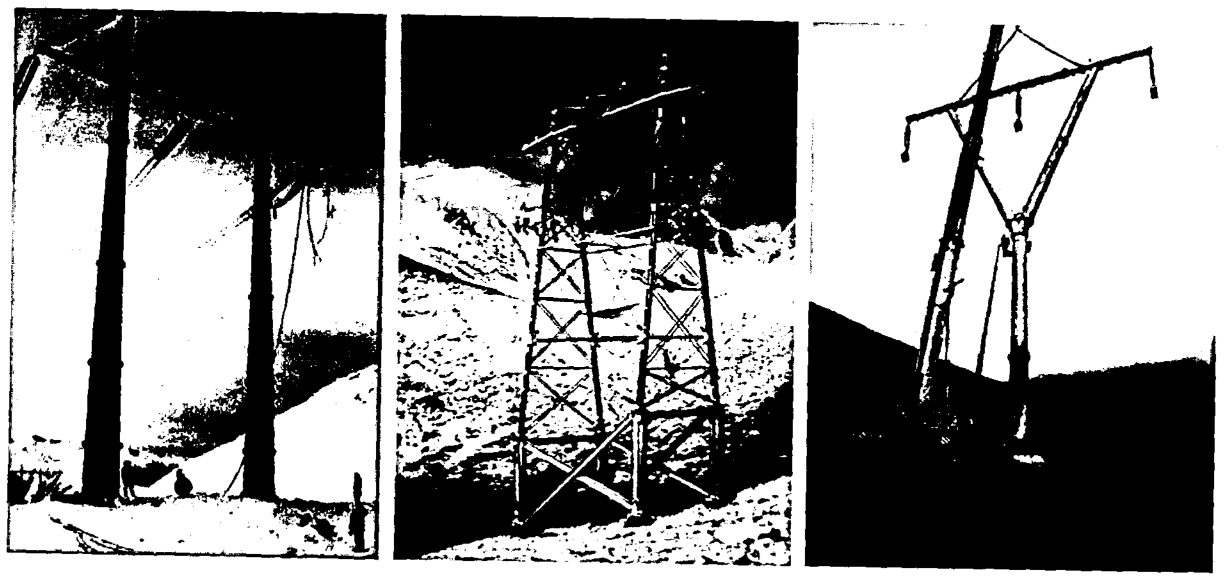


Figure 4. Different types of "avalanche" masts, to the left the French type used in Western Norway, in the middle a local type used in Western Norway and to the right the erection of one of the avalanche towers in Áreyjadalur (photo: Línuhönnun 2006).

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