SNOW CREEP PRESSURE ON MAST CONSTRUCTIONS

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ABSTRACT

In Norway snow-creep quite often causes damage on mast constructions on hillsides exposed to deep snow-cover. An extensive snow-creep measurement program has therefore been carried out for different constructions at NGI's snow and avalanche research station in Grasdalen during the period 1975 to 1990.

Examples from power-line masts and ski-lift masts are shown to illustrate the snow-creep pressure problem. The aim of the research project is to be able to draw up guidelines for the design of masts in snow-creep exposed areas.

INTRODUCTION

In Norway the main energy source is hydro-power. As most of the hydro-power plants are situated in the mountains the electricity is transported with power-line masts through the mountains to the cities. Helicopters are normally used for the construction works, because of difficult terrain. The weight of the material and the helicopter capacity is therefore important. Quite light lattice towers are preferred from this point of view. These are normally only designed for wind forces and ice loads.

Winters with deep snow cover have caused a lot of damage to the Norwegian power-line masts and lattice towers. The winters 1988-89 and 1989-90 were both winters with extreme amounts of snow in western Norway. Snow depths between 10 and 15 m were reported in areas with wind-accumulated snow. Damages on lattice towers and power-line masts occur due to snow-creep pressure, avalanches and also just because of the weight of the snow.

THE GRASDALEN PROJECT

There is very little research done, and therefore little data, on snow-creep pressure against mast constructions. In 1975 NGI was awarded a research contract from the Norwegian State Power Board to find criterias for dimensioning

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masts exposed to snow-creep. In 1975 a tubular mast with 0.42 m diameter was erected at a 25° steep slope at NGI's snow and avalanche research center in Grasdalen in western Norway (Fig. 1). A second smaller and more flexible mast with 0.22 m diameter (Fig. 2) was erected in 1983 about 10 m south of the large mast. Both masts were instrumented with strain gauges to determine the moment in different sections.

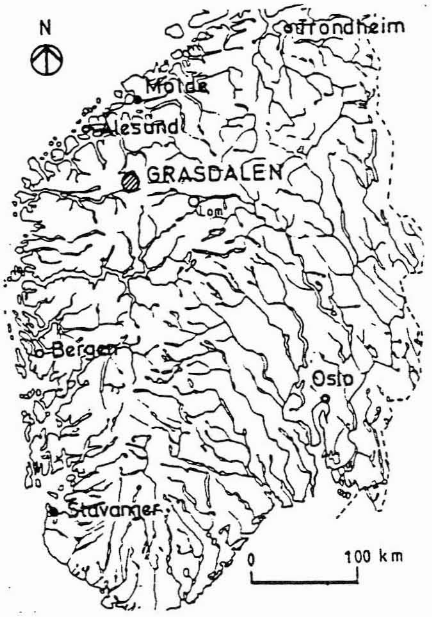

Figure 1 Map showing the position of the research field at Grasdalen

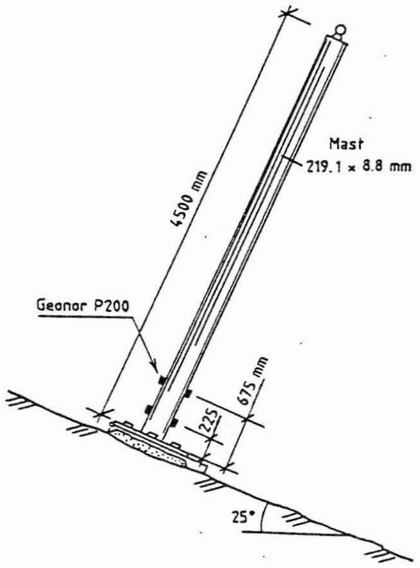

Figure 2 The small mast at Grasdalen

These stresses can easily be transformed to snow-pressure distributions. Above the masts the snow glide between the snow-pack and the ground was controlled with glide shoes. The measurements showed that the snow glide was negligible. The snow properties (snow depth, density, temperature etc.) were measured twice a month.

In the winter of 1988/89 the small mast failed when the snow depth was about 6 m and reached over the top of the mast. At the time of failure the moment at the bottom of the mast was about 150 kNm which corresponds to an evenly distributed load of 15 kN/m. The average density of the snow-pack was about 400 kg/m^3. On the same occasion the moment at the bottom of the large mast was about 340 kNm and the evenly distributed load was 30 kN/m. The steel of the large mast was close to the yield point.

THE CHAIR-LIFT AT THE STRYN SUMMER SKI CENTER

The first results from the Grasdalen project were used for dimensioning a chair-lift at the Stryn summer ski center in 1978. The summer ski center is just 7 km away from the Grasdalen research field. The slope is about 25°, just as at the research field in Grasdalen. The measured values from the research field were extrapolated and these indicated the need for a steel mast that was 1 m in diameter at the bottom and then linearily decreased to 0.5 m near the top. The chair-lift was built in 1987 and designed for 8 m snow depth. In 1989 the maximum snow depth was 7 m and there were no damages registered damages on the chair-lift masts. In 1990 one of the masts failed for a snow depth of about 10 m. The moment at the bottom of the mast would then have been about 100 % higher than the mast was dimensioned for. It is assumed that there was no glide between the snow-pack and the ground. A back calculation indicates that the moment at the failure occasion must have been about 3000 kNm which corresponds to an evenly distributed load of 70 kN/m.

The mast was temporarily repaired for the summer ski season 1990 by extending the concrete foundation and moving the mast 40 cm up-gradient. Looking back, it is clear that in 1978 when the masts were dimensioned the basis for the load assumptions was too thin. The Grasdalen project had just started and very little data was available because of a period of low-precipitation winters with snow depths below normal. At the actual area, the assumption of the snow depth had to be based on information from the nearby station at Grasdalen, from local observations and few representative meteorological data.

RESULTS AND CONCLUSIONS FROM THE GRASDALEN PROJECT

From the Grasdalen project and from other practical examples we found that:

1. The maximum load is at the bottom of the mast (Fig. 3).

Diagrams of the load distribution show an increase in pressure beneath the surface. Between one and two meters below the surface, the pressure increases slowly up to a constant value which continues to the bottom of the mast.

2. At a given slope with snow-creep pressure and no glide in the snow-pack there is a good correlation between $\bar{\rho}gh$ (snow-density x snow depth) and the load on the mast (Fig. 4).

This means that the "heavier" the snow-pack is, the higher snow-creep pressure can be expected.

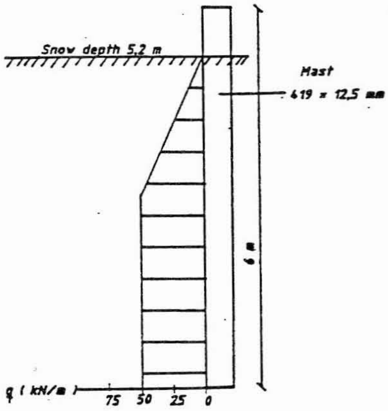

Figure 3 Typical load distribution on the large mast in Grasdalen (19.04.90)

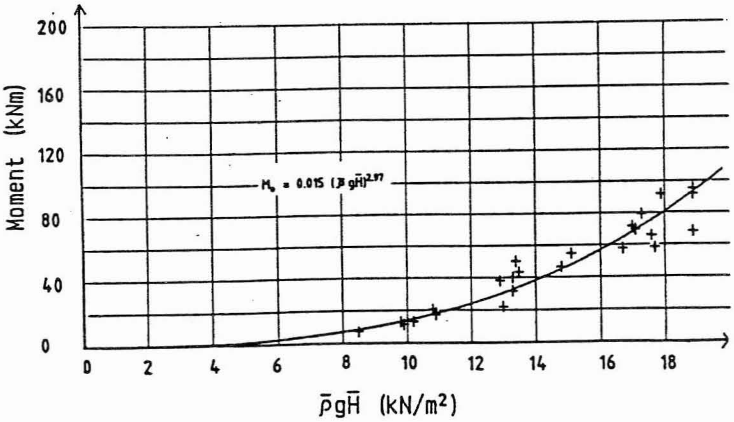

Figure 4 Maximum moments in the large mast (1984-87) as a function of $\bar{\rho}gh$

3. The snow-creep pressure increases gradually throughout the winter and reaches it's peak when the snow-pack is 0° C isothermal (Fig. 5).

Increasing air temperatures in spring warm up the mast and decrease the measured stresses.

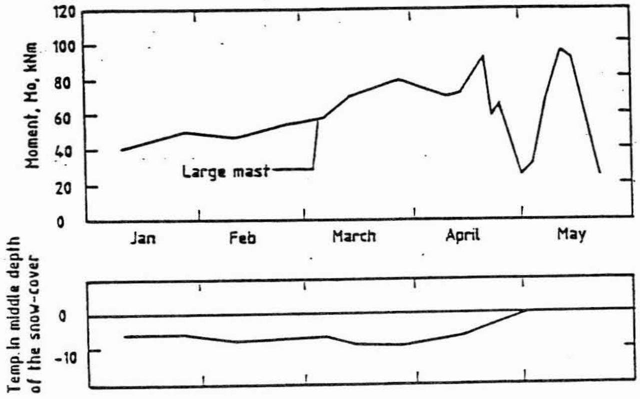

Figure 5 The variation of maximum moments on the large mast with the temperature in the middle depth of the snow cover during the winter 1984

4. Winters with equal amounts of snow but with milder climate give higher loads on the masts due to the fact that the snow-creep pressure rate is higher when the snow is warmer.

5. The snow-creep pressure load seems to increase with the square root of the diameter (Fig. 6).

This correlation needs to be examined further.

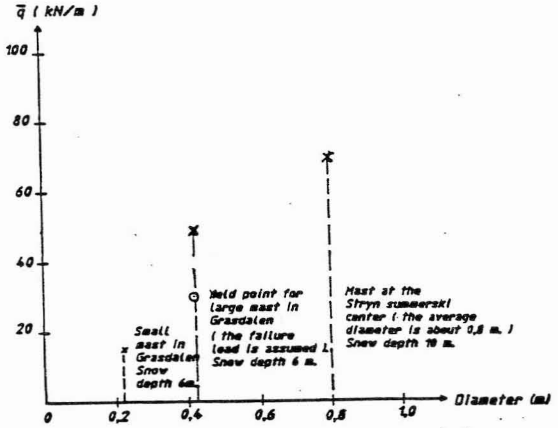

Figure 6 Failure loads for different mast diameters at a 25° steep slope

It is difficult to compare data from Norway's climate with data from areas with more continental climate, since Norway has a different type of snow. Generally the results from the project showed that the snow-pack has a higher density than found in the Alps. This is due to the fact that these constructions are located maximum 1000-1500 m a.s.l. where the climate is milder and the snow-pack more humid. The coastal climate has also contributed to this phenomenon. Therefore the Swiss regulations for calculating snow defence structures often give too low values for Norwegian conditions.
Some of the results from the Grasdalen project have already been taken into account by the Norwegian State Power Board.

To prevent snow-creep pressure damages the most exposed lattice towers have been concreted around to a circular shape the first 3 to 5 m above the ground. The diameter is 75 to 100 cm. For new constructions in areas exposed to snow-creep pressure the lattice towers are put on top of a 3 to 5 m high circular reinforced concrete construction. The philosophy behind this is that the major snow-creep forces are on the first few meters above the ground. There has not been reported any snow-creep pressure damages on these constructions.

Guidelines for dimensioning power-line masts on the basis of research (the Grasdalen project) and experience are now being prepared by NGI.

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