Design Criteria for Cylindrical Masts Exposed to Snow Creep Forces

Jan Otto Larsen, Krister Kristensen
Norwegian Geotechnical Institute, P.O. Box 3930 Ullevaal Hageby, 0806 OSLO
(J. O. Larsen has a temporary address at the Norwegian University of Science and Technology, Department of Geotechnical Engineering, 7034 Trondheim, Norway)

ABSTRACT. Based on 23 years of measurements of snow creep forces on cylindrical masts, a relation between the pressure and snow parameters as snow depth, density and temperature, has been established. The long observation period has made it possible to find series of pressure values which have been used to develop an empirical model. In the model, the pressure at different depths in the snowpack can be calculated by factors which depend on the total snow depth. Long term observations on masts with different diameters, have also made it possible to estimate the influence of mast diameter on the pressure. Finally, an inclination dependent factor is taken into account.

THE SNOW CREEP PROJECT

The project has been carried out to investigate the forces of snow creep applied to different types of fixed constructions on a snow covered slope with an inclination of about 25° The experiment site is on a slope consisting of rock slabs at 1200 m a.s.l. below the Grasdalen glacier, close to NGI's research station Fonnbu, Grasdalen, Western Norway Larsen et al. (1989) and Larsen (in press). The aim of the project has been to develop design criteria for masts and other constructions exposed to snow creep on snow covered slopes.

OBSERVATION METHODS

The installations consist of two tubular steel masts of 6 m and 4,5 m height. The taller mast, erected in 1975, has been a part of the project for 21 years The shorter mast was erected in 1983, and broke due to the high snow pressure during the winter 1988/89.

The constructions are fitted with opposing pairs of Geonor vibrating wire strain gauges, that are connected to data loggers situated in a steel tower near by. For more technical specifications refer to Hansen (1980) and Larsen et al. (1989).

In addition to measuring the strain in the constructions, snow investigations have been carried out to record the properties of the snow. The standard snow investigations have been done in accordance with the ICSI (1990) snow classification standards.

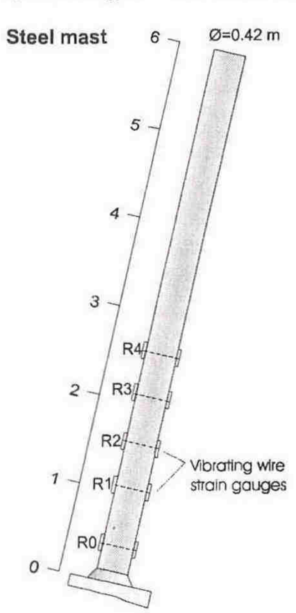

Figure 1. The 6 m high mast.

During the winter 1996/97 a temperature logger/sensor was placed on the ground at the foot of the construction, and another in a connector box above the snow surface at the steel tower. Other weather parameters were measured at NGI's field station at the valley floor 270 m below the test site.

Snow gliding has been observed at the test site, but this does seem to have any significance with regards to the pressures recorded as this have only occurred on special occasions in the late winter, and after the forces have exceeded peak values.

A cylindrical chair lift tower situated at similar elevation and aspect as the structures at NGI's test site a few kilometres to the south, has also been studied. The tower broke as a result of creep pressure during the winter of 1990. The design of the tower was based on preliminary observations at the NGI test site.

The fracture occurred because the lift manufacturer did not believe in the load estimates given. However, the loads were even higher than the estimates because of unusual snow conditions with 10 m snow depth and a long creep period due to early isothermal snowpack Larsen (in press). Back-calculation of the forces acting on the tower, have been used to supplement the data from NGI's test site.

SNOWPACK, WEATHER AND CREEP FORCES.

The measurements seem to indicate that as long as the snowpack is cold (<0°C), the temperature of the snow is of less significance to the pressure than the increase in total water equivalent of the snowpack. The highest pressures occur normally in the transitional period when temperature in the snow approaches 0°C throughout the snowpack. Figure 2 shows the development of the snow creep pressure on the steel mast related to snow and weather conditions.

As can be seen from this graph, the pressure acting on the structure in the end of the winter has fairly large daily fluctuations due to changes in the air temperature from night to day. In addition, warming of the steel by direct sun radiation, and subsequent melting around the mast, has a significant effect on the pressure. Prolonged periods with cold temperatures and no sun after earlier warm periods in the spring, can however increase the pressure towards the peak values for the winter.

In figure 2, daily variations can be seen as an oscillating curve from the end of April. A marked increase in the pressure during a cold period following a relative warm period is evident in early May.

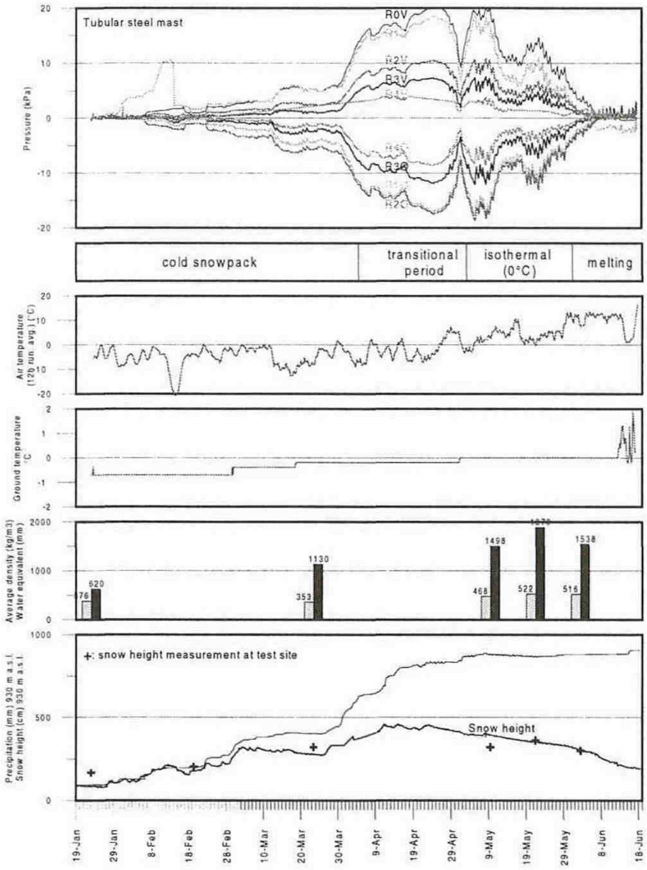

Figure 2. Development of snow creep pressure on the steel tube, weather and snow conditions in the course of the winter 1996/97.

DESIGN CRITERIA

For the development of design criteria for mast constructions, observations from late winter when the peak pressures occur have been used. Peak pressures normally occur in the 0° C isothermal snowpack in late winter

To find the pressure dependence related to the diameter of cylindrical masts, a comparison between the acting pressures on the 42 cm diameter tall mast and the 22 cm diameter short mast, has been done. As mentioned before, the shorter mast unfortunately broke during the winter 1989 because of overloading, and was not re-erected. The relatively short measurement period from 1983 to 1989 gave however some indication of the diameter influence. The smaller diameter mast was situated at the same site only 9 m from the tall mast (Larsen et. al. 1989).

Diameter dependency

Comparison of measurements for the masts exposed to similar snow conditions gave a diameter dependency which can be expressed by factor f_β:

$$\mathbf{f_\beta = d^{0.63} + 0.42} \qquad (1)$$

$\mathbf{f_\beta}$ = diameter pressure factor
d = tube diameter (m)

In figure 3 below the relationship between the «diameter pressure factor» and diameter of the mast is illustrated.

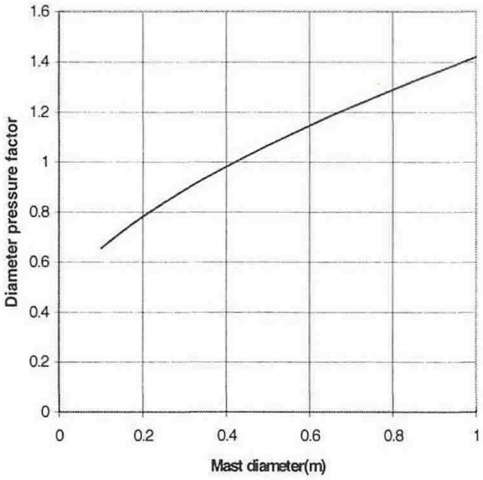

Figure 3. Diameter pressure factor f_β as a function of the mast diameter.

Snow depth dependency

The density of the snow normally increases with snow depth But the maximum density in a seasonal snowpack will normally not exceed 600 kg/m^3, and the snowpack will become increasingly homogeneous towards the late winter. To be able to calculate the design pressure at a specific level in the snowpack the density distribution has to be taken into account. A pressure index related to the snow depth is given in figure 4. This snow depth index is used in expression 2 below to calculate the snow pressure at different depth levels in the snow.

$$\mathbf{p = K * f_\beta * z^e} \qquad (2)$$

p = pressure at a depth **z** (kN/m)
K = the correlation factor shown in figure 5
z = depth (m)

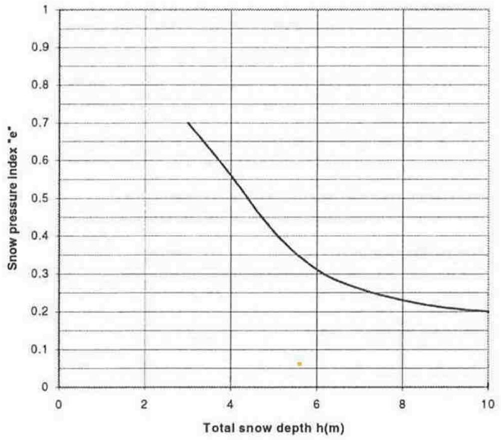

*Figure 4. Snow pressure index e dependency on total snow depth **h**.*

Inclination factor

Expression 3 gives the snow pressure against a mast at a certain level for a slope at 25° (the inclination at the test site). To correct for variations in the inclination φ, the inclination factor $\mathbf{f}_\varphi$ has to be taken into account:

$$\mathbf{f}_\varphi = \sin\varphi / \sin 25° \qquad (3)$$

Correlation factor

The correlation factor **K** is dependent on the total snow depth **h.** Values for **K** which fit the results from our measurements are given in figure 5.

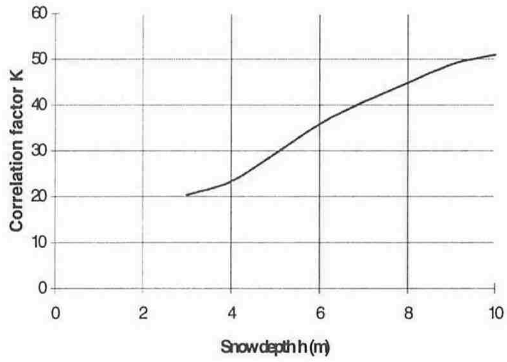

Figure 5. Correlation factor K dependency on total snow depth h.

Total snow creep pressure

To find the total snow creep pressure against a mast, the calculated pressure has to be integrated over the total snow depth:

$$\mathbf{R} = \int \mathbf{p}\,(z)\ \mathbf{f}_\varphi\,\mathbf{dz} \qquad (4)$$

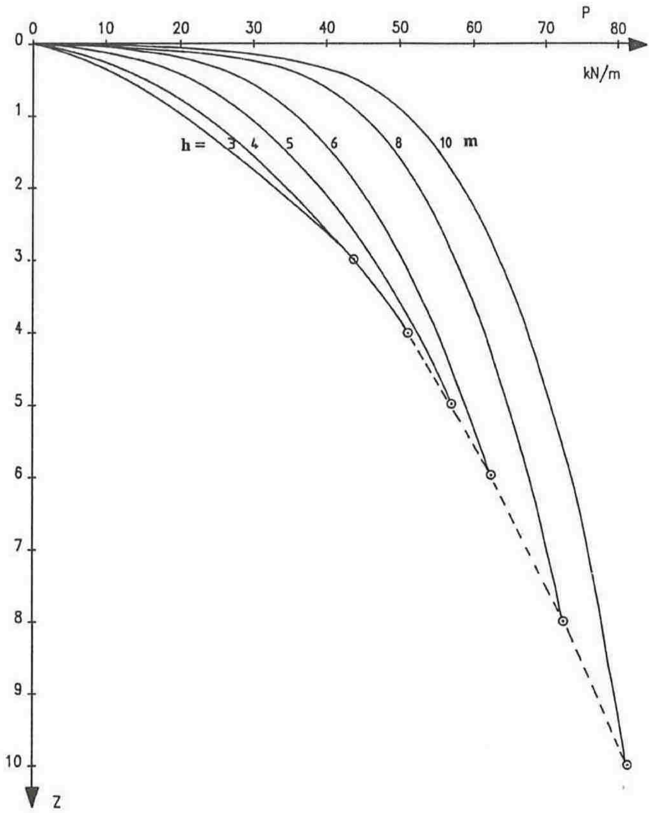

Figure 6. Snow pressure distribution for different snow depths. (In this case the mast has a diameter of 0.42 m, and is erected on a 25° steep slope).

Figure 6 shows the exponential pressure distribution for a 42 cm mast at a 25°steep slope at different snow depths **h**.

DISCUSSION

Design criteria for snow creep pressure on cylindrical masts with diameters ranging from 0.3 m and 1.0 m can be estimated by the proposed expressions. These are based on data from the measurements through a long test period. There are, however, limitations to the data base, as it has relatively few measurements for snow heights above 5 m, and few measurements on masts with diameters greater than 42 cm.

The proposed method gives an upper limit of the pressure measured in the field under environmental conditions typical for the Norwegian west coast climate. For other climate zones, the observed pressures may be different, and it is reasonable to expect lower pressures in continental climates than those found in the coastal mountains in Norway.

CONCLUSION

The method of using the measured data from long time series for developing design criteria gives a good estimate of the expected pressure. The limitation lies in the fact that only masts with three different diameters, 22 cm, 42 cm and 100 cm have been tested. As this method is time consuming in practical use, a more user friendly numerical model based on the present data should be developed in the future.

ACKNOWLEDGEMENTS

The authors wish to thank Statnett, the Norwegian Power Grid Company for funding of the project. In addition, support in field work and in discussions from the colleagues at the NGI Environment and Avalanche department is gratefully acknowledged.

REFERENCES

Bader, H., Haefeli, R., Bucher, E., Neherer, J., Eckel, O., Thams, C. and Niggli, P. 1939. Der Schnee und seine Metamorphose, Beitrag zur Geologie der Schweiz. *Geologische Serie, Hydrologie, Lief.* **3**.

International Commission on Snow and Ice of the International Association of Scientific Hydrology, 1990 *The International Classification for Seasonal Snow on the Ground.*

Hansen S. B., 1980. Resultater av målinger på rør vinteren 1978/1979 (Results from measurements on tubes the winters 1978/1979). *NGI-report* **75420-4**, Norwegian Geotechnical Institute, Oslo , Norway.

Kristensen, K. 1998. Snow Creep Project. Field measurements winter 1996/97. *NGI-report no.* **581300-7**, Norwegian Geotechnical Institute, Oslo, Norway.

Larsen, J.O. 1982. Snøens sigetrykk mot konstruksjoner i bratt terreng (Snow creep forces on constructions on steep slopes). *NGI-report.* 75420/**58110-1**, Norwegian Geotechnical Institute, Oslo, Norway.

Larsen, J.O., McClung, D.M. and Hansen, S.B. 1985. The temporal and spatial variation of snow pressure on structures. *Canadian Geotechnical Journal* **22** (2), 166-171

Larsen, J.O., Laugesen, J. and Kristensen, K. 1989. Snow-creep pressure on masts. *Annals of Glaciology,* **13**, 154-156.

Larsen, J. O., 1991, Snøens sigetrykk på konstruksjoner i bratt terreng. (Snow creep forces on constructions at steep slopes). *NGI-report* **581300 -3**, Norwegian Geotechnical Institute, Oslo, Norway.

Larsen, J. O., Snow creep forces on masts, *IGS meeting in Chamonix, France, May 26 - 30. 1997.* In press.

McClung, D.M., Larsen, J.O. and Hansen, S.B. 1984. Comparison of snow pressure measurements and theoretical predictions. *Canadian Geotechnical Journal.*, **21** (2), 250-258.