DEPENDENCE OF GROUND SNOW LOADS ON ELEVATION IN WESTERN CANADA

by

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ABSTRACT

Provincial and territorial snow course measurements and the Atmospheric Environment Service (AES) snow depth measurements were combined and analyzed using Geographic Information System (GIS) software to study the spatial variation of design Ground Snow Loads in mountainous areas of western Canada. With careful attention to mesoscale climate processes, physical models were developed that described the regional variation of snow loads with elevation dependency for regions of homogeneous snow climatology. Valley and mountain range specific regression relations were derived that were used to normalize return period snow observations with respect to critical or reference elevations. Interpolation procedures were applied to determine site specific or grid point snow loads. Further work is needed to better quantify uncertainties associated with the snow fields and snow data. The results of the study provided an improved methodology for determining Ground Snow Load recommendations supporting the National Building Code of Canada in mountainous areas.

INTRODUCTION

The accumulation of snow can pose significant loads on buildings and structures in cold climates. The National Building Code of Canada (NBCC) provides minimum design snow loads for roofs (Associate Committee on the National Building Code, 1990). The magnitude of the Ground Snow Load (GSL) that is used to calculate the roof snow load distribution is very important, both in relation to the probability of roof failures and to the cost of building construction. The load provisions of the NBCC that are used to convert ground snow loads to roof design snow loads account for many factors. These include: local climate, removal of snow from roofs by wind action, the unbalanced loads caused by drifting, load shifts that occur due to sliding of snow on sloped roofs, and additional loads from rain absorbed into the snowpack.

Ground snow loads can be estimated using recordings of snow depth (Equation 1) or water equivalents (Equation 2). Traditionally, in Canada, the return period snow load has been calculated as the product of the 30-year return period snow depth and an average or seasonal density. The 1990 NBCC ground snow load recommendations (Newark et al, 1989) were based on AES snow depth observations from 1618 sites. Snow depths are measured on a daily basis at the principal stations and month-end at volunteer climatological stations, which comprise the majority of the data. In recent years, digital snow course measurements have been obtained from provincial and territorial agencies in western Canada and added to the snow depth measurements. The additional data, which includes a number of high elevation sites, has recently allowed detailed mesoscale analysis of Ground Snow Loads in mountainous areas. Typically, the snow depth observations are representative of the lower level or valley locations while the snow course observations are more representative of higher elevation locations.

CALCULATION OF GROUND SNOW LOADS

The equation used to calculate the snow load , SL, at a station is as follows:

$$SL = g\ (S_{30}\rho m) = .0000981\ (S_{30}\rho m) \quad (1)$$

where SL is the ground snow load expressed in kiloPascals (kPa), g is the acceleration due to gravity, ρ is the average seasonal density of the snow pack expressed in Kg/m^3, S_{30} is the 30-year return period maximum

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snow depth in metres, and *m* is the melting index. The melting index, *m*, is a factor that is used to adjust monthly observations to comparable daily observations and is especially important for regions with mild winter climates where snow thawing episodes are frequent. When water equivalent depth observations, W_{30}, are available and given in mm and ρ_w is the density of water, the snow load can be calculated as:

$$SL = g\,\rho_w W_{30} 30 \quad = \quad .00981\,W_{30} \qquad (2)$$

Probabilistic models can be used to obtain 30-year return values of the ground snow load using annual maximum snow depth or water equivalent observations. For the 1990 NBCC, the 30-year return value snow depths were calculated using a Gumbel Type 1 extreme value distribution fitted according to the method of moments (Newark et al, 1989).

When using monthly data to estimate annual maximum snow loads for the Gumbel Type 1 distribution, it is important to screen for missing data. A method was used in calculating the 1990 NBCC snow loads that identified and eliminated from consideration those years when too much data was missing (Newark et al, 1989) . A minimum of 7 acceptably complete years of observations were required for calculation of the snow loads. When snow course observations were added to the database for the current analysis, observation years were eliminated if data was missing during periods of maximum snow pack. A few higher level snow course sites also were eliminated from consideration after it was determined that the snow observation program likely ended too early to capture the maximum snowpack.

Snow Densities

An average seasonal snow pack density of 200 Kg/m^3 has been used in past codes as a reasonable approximation in the maximum load situation (Boyd, 1961; Leslie et al, 1987). While somewhat lower than measured values, it was justified on the argument that the maximum depth of snow would occur immediately after a deep layer of new, lighter snow has fallen on top of the old (Boyd, 1961). The 1990 NBCC delineated regional values of a seasonal average snow pack density, with greater detail provided for British Columbia. While the current analysis employed the regional values of Newark et al. for lower elevations, adjustments were made for the higher elevation sites based on densities calculated from snow course data. Unfortunately, the scope of this paper does not allow for greater discussion of snow densities.

ELEVATION AND SPATIAL INFLUENCES

Ground snow loads exhibit significant variability from one climate region to another, with elevation, and from one winter to the next. While some studies have investigated the effects of elevation on ground snow loads in mountain climates (e.g. Claus et al, 1984), few of these have been concerned with climatological criteria to determine geographical areas where the specific elevation functions apply. Studies from Europe (Gabl, 1989), Japan (Takahashi et al, 1992), and Canada (Newark et al, 1989) have attempted to define zones for snow load variation with elevation.

Work on the elevation and spatial influences on snow loads has progressed considerably in Canada since the 1990 NBCC and has resulted in improved estimates of ground snow loads in the mountains of western Canada. The use of GIS software and the incorporation of snow course data with the existing snow depth information have contributed to a better understanding of the regional climatology of snow.

The calculated 30-year return period snow load for both snow course water equivalent measurements and the AES snow depth measurements were plotted against elevation for each observation location. Least squares regression analyses were calculated and the goodness of fit, r^2, was determined, where r is the regression coefficient. While the 1990 NBCC ground snow load calculations used a linear relationship to describe the elevation effects for practical reasons, other studies have recommended the use of quadratic relations. Both types of curves were fitted for this study. While the quadratic relations gave high degrees of fit in climatic regions where mountain range upslope processes prevailed, such as west facing slopes, linear relations were suitable for regions where downslope processes prevailed.

Regions with similar snow pack characteristics were delineated using GIS software and defined on the basis of plotted relationships, similar wind flow and climate processes, trial calculations, and geographical similarity. Topography was used to identify significant mountain features that might alter or influence weather patterns. It was found that snow loads increased more rapidly with elevation for the upslope side of mountain ranges than for the downslope side. Figure 1 illustrates the influence of elevation on snow loads to the west and east of the Arrow Lakes valley in British Columbia. To the west, snow loads vary linearly with elevation on the lee or eastern slopes of the Monashees but increase more rapidly with elevation (quadratic relation) to the east as the Selkirks are ascended. The data indicated that snow loads varied more slowly with elevation for mountain ranges located further inland than for coastal ranges. Snow loads also increased more slowly with elevation for the colder mountain ranges located further north. The influence of elevation on snow loads was greatest for the highest ranges and for mountains extensive in length or area. In most regions, the regression relationships between elevation and snow loads were significant, with r values typically above .90 and values above .95 not uncommon.

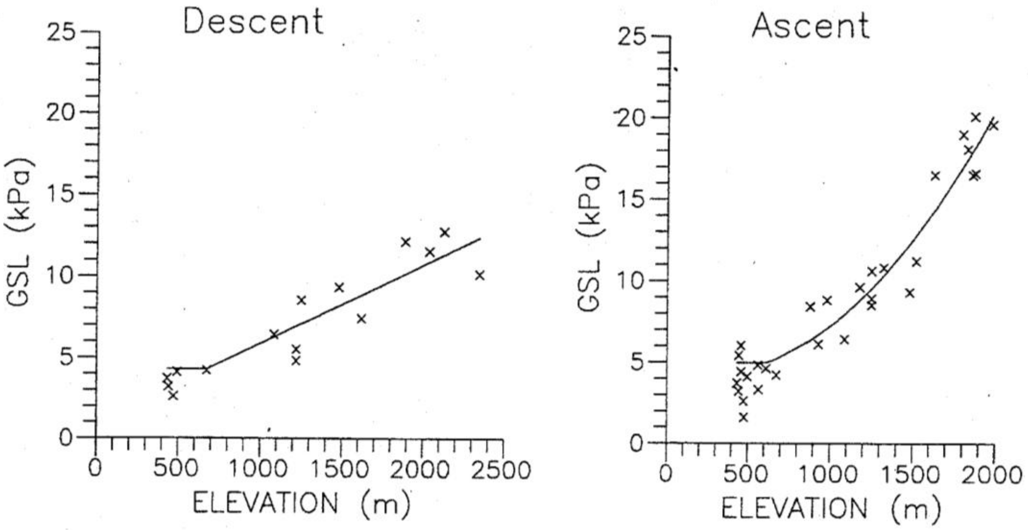

Figure 1. Variation of Ground Snow Loads with elevation as mountain ranges are descended and ascended. On the left, snow loads increase linearly as the Monashees are descended but, on the right, increase more rapidly (quadratically) as the Selkirks are ascended.

As shown in Figure 1, elevation often does not noticeably influence snow loads at the lowest elevations (valley bottoms), but does influence snow loads above a critical level of about 600m. Local influences, other than elevation, appear to have greater influences on snow loads at valley bottom elevations. Regional regression relationships were used to describe the increase of snow loads for all elevations above the reference level. The regional reference level can be compared to a climatological freezing level, where snow on the ground tends to accumulate and persist above an average freezing level over the course of a winter.

Error Analysis and Interpolation of Ground Snow Loads

The snow loads at any point can be calculated using nearby climatological stations, by normalizing these snow loads with respect to a reference elevation, and then smoothing or interpolating the normalized values using an uncertainty-weighted moving-area average. The error analysis and interpolation procedures described by Newark et al. were used to minimize the uncertainties associated with the snow field and related values.

Several sources of uncertainty influenced the calculated value of the ground snow load. These included the statistical uncertainties associated with measurement of snow depths and site-representative uncertainties. Model uncertainties included the density assumptions used to transform snow depth measurements to snow loads, the probabilistic distribution function or model used, and unknown regional variability. The interpolation scheme also considered the distance of stations from the point of interest and allowed a subjective climatological weighting factor of magnitude 0 to 1 to be applied for each observation site relative to the point of interest.

CONCLUSIONS

Snow course and snow data measurements were analyzed using GIS software to define valley-specific relations that described the variation of snow loads with elevation. The statistical relations derived were significant, with regression coefficients typically above .90 and values above .95 not uncommon. The results provided an improved methodology for determining GSLs supporting building codes in mountainous areas. Further work is needed to describe the influence of elevation and geography on snowpack densities and melting indices. The importance of climate cycles (years with greater snow followed by years of relatively less snow accumulation) appears to be significant and needs to be investigated further. The uncertainties associated with snow data and with the snow fields also deserve further study.

Currently, AES is assembling snow data from a number of agencies and sources in order to develop a digital snow database that will contain longer records, measurements from a greater number of snow observing sites, and, where available, more frequent observations. The additional data will allow better analysis of snow densities and melting indices and better estimation of snow loads at the lower elevations. The longer records should indicate the significance of climate cycles for calculation of extreme value snow values. In all mountainous areas of Canada, where snow loads can vary significantly with small changes in distance or elevation, greater data coverage should result in further improvements to our understanding of the elevation dependency and spatial variability of snow fields.

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