METHODOLOGY FOR ESTABLISHING GROUND SNOW LOADS[1]

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INTRODUCTION

Snow loading is the most severe test of a roof structure in the United States from the northeast to the northwest. Economical structural design in these areas requires a thorough understanding of ground snow loads, but there is a paucity of data available for describing the loads. The majority of the monitoring stations merely measure snow depths with no attempt made to determine the weight of the snow. In spite of this, a country-wide snow load map has been published by the American National Standards Institute (ANSI A58.1-1982). However, in certain areas, the snow loads shown are not appropriate for unusual locations such as the high country, and some territories may have extreme variations in snow deposition. As a result, local jurisdictions and entire state areas have been motivated to initiate and publish their own snow load studies. An investigation of ground snow loads for a region proceeds by: a) identifying and studying the available data; b) adopting and using an appropriate probabilistic model to predict extreme values of the snow loads; and c) spatially extrapolating these loads to give ground loads for all locations within the designated region. The methodology for performing such a study, and the details of the investigation performed for the State of Idaho are described in this paper.

DATA BASE

The Soil Conservation Service (SCS) and the National Weather Service (NWS) are the two principal agencies that gather data on ground snow in the United States. The NWS makes daily snow load measurements at 184 so-called first-order stations, and only daily snow depths are recorded at approximately 9,000 additional locations. The SCS makes monthly measurements of depth and water equivalent (in inches of water) for the accumulated snow. These data are obtained by trained professionals in the Western U.S.; whereas, the agency must rely primarily upon volunteers to take the measurements in the East. The NWS stations are typically located adjacent to towns and cities. Those of the SCS in the Western U.S. are in the remote high mountainous areas, since the information is intended to be used principally to predict annual runoff. The NWS stations are near the majority of the building activity so the construction industry could potentially make use of these data; however, snow depths alone do not yield design loads. The SCS stations vastly outnumber NWS locations in the Western United States.

We encounter a difference in the temporal content of the data when attempting to juxtapose SCS and NWS information. The NWS daily measurements tend to reveal small fluctuations in deposition and ablation; whereas, the monthly SCS quantities do not reflect these changes. It is necessary to select maximum annual quantities for use in a probabilistic model for predicting extreme values. Typically, the NWS quantities peak during January and February, and in contrast, snow packs in the mountainous areas, as characterized by the SCS data, maximize in March and April.

PROBABILISTIC MODELS

The annual maxima obtained from the data base for each station must be extrapolated beyond the historical period of observations. This is done using one of the standard cumulative probability distribution functions (cdf) as a model. The parameters describing the cdf are determined from the data at a given site. The Freshet (Type II) and Log-Pearson Type III are both three-parameter models; whereas, the two-parameter limiting forms of these distributions are the Gumbel (Type I) and lognormal, respectively. Since the cdf extrapolates extreme values from the historical data, it is extremely important that the correct model be chosen by examining the data using measures such as the Chi-square test of fit, the Kologorov-Smirnov test or using probability plot correlation coefficients (Filliben, 1975). For example, predicting the annual extreme water equivalents from first-order NWS sites from the Dakotas to the east coast requires both Gumbel and lognormal distributions (Ellingwood, 1984). The Gumbel distribution is used for Canada (NBCC, 1977; Newark, 1984) and Europe (ISO 4355, 1981); whereas, the lognormal model is employed for nation-wide studies of snow loads in the United States (ANSI A58, 1982). In the Western United States the Log-Pearson Type III distribution is used in California (Nevada County), Idaho, Montana, Oregon, Utah and Washington.

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A value of snow load accumulation with a small probability of being exceeded in any one year is selected from the cdf for design purposes. Annual probabilities of being exceeded which range from 0.01 to 0.04 are used in the United States. The mean recurrence interval (mri) is the reciprocal of the annual probability of being exceeded. Thus, a 50-year mri corresponds to an annual probability of occurrence of 2 percent. It is important to note that during a 50-year period, there is a 63.6 percent chance of exceeding the value designated by the 2 percent annual probability of occurrence.

SNOW DENSITY

The snow depths recorded by the majority of the NWS stations constitute a potentially useful set of design information since these sites are typically located near populous areas. In order to use these data a number of methods have been devised to estimate the snow density. Canada initially adopted a constant specific gravity of 0.192 for all locations and added the maximum 24-hour rain occurring during the winter months (Thomas, 1955). In a similar fashion, the State of Idaho used a value obtained from the mean specific gravity of the 270 SCS stations within the region (0.385). This high density probably is accurate for mountainous locations where the snow compacts throughout the winter, but is not representative for sites where the snow remains on the ground for only a short period. The assumption of constant density does not recognize the fact that snow deposition and density are dependent upon regional climatology. The current approach favored by Canada (Newark, 1984) is patterned after the work by McKay and Findlay (1971) in which density is associated with forest type. This rationale gives mean specific gravities of 0.190 to 0.390 for the non-melt period of the year and 0.240 to 0.430 during the spring-melt interval. The methodology used in the United States involves plotting the 50-year (mri) ground depths against the 50-year (mri) ground loads for the 184 first-order NWS stations. The resulting nonlinear regression curve relating these extreme values was used to predict ground snow loads for the NWS stations where only depths were measured. A fourth approach is reflected in the Colorado study and the current investigation for Idaho, wherein snow course data are analyzed to obtain a relationship between depth and snow load. Colorado utilized a power law obtained from 128 stations within the state, while the current Idaho study uses a bilinear curve developed from over 3,000 SCS stations.

SPATIAL EXTRAPOLATION

The extreme values at all stations within a region form the basis for structural design. This information can be tabulated by station but is of little value to the person required to design for a location that is not near a measurement site. It is more beneficial if snow loads for all locations within the region are extrapolated from the calculated station extreme values. Canada and the United States both display contour maps of ground snow loads. This method seems to work for regions with no extreme terrain features; such exceptional areas are excluded from both national studies. In the Western United States a number of methods have been developed by regional agencies to cope with this problem. The State of Oregon created curves of snow load versus elevation for each county. This makes the standard easy to administer; however, there is a large amount of scatter in the data which makes single-valued relationships difficult to obtain. Another methodology is used by Arizona, California (Placer and Nevada Counties), Colorado and Utah; wherein, ground snow loads are expressed as a function of elevation. A unique relationship is derived from each of the various geographical areas within the region. Normalized ground snow load contours are used by Idaho, Montana, and Washington. For this technique the snow load at each measurement site (in units of force per area) is divided by the elevation of the station to give a quasi-normalized quantity in units of force divided by length cubed. These quantities seem to have no obvious physical significance; however, the effect is to reduce the entire area to a common base elevation. This procedure masks out the effect of the environment on the snow-making mechanism and gives single-valued contours that are impossible to obtain without normalization.

THE IDAHO STUDY

The early snow load study for the State of Idaho (Sack, et al, 1976) included 270 SCS stations and 129 NWS sites. The mean specific gravity of 0.385 obtained from the SCS data, was used with the NWS snow depths to obtain snow loads. The predicted snow loads were accurate for most high elevations, but were conservative for some low-elevation locations. This early study used a 30-year mri. In order to bring the values in line with the national study which used a 50-year mri and to refine the snow loads throughout the state, a subsequent study was initiated.

A total of 514 stations from both SCS and NWS were used for this second study. The 375 SCS stations are composed of 234 from Idaho, 93 from Montana, 30 from Oregon and 18 from Washington. All snow courses included in the study had a minimum of ten years of data. The maximum recorded weights of snow on the ground were selected from records taken during the following snow seasons: Idaho (1927-1983); Montana (1922-1974); Oregon (1928-1972); and Washington (1915-1969). Most of the maxima for these occurred in April with a few exceptions. The annual maximum values of snow-water equivalent for each station were analyzed for various mri using a Log-Pearson Type III model. Snow depth data were available from 139 NWS stations in Idaho (1927-1981), and they were also analyzed for various mri using the Log-Pearson Type III model. The maxima for the NWS data generally occurred during January and February which reflects the usual situation where these stations are located.

For this follow-up study we decided that all NWS snow data should be utilized; therefore, an appropriate specific gravity was chosen. A number of maps were constructed using various values, but the Rocky Mountain Conversion Density (RMCD) was judged to be most appropriate. The depth-snow load relation was obtained by fitting a bilinear distribution to data from 3,000 Western SCS stations with over five years of record. The relationships developed are:

$$P_g = 0.90h \qquad (\text{for } h \leq 22 \text{ in.})$$

and

$$P_g = 2.36h - 31.9 \qquad (\text{for } h \geq 22 \text{ in.})$$

where P_g is the ground load in lb/ft^2 and h is snow depth in in. (note that 1 lb/ft^2 = 47.88 Pa and 1 in. = 25.4 mm). For depths less than 22 in. (560 mm) this gives a specific gravity of 0.175 and for depths greater than 22 in. (560 mm) the specific gravity is variable, but if the line started from the origin it would give a value of 0.444.

The nation-wide study presents a map using a 50-year mri; thus this was the probability of occurrence chosen for the Idaho map. In order to convert to other mri we found that $\bar{X}_{25}/\bar{X}_{50}$, $\bar{X}_{30}/\bar{X}_{50}$, and $\bar{X}_{100}/\bar{X}_{50}$ are 0.952, 0.967 and 1.042, respectively for the Idaho SCS water equivalents, and 0.884, 0.911 and 1.116, respectively for NWS depths ($\bar{X}_N$ is the mean value with a N-year mri).

We elected to use the normalized ground snow loads following the approach established for the state in the 1976 study. The computer plotting program SURFACE II (Sampson, 1978) was used to generate contour maps of normalized ground snow loads. The surface of snow loads is approximated by superimposing a regular rectangular grid of values over the region and interpolating between these points. Typically mesh point values are determined by a two-part procedure. First, the slope of the surface is estimated at every data point, and second the value of the surface at the grid nodes is estimated using a weighted average of the nearest neighboring data points. The user can select from a number of different weighting functions. The grid size must also be specified by the user. Using all 375 SCS data points and the 139 NWS snow depths converted to loads, we created two maps with a grid size of 100,000 ft. These maps used weighting functions of $1/D^2$ and $1/D^6$ Fig. 1 shows an example plot using $1/D^2$). The former is appropriate for relatively flat regions, while the latter characterizes behavior in mountainous areas. By making a composite of these two maps we produced the final snow load map with a 50-year mri for the State of Idaho.

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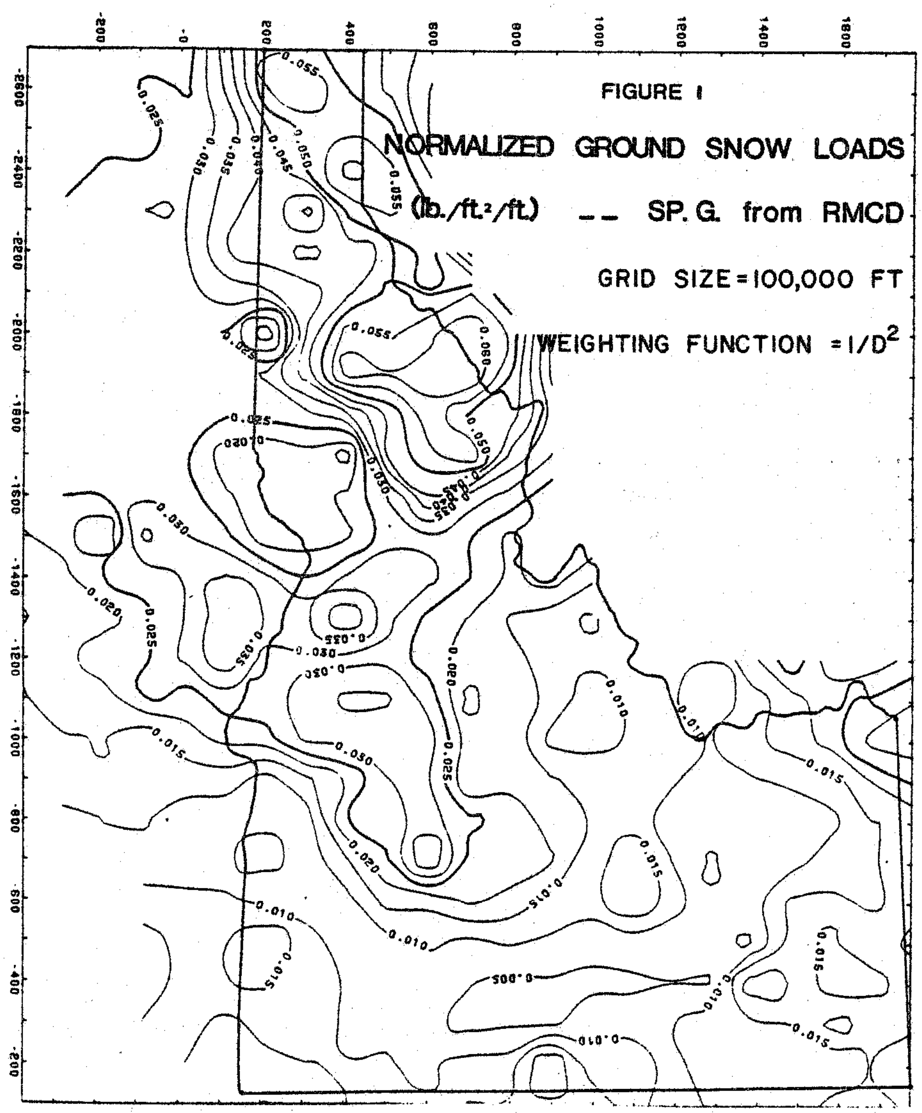

FIGURE 1

NORMALIZED GROUND SNOW LOADS (lb./ft.²/ft.) -- SP.G. from RMCD

GRID SIZE = 100,000 FT

WEIGHTING FUNCTION = $1/D^2$