Design Ground Snow Loads for Ohio

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ABSTRACT

The weight of snow with a mean recurrence interval of 50 years, called the design ground snow load, is used by engineers and planners to estimate the weight of snow that roofs must be designed to support. National maps of ground snow load have small scales, showing little detail at the state level, and present data with apparent inconsistencies. Snow water equivalent data at ten National Weather Service offices in Ohio and adjacent states were examined to obtain a typical density of 0.15 g cm$^{-2}$ for the snowpacks with the greatest snow loads. After critical review of 1948–90 daily snow-depth data, 50-yr return-period snow depths were determined for 55 sites in Ohio. Design ground snow loads were calculated for these sites by applying the density of 0.15 g cm$^{-2}$ to the 50-yr return-period snow depths. Several differences were noted between these results and previous maps. Minimum design ground snow loads specified in Ohio building codes are 5–10 lb ft$^{-2}$ greater than reported here for western Ohio and the Lake Erie snowbelt.

1. Introduction

The ground snow load is the force per unit area exerted on a horizontal surface at ground level by a snow cover. This is measured indirectly as the water equivalent of snow on the ground by National Weather Service (NWS) offices in the United States whenever snow depth is 5 cm or greater. The measurement, also called the snow water equivalent (SWE), is the depth of water that would result if a column of snow were melted. This can be converted to a force per unit area with the mass of water. Measurement of SWE was initiated at NWS offices during the winter 1952/53. The SWE is used in snowmelt and river forecasting studies, but its primary application has been in developing snow-load standards for building design (ANSI 1982; ASCE 1990).

The roofs of buildings must be designed to support the maximum weight of snow expected during the building's lifetime. This is called the design roof snow load. The occurrence of a snow load in excess of the expected load or failure to adequately design roofs may result in catastrophic failure of roofs. The monthly federal publication Storm Data contained reports of collapsed buildings in Ohio after snowstorms of January 1979, February 1985, and April 1987. Snows of December 1974 caused the collapse of several large structures valued at over $1.2 million. The design roof snow load at a site is estimated from the design ground snow-load data and characteristics of the structure and roof, such as building importance, exposure to drifting, roof shape, and orientation (ASCE 1990, pp. 23–32; O'Rourke and Stiefel 1983; Sack 1989). Thus, to establish design roof snow loads, it is necessary to know the ground snow load for the site.

In the United States, the American National Standards Institute (ANSI) produced a national map of the ground snow loads that have an annual probability of 0.02, or a 50-yr mean recurrence interval (ANSI 1982, pp. 41–45). This map was revised by the American Society of Civil Engineers (ASCE) (1990, pp. 24–26), but the only changes from ANSI (1982, pp. 41–45) were in the northern Great Plains. The design of roofs in the United States is based on the 50-yr ground snow loads shown on these maps (or other local calculations), with the appropriate adjustments to obtain roof snow loads. The ANSI (1982) and ASCE (1990) maps show design ground snow loads of 15–30 lb ft$^{-2}$ in Ohio, with no information provided for the Lake Erie snowbelt (Fig. 1). Based on these data, the 1989 Ohio Basic Building Code, section 1111.2, specifies a ground snow load of 25 lb ft$^{-2}$ to be used in determining roof snow loads in Ohio, unless local experience indicates that this is inadequate (BOCA 1988). Based on local experience in the Ohio snowbelt, Lake, Geauga, and Ashtabula counties have established a minimum roof snow load of 30 lb ft$^{-2}$. Using a roof–ground snow-load ratio of 0.7 for houses where wind does not remove snow (ASCE 1990, pp. 2 and 23), this converts to a design ground snow load of 43 lb ft$^{-2}$. For essential

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facilities, such as hospitals, fire stations, and government buildings, the roof-ground snow-load ratio is designated as 0.84 (ASCE 1990, pp. 2 and 23); therefore, the snowbelt design roof load of 30 lb ft\(^{-2}\) converts to a design ground snow load of 36 lb ft\(^{-2}\).

The map published by ASCE (1990) is a small-scale map and does not provide information for the Great Lakes snowbelts or mountainous regions where there is large local variability in snow cover. In addition, several apparent large errors have been found in extreme SWE measurements at NWS offices that may have caused significant errors in ground snow loads shown on the ANSI (1982) and ASCE (1990) maps (Schmidlin 1990). The purpose of this paper is to provide the first analysis of the design ground snow load at the state level east of the Rockies that is in greater detail than the analysis provided by ASCE (1990), incorporating snowfall records of the 1980s and with a critical review of snow-data quality.

2. Ohio snow climatology

Average annual snowfall in Ohio is 50–75 cm in the southern half of the state and 75–100 cm in most of the northern half of the state. Average annual snowfall increases sharply to 200–260 cm in the Lake Erie snowbelt of the extreme northeast (Schmidlin 1989a). Mean January temperatures range from -5\(^{\circ}\) to 1\(^{\circ}\)C across Ohio, and frequent winter thaws prevent a long-lasting, deep snow cover from developing during most winters. For example, in the snowbelt, where mean annual snowfall is comparable to that in northern New England and southern Quebec, the longest subfreezing period of winter is typically just 10 days, and the longest winter period with continuous snow cover (>2.5 cm) averages 40 days (Schmidlin 1989a). The longest winter period with continuous snow cover averages 20–30 days in northern Ohio outside the snowbelt and 10–20 days in central and southern Ohio. Severe winters, such as 1976/77 and 1977/78, can give a continuous snow cover for 60–100 days. Maximum snow depths (1950–90) have exceeded 50 cm in most of Ohio and have approached 100 cm in the snowbelt.

3. Literature review

The first summaries of the snow water equivalent over large areas of the United States analyzed the first 10 years of SWE data collected at NWS offices (USWB 1964; Thom 1966). Ellingwood and Redfield (1983, 1984) later used a longer period of data to study the frequency distribution of the annual maximum SWE at 76 NWS stations in the northeastern United States and calculated 50-yr return periods of ground snow loads. Their statistics were extended to roof snow loads by O’Rourke and Stiefel (1983). The methodology developed in these papers is partly incorporated in ASCE (1990). Steyaert et al. (1980) developed a model to estimate 2-, 50-, and 100-yr return-period ground snow loads at 300 sites in the northeastern United States. However, the 50-yr ground snow loads shown by ASCE (1990) for Ohio differ substantially from those shown by Steyaert et al. (1980) and Ellingwood and Redfield (1984). This may be due to the different periods of data examined, the use of different methods of extreme-value analysis, the varying number of stations used, or the differences in the degree of snow-data quality control prior to the analysis.

Design snow loads for buildings in Canada are based on the 30-yr return-period maximum ground snow load but are not based on SWE measurements. Instead, the 30-yr return-period maximum snow depth is combined with regional snow densities and the 30-yr return-period 1-day winter rainfall to give an estimate of maximum ground snow load (Newark et al. 1989). Snow loads for building design have been calculated for some western states where the ASCE (1990) map shows little detail, generally by the Structural Engineers Association of the state (SEAQ 1978; SEAW 1981; SEA 1981; SEA 1984; Sack and Sheikh-Taheri 1986; Leslie et al. 1987). These are based on data from the Soil Conservation Service snow surveys conducted in mountainous terrain rather than on NWS airport-station data. Snow-load studies for the Nuclear Regulatory Commission have addressed extreme environmental loads with return periods of 10,000 years or more (Ellingwood and Harris 1982). Much of the recent snow-load research has focused on improving methods of converting the ground snow load to a roof snow load for various kinds of roofs (Taylor 1979, 1980; Sack 1988; O’Rourke and Galanakis 1990). Little additional research has been done on the more fundamental measurement of ground snow loads in the United States. Recent work showing errors in snow data archived in the United States indicates that revisions of design
Daily climate data were obtained from the National Climatic Data Center, the office of the Ohio State Climatologist, and the monthly federal publication Climatological Data (which is published by state). The 42 winters from 1948/49 to 1989/90 were examined, but some stations had shorter records. Previous research into SWE data revealed significant errors in extreme values of SWE, including obvious misplacement of decimals in the SWE data and large inconsistencies in SWE from one day to the next that were not justified by precipitation or melting (Schmidlin 1990). Therefore, for this study, the winter maximum SWE data were examined in more detail at ten NWS stations in Ohio and surrounding states. If the reported SWE seemed unreasonable with respect to snow depth or in light of previous days’ measurements (i.e., a large increase in SWE without precipitation) then that winter’s maximum SWE was estimated from available climatic data. The estimation procedure for SWE considered snow depth, precipitation, and temperature on previous days. Using this protocol, 15% of winter maximum SWE observations were judged in error among the ten NWS stations. The quality of winter maximum SWE data varied widely among stations, perhaps due to differences in care taken with the measurement or to local difficulties with snow measurement.

The winter maximum reported snow depths at NWS first-order and cooperative stations were also examined critically. An apparent error noted in several cases occurred when each day’s snowfall was consistently added to the depth reported the previous day. For example, if 20 cm of snow fell on each of four days in a week, it was unlikely that the snow depth at the end of the week would have been 80 cm, since settling would have occurred. In a few cases, reported snow depth was clearly unreasonable in relation to snow at neighboring stations, perhaps due to local drifting or errors in reporting. Large daily changes in snow depth were verified or rejected based on the reported snowfall and high temperatures or rain that might have caused snow melt. Periods with missing data were examined for the possibility that the winter maximum snow depth occurred during the period with missing data. If that possibility could not be excluded then data for that year were not used for the station. After data quality control, winter maximum snow depth at 45 cooperative stations with at least 30 years of data were used in this analysis.

The SWE with a 50-yr mean recurrence interval (.02 annual probability of occurrence) was determined by fitting the lognormal frequency distribution to the annual series of maximum SWE at each first-order NWS station, following the methods of ASCE (1990) and Ellingwood and Redfield (1983). The SWE with an annual probability of .02 was calculated as

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\exp\{\bar{x} [\ln(\text{SWE})] + 2.056 s [\ln(\text{SWE})]\},
\]

where \(\bar{x} [\ln(\text{SWE})]\) is the sample mean of the natural logarithms of winter maximum SWE, \(s [\ln(\text{SWE})]\) is the sample standard deviation of the natural logarithms of winter maximum SWE, and 2.056 is the ordinate of the 98th percentile in the normal frequency distribution. It should be noted that the SWE measured at NWS stations may not be representative of the SWE in natural terrain since the measurements are generally made in flat, wind-swept, grassy areas of major airports (Edgell 1988; Schmidlin and Edgell 1989). Airport measurements may underestimate the local SWE even in regions of open, flat terrain, such as the Great Plains (Schmidlin 1989b). This problem of lower snow depths in large wind-swept, open areas (where official weather stations are located), compared to forests or mixed-land uses, was recognized many years ago by Horton (1905) and is incorporated in the exposure factor used to convert ground snow loads to roof snow loads (ASCE 1990, p. 27). Conversely, snow depths may be greater in small clearings (<20 ha) than in adjacent dense forests due to capture of snowfall by trees (Plamondon et al. 1984; Golding 1986).

The 50-yr return-period ground snow loads for 55 sites in Ohio were estimated with snow density data from the NWS first-order stations and snow-depth data from the first-order and cooperative stations. Figure 2 shows this process. The snow density on the days with the winter maximum SWE was examined for the ten NWS offices to obtain a typical density that could be

![Research Model](image-url)

**Fig. 2.** Flowchart of research methods.
applied to the 50-yr snow depths at all stations. The 50-yr return-period snow depths at the first-order and cooperative stations were determined with the lognormal distribution using (1) and substituting snow depth for SWE (ASCE 1990, p. 67). The 42-yr record of annual maximum snow depths at three Ohio sites in the northern, central, and southern portions of Ohio were found to fit the lognormal distribution, as tested with the Shapiro–Wilk test (Shapiro 1986). The 50-yr return-period ground snow loads at the 10 NWS first-order stations and the 45 cooperative stations were then estimated by applying a typical density of the winter maximum SWE to the 50-yr return-period snow depths. This method assumes that the winter maximum ground snow load occurred on the same day as the winter maximum snow depth. While this will not be true for each winter, the assumption was used in calculating the design snow loads in Canada (Newark et al. 1989), and it held for a majority of the winter maximum ground snow loads at NWS stations in Ohio and surrounding states reported by Steyaert et al. (1980).

5. Results

a. Estimates of snow density associated with extreme snow loads

To determine 50-yr return-period ground snow loads (lb ft⁻²) at cooperative stations in the United States, ANSI (1982) and ASCE (1990) used the power function 0.302D₁.₁₃, where D is the 50-yr return-period snow depth in inches (Leslie et al. 1987; Allan Greatorex, CRREL, personal communication). For typical 50-yr return-period Ohio snow depths of 40–70 cm, this power function gives densities of 0.14 to 0.17 g cm⁻³. Newark et al. (1989) found that a snow density of 0.22 g cm⁻³ for the greatest snow loads was appropriate in southern Ontario, where the landscape and climate are similar to Ohio.

Median snow density on the data with the winter maximum SWE ranged from 0.10 to 0.12 g cm⁻³ among the ten NWS offices examined in Ohio and adjacent states. However, snow densities occurring with the greatest of the winter maximum SWE values were judged to be more appropriate in extreme-value calculation for design ground snow loads. Therefore, the greatest 20% of the winter maximum SWE values at each NWS station were examined separately for snow density. Median snow density for the largest 20% of winter maximum SWE values was 0.14 to 0.17 g cm⁻³ at nine of the ten NWS stations and averaged 24% more than the density of all winter maximum SWE events. The snow density obtained from the ratio of 50-yr return-period SWE and the 50-yr return-period snow depth among ten NWS stations was also determined. This ranged from 0.09 to 0.15 g cm⁻³ at the ten stations, with a median value of 0.12 g cm⁻³. In another approach, the snow densities on the occasions of the station maximum SWE were examined at the ten first-order NWS stations. These densities ranged from 0.08 to 0.25 g cm⁻³, with a median value of 0.15 cm⁻³.

Thus, the power function used by ANSI (1982) and ASCE (1990) seems to fit the Ohio data well, but the density of 0.22 g cm⁻³ used in southern Ontario is too high to be used in Ohio. Based on the aforementioned methods, the density of snow in the design ground snow loads is variable, but a typical density of 0.15 g cm⁻³ was adopted to convert 50-yr return-period snow depths to 50-yr return-period ground snow loads. This will appear to many snow climatologists to be a low density for extreme snow loads. There may be some error introduced in snow densities by using NWS first-order station data. However, in this climate of short-lived snowpacks, the snow depths do not exceed 100 cm or go through the many weeks of compacting metamorphosis that occur in the colder, snowier climates.

b. Fifty-year return-period snow depths

The medians of winter maximum snow depths are shown in Fig. 3 to further illustrate the snow-cover climatology of the region and to show the distribution of stations. A pattern of decreasing winter maximum snow depths from north to south is evident with little spatial variability outside the snowbelt. The 50-yr return-period maximum winter snow depths are shown in Fig. 4. Rather than a north–south gradient, as evident in the mean of winter maximum depths, the 50-yr return-period depths show a gradient decreasing from east to west. Large values of the 50-yr snow depths extend beyond the snowbelt into southeastern and southwestern Ohio so that much of southern Ohio has

![Fig. 3. Median winter maximum snow depths (cm) for the period 1948–90.](image-url)
greater 50-yr return-period snow depths than northwestern or north-central Ohio. This irony was also shown by Miller and Weaver (1971, pp. 19–21). Mean snowfall and median winter maximum snow depths are not great in southeastern Ohio, but occasional deep snowfalls give a large variance in the time series and larger values of 50-yr return periods. Several factors contribute to these occasional deep snowfalls in southern Ohio. Elevation is generally greater (300–400 m) in southeastern and southwestern Ohio than in the northwest or north-central counties (180–300 m). Also, powerful winter storms that track northeastward along the Atlantic coast or Appalachian Mountains affect eastern Ohio more than western Ohio. These storms, such as those that occurred in November 1950, January 1968, and April 1987, have given snow depths of 40–80 cm in southeastern counties, with lesser depths in the northwest. Storms affecting western Ohio generally are moving from the central or southern Great Plains and have less moisture than Atlantic or Appalachian snowstorms.

c. Design ground snow loads

The 50-yr return-period ground snow loads estimated for 55 stations are shown in Fig. 5. Results are presented in units of pounds per square foot because these are the units of application for the data. The values were obtained by applying the typical snow density of 0.15 g cm\(^{-3}\) for maximum snow loads to the 50-yr return-period snow depths (Fig. 4). Since these results may be used for design purposes, a conservative mapping approach was taken. The mapped area labeled 25 lb ft\(^{-2}\) represents station data of 20–25 lb ft\(^{-2}\). Values presented in Fig. 5 agree with the ASCE (1990) map in northwest, north-central, and extreme southwest Ohio (Fig. 6). The values in Fig. 5 are higher than the ASCE (1990) values in west-central, central, and portions of eastern Ohio but lower than the ASCE (1990) values in extreme eastern Ohio. The difference in extreme eastern Ohio may be a result of large errors in the extreme SWE observations at the Pittsburgh NWS office (Schmidlin 1990), which caused ASCE (1990) to overestimate design ground snow loads in the upper Ohio Valley. In addition, data are presented in Fig. 5 for the Ohio snowbelt where the ASCE (1990) map indicates that local variations were too great for mapping at their scale.

The 1989 Ohio Basic Building Code (BOCA 1988) statewide minimum design ground snow load of 25 lb ft\(^{-2}\) may result in overdesign in western Ohio, where design ground snow loads are 15–20 lb ft\(^{-2}\) (Fig. 5). The Ohio Basic Building Code minimum of 25 lb ft\(^{-2}\) is appropriate in eastern Ohio. Figure 5 shows design ground snow loads of 30 lb ft\(^{-2}\) in the snowbelt. As already stated, county building codes in the snowbelt specify a 30 lb ft\(^{-2}\) design roof load that converts approximately to 43 lb ft\(^{-2}\) ground snow load. This may indicate that present building codes in the Ohio snowbelt require an overdesign in roof strength or may represent the wisdom of local experience that cannot be obtained from climatic data.

6. Conclusions

Design ground snow loads were calculated for 55 sites in Ohio for the period 1948–90 with critical review of snow data at NWS first-order and cooperative stations and incorporation of data from the Lake Erie snowbelt. Numerous errors were found in the snow
data. This was expected based on the difficulty in measuring snow and on earlier findings on snow-data quality (Robinson 1989; Schmidlin 1990). Figure 5 provides design ground snow loads for the Lake Erie snowbelt where ASCE (1990) did not provide data. Design snow loads in Fig. 5 differ from the ASCE (1990) map by up to 5 lb ft\(^{-2}\) in some other portions of Ohio. The differences may be due to a longer period of data used in this research (1948–90), the critical review of snow data, the different stations used in the analyses, and the subjectivity in assigning the mapped 5 lb ft\(^{-2}\) snow-load categories from the station data. Present Ohio building codes require a conservative overdesign in western Ohio but are appropriate in eastern Ohio, including the snowbelt. These methods and results are offered as examples that might be followed (or improved upon) in other central or eastern states to make the climatology of design ground snow loads better than that provided in previous national studies.

REFERENCES


