Natural Hazards

Roofs - Snow Loads

Report Number: NH-20-02
Release Date: February 18, 1998
Section Title: Construction Hazards

Abstract

Adverse weather conditions, can affect the structural integrity of buildings and bridges, and can cause a partial or complete collapse. Even an unimpressive snowfall can create a considerable snowdrift that causes a collapse. This report discusses the factors specific to roof snow loads and provides recommendations to aid loss control personnel with the evaluation of a potential risk.

Introduction

Past events have demonstrated that roofs do fail. One of the most dramatic and costly roof structure collapses in history occurred in Hartford, Connecticut, in 1978. After several hours of snow, rain, and freezing temperatures, the 108,000-ft^2, $30 million space-frame roof of the Hartford Civic Center Coliseum failed. This collapse occurred in the predawn hours after a capacity crowd departed from a popular college basketball game. Fortunately, the building was unoccupied at the time and there was no injury or loss of life. Three days later, a double-layered steel and aluminum space dome spanning 171 ft (52.12 m) over C.W. Post College's auditorium on Long Island, New York, collapsed under accumulated snowdrifts. Fortunately, again no one was injured or killed when this $1.5 million structure failed. Such was not the case in Washington, D.C., when the Knickerbocker Theater roof collapsed in 1922 during a performance. The heavy snows that day kept many of the theatergoers home, so the human cost was lower than it could have been; nonetheless, 100 people were injured and 95 people died.

It is estimated that, over the past few years, thousands of snow-related roof failures have occurred, resulting in losses in hundreds of millions of dollars. Most of these were not as extensive or dramatic as the examples illustrated, but the cumulative losses were very significant. These collapses indicate that not all building codes have treated the snow-load problem adequately. Also, quality of construction and lack of inspection and maintenance are factors in structural failures. It would not be in the best interests of insurance companies to rely solely on building codes and their enforcement to prevent or reduce the chance of collapse or other structural malfunctions. Several simple precautions can be taken to help further reduce the risk. In addition, many plan-design-construct-inspect-maintain processes leave much to be desired. While special loss control efforts may not be cost-effective on smaller accounts, it is suggested that where the building has unusual features and/or long spans and where the potential for loss is significant, loss control personnel should review plans during the design phase of a project for potential problems. When failures occur in buildings with high concentrations of people, such as offices, hotels, auditoriums, and sports complexes, the results can be particularly catastrophic. [1]

Loss control personnel should be familiar with factors that can influence or cause a snow-related roof failure, so that they will be better able to inform their underwriting departments on the status of a potential risk.

Factors Affecting Roof Snow Loads

It is important to be able to predict the maximum snow load to which a roof or portions of a roof will be subjected so that it can be constructed to resist such a load and satisfactorily perform its intended function. This cannot be accomplished with complete certainty. However, through the statistical analysis of weather records, snow-load intensities can be developed which will reduce the risk of a snow-related failure to an acceptably low level.

There are several factors that can be expected to influence the snow-load intensity and/or distribution on roofs or portions of roofs. Engineers generally agree that the following are the most significant:

- Geographical location of the structure
- Roof design, system and type of construction
- Exposure to wind
- Thermal condition of the structure
- Slope of the roof's surfaces
- Drifting of snow
- Geometrical shape of the roof

In conjunction with snow loads, consideration must be given to additional loads caused by rain-on-snow and ponding loads, both of which have accounted for numerous collapses.

Geographical Location [2]

Maps have been developed for specific sections of the United States which indicate the variation of ground snow load intensities across the country. [Footnote[1]] Probably the best consensus-type information available for use in the prediction of snow loads are shown on these maps.

Exposure to Wind

Usually, less snow is present on most roofs than on the ground, primarily because of exposure to wind. [Footnote[2]] The more wind to which a structure is subjected and the less shelter (obstruction to wind) afforded by terrain, higher structures, or trees, the less snow can be expected to remain on the structure's roof. In some portions of the country, the snow loads on unobstructed areas of conventional flat roofs have averaged less than 50% of the ground loads. However, because of the variability of wind action, great care must be exercised when taking this factor into consideration. Guidelines are presented in the American National Standards Institute/American Society of Civil Engineers Standard 7-93, *Minimum Design Loads for Buildings and other Structures*. [2]

Thermal Condition of Structure

In general, more snow accumulates on the roofs of unheated buildings (cold roofs) than on those of heated buildings (warm roofs). Escaping heat melts some or all of the snow, causing it to run off as water.

Discontinuous heating of structures, however, can cause problems, such as overloading. For example, during the heated periods, snow melts and runs off towards lower elevations. During the unheated periods, it subsequently refreezes in lower areas, clogging drainage systems with ice. The cycle continues, causing a buildup of layers of ice several inches thick at higher roof elevations, which in turn results in extra loads that could cause structural damage. [5] Similar problems can develop on cold roofs subjected to water from roofs above. Exhaust fans and other mechanical equipment on roofs may also generate water and subsequent icings.

A common occurrence on sloped, warm roofs is that water refreezes on cold eaves, forming large icicles and ice dams. More often than not, leakage occurs when water "backs up" under shingles and roof sheathing, causing water damage. Structural problems can result, creating hazardous conditions and expensive repairs.

Specialty-type roofs constructed of glass, plastic, or fabric used on continuously heated structures are seldom subjected to much snow load because they usually permit high heat losses that cause melting and aid sliding of snow off the roof. However, for significant exposures, knowledgeable manufacturers and/or designers should be consulted. Similarly, little snow usually accumulates on warm air-supported fabric roofs because of their geometry and slippery surfaces. However, any accumulation of snow that is noticed must be dealt with and remedied since any snow load is considered significant for these types of structures.

Roof Slope

As roof slopes increase, snow loads decrease. The action of the wind is partly responsible for this phenomenon. In addition, sloped roofs have the tendency to shed some snow that accumulates on them by sliding and they also offer improved drainage for melted snow. The ability for a sloped roof to shed snow depends on the magnitude of the slope. Roofs with a slope as flat as 10 degrees have been observed to shed snow. In addition, the absence of obstructions on and below a roof, its temperature, and the slipperiness of its surface are also factors that affect sliding. Great care must be used, however, when these factors are taken into consideration. As mentioned previously, discontinuous heating may produce the formation of ice dams. These can "lock" snow on roofs and prevent sliding. In addition, when a roof is constructed such that its eave is close to ground level or where there exists another roof of a flatter slope at the lower termination of the higher roof, snow may not be able to slide off completely.

Sliding snow also has the potential for significantly increasing loads on roofs. Where the situations exist that snow can slide onto lower roofs of multi-roof structures, canopies, porches, covered walkways, and other similar lower structures, it is prudent to give serious consideration to the additional loads imposed. When possible, these situations must be discouraged in new construction.

The exposure of the area underneath a roof that has potential sliding snow must also be evaluated to reduce the potential for injuries and property damage.

Drifting

Approximately 35% of all structural failures are roof failures. Of roof failures, 36% are caused by snow and ice, and about 75% of these snow-related failures are caused by snow drifting.

Snow drifting can easily result in significant additional loading of a localized portion of a roof. In the past, engineers have not sufficiently appreciated the problems associated with snow drifting. During the winters of 1978 and 1979, Chicago experienced hundreds of snow-related roof collapses. At that time, the Chicago building code required a 25 psf uniform design load with no consideration given to drifting. Roofs are usually designed with a factor of safety ranging from 1.5 to 2 so that, at best, a roof designed in conformance with that code would probably sustain 50 psf, assuming it was designed, constructed, and maintained properly. Drifting loads, however, can easily exceed 50 psf with some snow drift loads having been recorded in the range of 300 psf.

Snow drifts accumulate on roofs (even sloped roofs) in what is known as the "*aerodynamic shade*" or "*wind shadow*" of the following: higher portions of the same structure; nearby higher structures or terrain features (separation of 20 ft (6.1 m) or less); or roof projections, such as parapets, solar panels, penthouses, and mechanical equipment. It is extremely important to consider the localized load intensities produced by drifts and to realize that not all building codes treat drifting adequately.

Roof Geometry

The geometry of roofs also influence snow accumulations. For example, barrel vault and sawtooth roofs collect extra snow in their "valleys" because of drifting and sliding. In general, these types of roofs and similar "up-and-down" roof configurations are particularly vulnerable. They tend to accumulate significant amounts of snow and are therefore more expensive to build. Ventilation devices and windows on steeply sloped faces can become blocked by snow and rendered useless or actually damaged by the lateral pressure exerted by the snow. Melted snow and slush also have a tendency to accumulate in the "valleys" during warmer weather, almost assuring water infiltration that leads to progressive deterioration of the structure.

Rain-on-Snow Loads

The snow-load intensities illustrated include the effect of light rain on snow. The additional loads produced by heavy rains on snow can be significant and must be considered where heavy rain can be expected to occur after a snowfall. The magnitude of the additional load is influenced by the intensity and duration of the rainstorm, the drainage characteristics of the snow on the roof, the geometry of the roof, and the type and effectiveness of the roof drainage system.

Ponding Loads

Closely associated with rain-on-snow loads are ponding loads. The primary cause of rain or wet snow overloading is water ponding in the roof's depressions. Where adequate slopes to drains are not present or where drains are blocked by ice or other objects, melted snow can "pond" (accumulate) in low areas. As previously mentioned, discontinuously heated structures are particularly susceptible to drains that are blocked by ice. In addition, it is probable that very flat roofs contain undesirable low areas away from the drains where water can accumulate. When snow loads are added to such a roof, it is even more likely that low areas will be produced or existing low areas expanded. As rain and/or melted snow drain into these low areas, the resulting increased load produces increased deflections permitting deeper and larger ponds. If the roof structure does not possess sufficient stiffness to resist this progression, more and more load is accumulated until a failure is caused by localized overloading.

Susceptible Roof Systems/Shapes

Metal roofing systems, steel decks, and boards on joists are most susceptible to collapse from snow or rain loads. These systems have little rescue capacity in their ability to withstand large live loads of snow or rainfall. This is due to the result of their lighter construction or dead load capacity.

Every roof shape has its own susceptibilities to snow, ice, or rain loading. The three most common roof shapes that are most susceptible are:

Multilevel

Snowdrifts build on multilevel roofs at the intersection of high and low bays. Winds blow snow from higher bays onto lower ones, or across lower bays to create drifts against higher bays. If the upper bay is a sloped or gabled roof, the snow load drifts onto the lower bay.

Curved

On curved roofs, an unbalanced snow load can collect on the leeward side at the eaves. Even if the roof sustains the unbalanced snow load, ice forms easily at the eaves in a freeze-thaw cycle that prevents ice and snow from dropping off normally. This also creates the danger of ponding waterloads on curved roofs.

Valley (or Multi-gable)

Snow collects in the valleys formed by gable, saw-tooth and barrel-vault roofs. The snow load is these valleys can be as much as three times the balanced snow load. In extreme conditions of sustained high winds, even single gable roofs sloped about five degrees or 1 in per ft (2.5 cm per 0.31) can collect snowdrifts.

Loss Prevention

There are effective safeguards to lesson the potential against roof collapses. The following safeguards can help prevent roof collapse:

- Most important, keep the snow off the roof.

- Keep all drains clear and unblocked.
- Keep the roof well maintained and do repairs/replacements as soon as required.
- Keep workers trained and the proper equipment available for snow removal.
- Keep an updated winter emergency response plan in effect, especially for snow removal.

Preparation for Snowfall

Preparation for snowfalls should begin six to ten weeks before the start of winter. The roof's framework should be checked for damage or weakness and its capacity for snow loading should be reassessed. All shovels, snowblowers (if used), and other removal equipment should be examined and put into good working order. Never use any equipment that can damage a roof such as a ice chopper. Finally, inspect all drains for debris (e.g., leaves, dirt, silt) and clean them. The downspouts should also be clear, especially at the outlets.

During a Snowfall

Monitoring roof top conditions during a snowfall is the best way to prevent a roof from collapsing. The snow removal plan should take effect immediately after the snow begins to fall, rather than waiting until the snow begins to mount or the wind creates snow drifts. Additional recommendations during a snow fall are as follows:

- Remove snow from the roof in increments-do not allow unauthorized workers/persons onto roofs.
- Do not create snow drifts by putting snow from one area on another.
- Remove the snow systematically to maintain the balance of the structure.
- On a gable-type roof, do not remove all the snow from one side before removing any from the other side.
- Verify that drains are clear of ice and snow to allow melting and runoff. If the roof is pitched and without drains, open paths to the eaves to ensure drainage and prevent ponding.

Checklists

The following checklists should aid loss control personnel in evaluating potential risk.

Design-Related

- Has the map for snow loads contained in the latest edition of ANSI/ASCE 7-93, *Minimum Design Loads for Buildings and Other Structures* or better local information been used to develop the required design snow loads? Be assured that the methods used conform to or exceed those presented in the latest edition of ANSI/ASCE 7-93.
- Has drifting been considered?
- Has the thermal condition of the structure been considered?
- Have the roof's slope and sliding snow been considered?
- Has any reduction in load due to exposure to wind been performed conservatively?
- Has special consideration been given to roofs with "up-and-down" geometry?

- Have ponding and rain-on-snow loads been taken into account?

Existing Structure/Building

- Have there been any lower roofs, canopies, or covered walkways added to the structure? If so, have the effects of sliding and drifting snow been considered for these additions?
- Have any roofs been retrofitted with additional insulation in an effort to conserve energy? If so, have the increased snow loads due to reduced melting been considered as well as the additional dead load?
- Have solar panels, mechanical equipment, or other roof projections been added to the building? If so, has the roof been checked to assure that it can withstand the additional sliding and drifting snow loads, as well as the additional dead load?
- It is possible that the building will be unheated for long periods? If so, is the roof capable of withstanding any additional snow load?
- Do roofs that slope towards internal drains have slopes of at least 1/4 in per ft (6.35 mm per meter)? If not, these roofs must be routinely checked for ponding. Low areas should be repaired and/or additional drains added.
- Are all drains, gutters, and downspouts free from debris? If not, they should be cleared and kept cleared.
- Does a visual examination of the roof's structural members indicate any leaks? Is there any sign of sagging or misalignment? Are there any corroded, cracked, and/or buckled steel members, split and/or rotted timber members, or cracked and/or spalled concrete members? Is there any sign of efflorescence on concrete members and slabs? Do all connections appear sound? Qualified professional engineers should be retained to examine any problems noted.
- Have additional dead loads, such as air conditioners, heaters, and suspended storage platforms been added to the roof's structural members, thereby decreasing the roof's live load capacity?
- Has a taller building been built, or is there one planned to be built within 20 ft (6.1 m) of the existing building? If so, can the existing building's roof sustain potential snow drifts caused by the taller building?

If problems have been found to exist, the roof should be repaired, strengthened, or replaced, as required.

References

- 1. American Institute of Architects. *Towards Safer Long-Span Buildings*. Washington, DC: AIA, 1991.
- 2. American National Standards Institute. *Minimum Design Loads for Buildings and Other Structures*. ANSI/ASCE 7-93. New York, NY: ANSI, 1993.
- 3. American Society of Civil Engineers. "Winter Roof Collapses: Bad Luck, Bad Construction, or Bad Design?" *Civil Engineering Magazine* Dec. 1979.
- 4. Factory Mutual Engineering Corporation. *Preventing Roof Collapse From Snow Loading*. P 9408. Norwood, MA: FMEC, 1997.
- 5. Industrial Risk Insurers. "And The Walls Come A-Tumblin' Down." *The Sentinel*. 1st Quarter (1984).

Footnotes

- Footnote[1] Snow loads are zero for Hawaii and additional tables are available for Alaska from the American National Standards Institute.
- Footnote[2] Except in areas of "aerodynamic shade" where loads are often increased (see the section on Drifting in this report).