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March 2003 Denver Blizzard - A Retrospective
PART I: Building Damage Due to Snow Loading

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Abstract

In March 2003, Denver Colorado and the surrounding area experienced code-level snow loads due to one of the most destructive blizzards in Colorado history. According to the Rocky Mountain Insurance Information Association, personal claims from the storm exceeded $93,000,000 due to damage across the region. This is in addition to large commercial building losses as well as untold dollar amounts in lost business revenue while buildings were unsafe to enter. Hundreds of structures collapsed or sustained severe structural damage, and thousands of buildings sustained repairable structural or cosmetic distress. This paper discusses the types of structural systems commonly damaged as a result of the snow loads. Based on the lessons learned from this storm, recommendations are made for future design and structural condition assessment of snow loaded structures.

Photo 1. Collapsed roof due to snow load.

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Introduction

During the March 2003 blizzard, the Denver Metro area had an average snowfall of approximately 30 inches (76 cm), with the highest snowfall reported at 87.5 inches (222 cm) in Gilpin County in the Rocky Mountains about 30 miles (48 km) northwest of Denver. Snow density measurements, while varying with climatic conditions and elevation, were generally in the range of 10 pcf (1.57 KN/m^3) to 12 pcf (1.89 KN/m^3) in lieu of the usual 5 pcf (0.79 KN/m^3) to 7 pcf (1.1 KN/m^3). This means that 30 inches (76 cm) of snow weighed in the range of 25 psf (1.2 KN/m^2) to 30 psf (1.44 KN/m^2). For reference, current code requirements in the Denver area generally specify design snow loads of 25 psf (1.2 KN/m^2) or 30 psf (1.44 KN/m^2).

The types of snow-induced loads that caused damage were uniform or drifted snow, localized loads due to ponded water created as the snow melted, and impact or built-up snow loads from sloped roofs due to sliding. Most non-structural damage occurred due to large deflections of structural elements. Structural damage typically occurred as a result of inadequate design or improper construction.

During the storm, emergency services personnel were evacuating and red-tagging buildings even if only minor cosmetic damage was observed. While this safety precaution may have been prudent due to the emergency situation caused by the storm, it placed a huge demand and responsibility on the structural engineering community to perform rapid condition assessments of thousands of snow loaded structures. The findings from hundreds of structural investigations performed by the author and his coworkers revealed a pattern of problematic construction and design issues in the Denver Metropolitan area. It is hoped that by reviewing these observations, the engineering community will be better equipped to manage similar situations in the future.

Discussion of Commonly Observed Building Damage as a Result of the March 2003 Denver Blizzard

Non-Structural Damage

The most common symptoms of the heavy snow loads were failures of non-structural elements such as ceiling systems, interior finishes, waterproofing and roofing materials, and utilities. The most common cause of non-structural damage was roof deflection under the weight of uniform or drifted snow, combined with interior finishes that were not installed in such a way as to accommodate these deflections. Longer-span roof structures were the most problematic since they are typically subject to larger deflections.

Cosmetic Damage: The most prevalent type of cosmetic damaged observed was that of ceiling systems. For example, drop-in ceiling tiles are usually installed such that they hang from the roof structure, but they often also tie into partition walls that are supported by the floor. When the roof deflects downward, so too does the ceiling (Photos 2 and 3). But partition wall elements do not deflect downward since the floor is unaffected by the weight of the snow. The result can be very alarming to people in the building and can appear to represent a significant structural problem, even if the roof deflection is less than code-required design limits.

Photo 2. Deflection of suspended ceiling system.

Photo 3. Incompatible deflection of ceiling system at partition wall.

Damage to roofing materials was another very common problem. This typically occurred where the roof elements running parallel to walls or chimneys deflected under the weight of the snow and the roofing materials were unable to withstand the incompatible deflections. This damage caused many water leaks and, if left unattended, resulted in further damage to roofing materials as well as deterioration of structural elements and building finishes.

Utilities: Broken utilities were a major concern following the storm. Water leaks in areas of electrical supply and broken utility pipes led to the shutdown of many building utility systems. In one example, a gas line was supported at the bottom of some wood roof beams (Photo 4). Because of poor drainage on the roof, ponding occurred over one of the beams (Photo 5) causing it to crack and fail, resulting in significant vertical deflections. Since the pipe was supported by undamaged beams on either side, the damaged beam pushed down on the pipe, creating a very serious potential hazard.

Photo 4. Utility line endangered by damaged roof beam.

Photo 5. Ponded water on warehouse roof.

In addition to high repair costs, one important aspect of cosmetic damage is that it can be an indicator of less obvious, yet more serious, structural damage or distress. A discussion of commonly observed *structural* damage is presented in the following section.

Structural Damage

Stick-Framed Structures (The "Denver Bungalow"): Most residences in the Denver area constructed prior to 1960 have "stick-framed" roofs. Figure 1 illustrates the general framing configuration of the common residential construction referred to locally as "The Denver Bungalow". While some of the roofs investigated had valleys, hips, ridges, dormers and setbacks, most were simple gable roofs having a single plane on each side of the ridge. The typical roof consists of 2x4 or 2x6 roof rafters spanning from the exterior walls up to a 1x ridge board. Hips and valleys are often framed with 2x4 or 2x6 lumber. The ceiling below is also typically framed with 2x4 or 2x6 joists bearing on the exterior and interior walls. It is not uncommon to see the roof rafters and valley beams spanning upwards of 15 or even 20 feet.

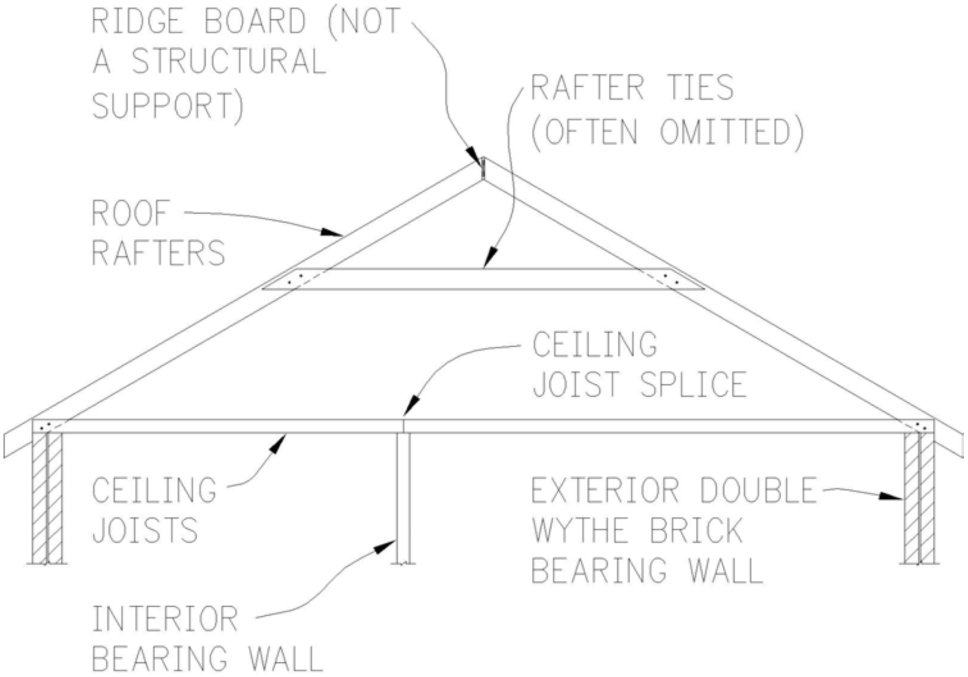

Figure 1. Typical "Denver Bungalow" stick-framed construction.

Damage due to excessive spans and incompetent framing members was common with overloaded roof rafters often cracking or splintering under the weight of the snow

(Photo 6). Also, many connections were simply damaged as a result of sub-standard framing techniques (Photo 7). Furthermore, without a ridge beam or adequate rafter ties, the roofs of these structures tend to spread apart when loaded, with the ridge sagging and the roof rafters thrusting outward on the exterior walls.

Photo 6. Cracked roof rafters in a Denver Bungalow.

Photo 7. Damaged roof connection of a Denver Bungalow.

Since the majority of the Denver Bungalows are constructed with double-wythe brick masonry walls that are incapable of restraining large horizontal forces, the outward thrust from the rafters typically also damaged the exterior bearing walls (Photo 8). As a result, gaps were observed between interior finishes at the intersection of the wall and ceiling (Photos 9-10), and at window frames where the exterior wythe of brick was moved outward while the interior wythe remained in place (Photo 11). This outward thrust was further revealed when looking at splices

Photo 8. Leaning brick on exterior wall of a house due to outward roof thrust.

Photo 9. Gap between exterior wall and ceiling framing due to outward roof thrust.

Photo 10. Gap between exterior wall and ceiling framing due to outward roof thrust.

of ceiling joists, which were pulled apart if the connection between them was not strong enough to withstand the tension created by the outward roof thrust (Photo 12).

Photo 11. Gap between window frame and exterior wythe of brick due to outward roof thrust.

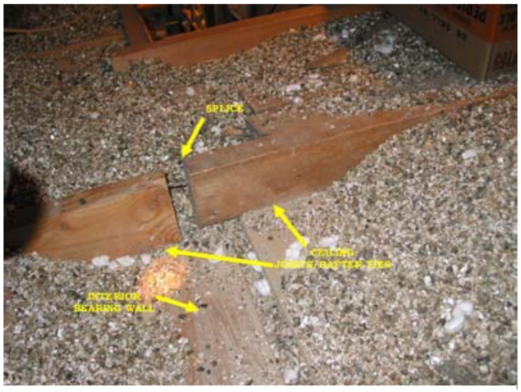

Photo 12. Splice of ceiling joists being pulled apart by outward roof thrust.

Finally, because of the excessive deflections of the roof, it follows that many of the roof framing connections were damaged as well. This was particularly true for rafter-to-wall, ceiling joist-to-rafter, and rafter tie-to-rafter connections.

Plate-Connected Wood Trusses: Failures of metal plate connected wood trusses were typically observed at truss panel point connections, although some instances of cracked and splintered truss segments were noted. The most common connection failures were those where web members pulled away from metal press plates (Photo 13). In addition to scenarios of inadequate design, possible explanations for the failures include field application of the press plates without adequate quality control, and damage to the connection plates or web members during storage or erection. Specific cases were also noted where the press plate failed in buckling stemming from a gap that was built into the compression chord splice of the truss (Photo 14). Finally, while most of the problems with plate connected wood trusses were seen at

Photo 13. Truss web pull-out from press plate at panel point connection.

Photo 14. Buckled metal plates at truss top chord splice.

panel points and with individual truss members, other, more catastrophic failures were also observed (Photo 15).

Light Gage Z-Purlins and Pre-fabricated Metal Buildings: The prefabricated metal buildings typically investigated for structural damage following the storm consisted of steel frames supporting z-shaped light-gage metal purlins, which in turn support a metal deck roof. Because of the shape of the z-purlins, their tendency when loaded is to rotate about the longitudinal axis of the member (Photo 16). Typically, the rotations are more pronounced at the mid-span of the member and less at the supported ends, where anti-roll clips provide rotational restraint. Rotation of the purlins under the weight of the snow resulted in increased weak-axis bending, further deflections, and higher stresses in the member. In several cases, extreme rotations led to irreparable damage of the roof (Photos 17 - 18).

Photo 15. Collapsed roof due to snow load.

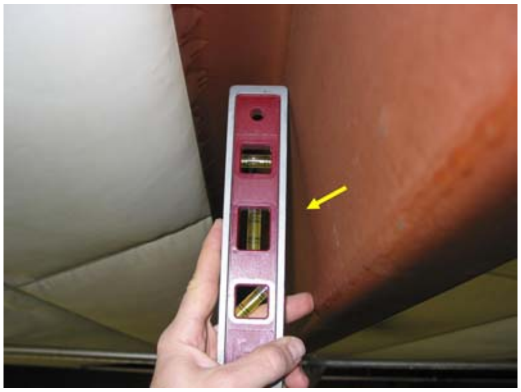

Photo 16. Deflected/rotated metal z-purlin.

Photo 17. Failed roof over metal z-purlin supports.

Photo 18. Failed roof - metal z-purlins rotated and buckled.

Another problem resulting from z-purlin rotation, whether or not the member fully failed, was that connections between the purlins and the roof deck could not accommodate the movement and broke or caused damage to the roofing components leading to water leaks.

Finally, in addition to the problems observed with z-purlins, other scenarios were observed where pre-fabricated metal building systems had been installed without proper structural modification/upgrade for site snow load requirements. In one instance, the structural support beams and columns of a building (used as a dog kennel in the mountains west of Denver) were crushed and buckled under the weight of the snow (Photo 19).

Photo 19. Crushed roof beam on prefabricated metal building.

Standard Dressed and Glued Laminated Timber Beams: Numerous examples of shear cracks parallel to grain were observed following the snow storm. This was most prevalent in glued laminated timber beams, but was also seen in standard dressed timber beams. Usually, the crack began at a bolt hole or existing wood check near the end of the beam, and propagated toward the middle of the beam. Often there are shrinkage cracks in wood, but these can be differentiated from new cracks by observing freshly exposed wood within the crack, or by other indicators such as marks or stains on the wood. Sometimes, one can see the horizontal displacement of the lower portion of the beam relative to the upper portion of the beam by looking at the offset of old stains on the wood (Photo 20).

Photo 20. Shear crack parallel to grain in glued laminated timber beam.

Trellised Roofs: Due to its unusual depth and moisture content, the snow was able to accumulate and bridge over the gaps on trellised roof structures. However, since there are gaps between the members of a trellised roof, they typically are not designed to carry the weight of snow. This mismatch in design philosophy and reality resulted in numerous failed trellis roof structures (Photo 21). Several instances were also observed where post-supported trellised roof structures collapsed laterally when loaded by sliding snow. This is further addressed in the next section.

Photo 21. Failed trellis roof structure due to snow "bridging" the gaps between roof members.

Structural Elements Prone to Damage from Sliding Snow: Many examples of damaged structural elements were observed as a result of snow sliding from sloped roofs. Typical structural elements damaged by sliding snow included parapet walls, decks, and trellis structures.

- ***Parapet Walls Damaged by Sliding Snow:*** Parapet wall damage typically occurred on parapets running parallel to the ridge line of a gabled roof. The damage occurred slowly as the snow melted, slid down the roof, and built up behind the parapet wall. One tenant of a building was able to photograph the sequence of events in the collapse of an unreinforced masonry parapet (Photos 22 - 24). Reportedly, the depth of snow behind the parapet shown here reached as high as six to seven feet. Due to the horizontal pressure from the snow, the parapet cracked at the roof line and began to tilt outward. Surprisingly, the parapet bowed outward as much as 18 inches in 5 feet of height before it broke.

Photo 22. Parapet wall bowing outward under lateral forces from snow build-up behind the wall.

Photo 23. Failure of a section of parapet wall.

Photo 24. Photograph showing extent of damaged parapet and break line of snow slide.

- ***Decks Damaged by Sliding Snow:*** When a large amount of snow slides off of a roof, the impact force from the falling snow can be significant, but is rarely accounted for in design. One house in the mountains just west of Denver (Photo 25) has a standing seam metal roof. However, no snow guards were installed to prevent sliding snow on this low-friction surface. Here, the snow slid off of the roof very quickly on the back side of the house and impacted the deck below, which was already heavily loaded with snow. The deck collapsed from the impact (Photo 26). Ironically, to reduce the risk of

Photo 25. House with standing seam metal roof and no snow guards.

damage from forest fires, the original wood shake shingle roofing was recently removed in favor of the standing seam metal roofing. Furthermore, it is interesting to note that the owner of the house was on the deck when it collapsed, and was able to grab the railing (indicated by the left-most arrow, but removed at the time of the photo) next to the door and then climb through the door to safety. The railing was the only portion of the deck that didn't collapse and fall down the mountainside.

Photo 26. The deck on the back side of this house collapsed under the impact of sliding snow.

- ***Trellis Structures Damaged by Sliding Snow:*** As previously noted, in addition to not being designed to support gravity snow loads, trellised structures are also typically not designed to resist significant lateral forces. To this end, several instances were observed where trellised roofs collapsed laterally when loaded by sliding snow (Photo 27).

Photo 27. Lateral collapse of trellis structure due to sliding snow.

Structures Prone to Damage from Ponded Meltwater: Many examples of damaged flat roofs were observed as a result of ponded meltwater. This damage was typically a result of inadequate consideration in design for deflections of roof members as well as ill-conceived drainage schemes and poor maintenance of roof drains.

Photo 28. Drainage on concrete double-tee roof.

One interesting case study involved a warehouse roof constructed of precast concrete double tees, where there was an obvious lack of coordination in design to account for deflections of the roof members, roof slope, and drain locations. Four years earlier, one of the double tees failed due to ponding following a hail storm. This was mainly due to the scuppers at the time being installed through the perimeter wall at high points corresponding to the supported end of the double tees (Photo 28, right arrow) combined with relatively large design deflection of the over 70-foot (21.3 m) long member. Upon installing a replacement double tee for the one that failed, a new interior drain was installed at the mid-span (Photo 28, left arrow). While the new double tee underwent significant deflection following the snow storm of 2003, this only resulted in cosmetic damage to interior finish systems and no structural damage.

Maintenance of roof drains was a key element in the efficient drainage of meltwater. Even if roof drains were maintained and kept free of debris prior to the storm, many problems arose in the days after the storm when meltwater would freeze overnight and block the drains with ice. Building owners were encouraged to shovel areas around drains to maximize solar exposure and minimize the potential for clogging (Photo 29).

Photo 29. Clearing of roof drains to promote efficient drainage.

Conclusion and Recommendations

The damage observed was by and large a result of inadequate design or improper construction for the snow loads encountered, and buildings that were designed and constructed in accordance with current building code requirements typically performed well.

New Design: The findings from the storm reinforce the value of an engineer's assessment during design of the anticipated *combined* maximum deflections of girders and beams on flat roofs, and emphasize the importance of installing internal roof drains at the low points of the *deflected* roof. This is particularly true for flat roofs sloped only 1/8"/ft (0.6°) or 1/4"/ft (1.2°).

Sliding snow caused many problems following the storm. One preventative measure against sliding snow that was seldom encountered but is very effective, is the use of snow guards. These are small projections located intermittently on a roof that serve to promote the even distribution of snow weight and to prevent large amounts of snow from breaking loose and sliding, especially on low-friction surfaces such as standing seam metal roofs. This is particularly important considering that current code provisions do not include design provisions for impact loads from sliding snow.

Special attention should be paid during design to the possibility of built-up snow behind a parapet wall or snow fence at the base of a gabled roof, as well as any roof projection on a gabled roof that is not located at or near the ridge. While current code provisions do not specifically address the lateral forces on these elements due to sliding snow, it is recommended that structural engineers consider designing such parapets and like projections to resist the lateral force from all snow between the projection and the roof ridge under the design assumption of a frictionless roof surface. As an alternative, installation of snow guards may be considered, in which case the gravity snow loads on the roof can be expected to increase.

Condition Assessment: When performing future condition assessments of snow-loaded structures, the investigating engineer will obviously draw upon their own experiences and knowledge of the local infrastructure. Depending on the age and type of construction of the building under review, the engineer may find that the previously outlined damage provides added insight to their investigation. Furthermore, the investigation should emphasize the *potential* for damage in addition to the current condition of a snow loaded structure. Even if there is no damage evident due to snow loading at the time of investigation, it is strongly recommended that the structure's capacity for efficient drainage of meltwater and the potential for sliding snow, including a review of susceptible structures below the roof, be carefully examined before a building is declared safe and serviceable.

Repairs: The inevitable result of performing hundreds of condition assessments of snow-loaded structures is that repairs for the observed damage must be defined. To this end, and based on the experiences of the March 2003 Blizzard in Denver, it is the author's opinion that the code requirements for repair and rehabilitation as they relate to snow loading damage are in need of reform. In Part II of this paper, "Building Code Requirements for Repairs," the challenges involved in providing responsible engineering services for the repair of snow load damaged structures are discussed considering current code and jurisdiction requirements. Also, attempts are made to clarify the sometimes ambiguous code requirements with authoritative interpretations from code officials. Finally, suggestions are made for improving the repair provisions of future codes.

References

M. Blackmer, *Statistics and Observations on the Colorado Blizzard of 2003*, Claims Quarterly (December 2003 Issue), CPCU Society, Malvern, Pennsylvania.

Building Officials and Code Administrators International, Inc. (BOCA). (1999). *The BOCA National Building Code*, Country Club Hills, Illinois.

COOP/CAST Observers. *March 17-20, 2003 Snowfall.* http://www.crh.noaa.gov/den/gif/pns6snow.gif

International Code Council, Inc. (ICC). (2003). *International Building Code*, Country Club Hills, Illinois.

International Conference of Building Officials (ICBO). (1997). *Uniform Building Code*, Whittier, California.

Rocky Mountain Insurance Information Association. *Colorado Blizzard of 2003*. http://www.rmiia.org/news%20room/catastrophe%20news/2003_04_07_blizzard.htm

Southern Building Code Congress International, Inc. (SBCCI). (1999). *Standard Building Code*, Birmingham, Alabama.

Structural Engineering Institute (SEI) and American Society of Civil Engineers (ASCE). *Minimum Design Loads for Buildings and Other Structures (SEI/ASCE 7-02, chapter 7 and commentary on chapter 7)*, American Society of Civil Engineers (2003), Reston, Virginia.

D.A. Taylor, Canadian Building Digest (November 1983); "*Sliding Snow on Sloping Roofs" (pp.228-1 through 228-4)*, National Research Council of Canada – Division of Building Research, Ottowa.

United States Geological Survey (USGS) and National Oceanic and Atmospheric Administration (NOAA). (April 2003). *Estimated Snow Load for Colorado: Storm of March 16-20, 2003*, Rocky Mountain Mapping Center.