Study of Structural Failures Associated with the Winter 2008-2009 Snow Event in the Spokane/Coeur d'Alene Area

December 2009

Structural Engineers Association of Washington (SEAW)

Spokane Chapter

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The committee would like to thank local engineering firms and building officials who provided data and information necessary for the preparation of this report.

Executive Summary

This report was prepared by an ad hoc committee of the Spokane Chapter of the Structural Engineers Association of Washington to study structural failures which resulted from the extreme weather event the Inland Northwest experienced during the December 2008-January 2009 period. Record snowfalls were recorded in the region with the majority of the winter's snowfall occurring in a 3 ½ week period.

Although many buildings experienced structural failures due to the snow loads, the total number of affected buildings was very small relative to the total building inventory in the region. Most of the failures occurred at snow loads less than the minimum design roof loads currently required by local building officials, thus other factors led to the failures.

Based on evaluation of the data collected for the 2008-2009 winter snow event, the Ad-Hoc Committee of the Spokane Chapter of Structural Engineers Association of Washington recommends retaining minimum design roof snow loads currently adopted by jurisdictions in the Spokane and Coeur d'Alene area. Structures at higher elevations should be evaluated on a case by case basis.

The committee reminds the engineering community that proper, code-compliant structural design of any structure includes modifications of the minimum basic design roof snow load based on various factors such as roof geometry, exposure conditions, insulation levels, building heating, adjacent structures, etc. In many cases, portions of a roof structure may be susceptible to drifting or sliding snow loads in excess of the minimum basic design snow load. Correct implementation of current code requirements in addition to improved communication between design professionals, contractors and building officials will reduce the number of future structural failures.

Introduction

The Spokane Chapter of the Structural Engineers Association of Washington formed an ad hoc committee to study the structural failures resulting from the extreme weather event the Inland Northwest experienced during the December 2008-January 2009 period.

During the winter of 2008-2009, the Spokane/Coeur d'Alene area experienced record setting snowfalls. The majority of the snowfalls occurred from December 12, 2008 through January 6, 2009. A considerable amount of snow accumulated in a short time period without any intermittent warmer temperatures that would normally result in a melt-off. This somewhat unusual pattern of consecutive snowfalls caused heavy ground and roof snow loads which resulted in an unusual number of roof failures. These failures varied from minor to total.

During late December and early January, most of the structural engineering firms in the region responded to requests from building owners to assess either the structural capacity of their roofs or snow-related damage and/or collapse of their buildings. The committee solicited input from these firms to determine the location of damaged structures, date of damage and/or collapse, insitu snow measurements, approximate building age, structural framing system, roof slope, approximate building size, and any conclusions they may have drawn. The local firms were very cooperative and a database was developed.

Photo 1: Failed Canopy and Bowstring Truss Roof

We also received the cooperation of local building departments which provided us with lists of properties that reportedly had snow-related damage and/or collapses. Where there was sufficient information, these were added to the database.

Photo 2: Sliding Snow

The committee's goal is to learn from the observed failures and determine how future occurrences might be prevented. Furthermore, this report summarizes actual snow loads based on available recorded data and makes recommendations concerning the appropriateness of the current design roof snow loads required for building design. This study is limited to the geographical region of Spokane County, WA and Kootenai County, ID.

The hope is that the information from this study will be useful not only to architects and engineers, but also to building owners and building officials. Conclusions drawn from this study are general in nature. A detailed analysis of the specific mechanism for each failure is beyond the scope of this study.

Current Design Criteria

The states of Washington and Idaho have both adopted the 2006 International Building Code (2006 IBC). The 2006 IBC has numerous provisions related to snow loads, and addresses issues such as ground snow versus roof snow, drifting and sliding snow, and unbalanced snow loading. Snow provisions of this type were first introduced in the 1988 Uniform Building Code. Many building officials also allow the use of the following documents as a basis for determining ground snow loads:

1. *Snow Load Analysis for Washington*, 2nd Edition, prepared by the Structural Engineers Association of Washington
2. *Ground and Roof Snow Loads in Idaho*, 1986, Sack and Sheikh-Taheri

The International Building Code makes a distinction between ground snow load and roof snow load. Ground snow load is defined as the weight of snow on the ground surface. The roof snow load is the weight of snow on the roof surface and is a function of:

- The ground snow load
- The structure's exposure to wind (Sheltered structures retain more roof snow than structures in open fields)
- The thermal characteristics of the roof (Well insulated and ventilated roofs retain more snow than poorly insulated, poorly ventilated roofs)
- The slope of the roof (Steeper roofs shed snow more easily than flatter roofs)
- The texture of the roof surface (Metal roofs shed snow more easily than shingled roofs)
- Drifted/sliding snow potential at roof offsets and vertical projections

Thus, two buildings on the same block can have different roof snow loads based on the factors listed above.

The cities of Spokane and Spokane Valley currently require a minimum basic design roof snow load of 30 pounds per square foot (psf). Coeur d'Alene, Idaho requires a minimum basic design roof snow load of 40 psf. Kootenai County provides a snow load map on their website based on the reference by Sack and Sheikh-Taheri.

Weather History

The city of Spokane receives an average of 48" of snow per winter, while in Coeur d'Alene the average is 67". The winter of 2008-2009 had the highest recorded snowfall for Spokane at 97.7". Table 1 shows the seasonal snowfall records for Spokane.

Table 1. Seasonal Snowfall Records for Spokane

Rank	Winter	Total Snowfall (in)
1	2008-2009	97.7"
2	1949-1950	93.5"
3	2007-2008	92.6"
4	1974-1975	89.0"
5	1992-1993	87.3"

Reference: www.wrh.noaa.gov/.../Winter2007_2008.php

What made the 2008-2009 Winter unique was that most of the snow fell during a 3-1/2-week period from December 12, 2008 to January 6, 2009.

During the first half of December 2008, the weather was relatively mild with minimal precipitation, but the weather pattern changed dramatically on December 11 as very cold arctic air moved into the area. Initially, this arctic front only brought a few inches of snow to Spokane, but points north and east of the city received nearly a foot. The temperatures remained extremely cold, with highs in the single digits and teens.

The first of the series of snowstorms occurred on December 17 and 18. The two-day storm accumulation was more than 23" with 19.4" of snow recorded in a 24 hour period at Spokane International Airport (SIA). Prior to this the 24-hour snowfall record in Spokane was 13", set in 1950. Additional storms occurred on December 21, 22, 24, 27 and 29 with several other days of minimal snowfall. As a result, December 2008 became the snowiest December on record with 61.5". The previous record was 42.7" set in 1996. In addition, strong winds gusting to 50 mph occurred on December 29, which caused considerable drifting.

In January 2009, more storms occurred during the beginning of the month with significant snowfall during the first week of January. On January 6, 2009, the weather pattern changed leading to warmer, drier conditions, thus marking the end of the severe snow event.

Figure 1 shows the ground snow that was recorded at five stations during the 3½ week period. For this same period Table 2 shows the cumulative depth of ground snow, water equivalency and load equivalent along with required minimum basic design roof snow load for these same areas. Note that the actual ground snow load equivalents are consistently less than the minimum basic design roof snow loads.

Figure 1. Accumulated Ground Snow Load

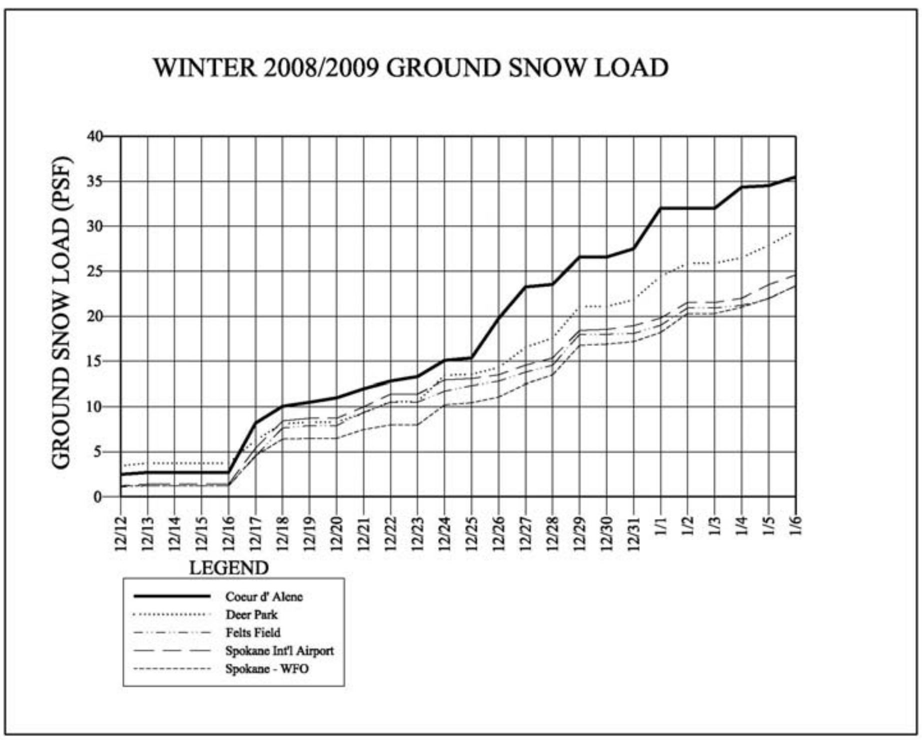

Table 2. Comparison of Actual and Design Snow Loads for Local Areas

Location	Ground Snowfall (in)	Water Equivalent (in)	Ground Load Equivalent (psf)	Minimum Basic Design Roof Snow Load (psf)
Spokane International Airport (SIA)	77.8	4.73	24.6	30
Deer Park	-	5.66	29.4	40
Felts Field	-	4.48	23.3	30
Airway Heights Weather Forecast Office (WFO)	-	4.49	23.3	30
Coeur d' Alene	-	6.81	35.4	40

References: National Weather Service - Records of River and Climatological Observations

In addition to the official measurements shown in Table 2, snow depths and weights were also collected and reported at many other locations, though careful measuring techniques were not always used by well-intentioned owners and occupants. In Spokane County, measured roof snow weights were reported between 22 psf and 34 psf. In Kootenai County reported values ranged between 31 and 40 psf. Measured snow weights exceeding the current minimum basic roof snow load may very well have occurred in drifted snow areas.

Basis of Evaluations

For the purpose of this report, a distinction is made between Primary Structures and Secondary Structures. Primary Structures are defined as buildings, including barns and open structures such as riding arenas. Secondary Structures are structures such as detached garages, awnings, storage sheds, and carports. In general, failures of Primary Structures pose the greater danger to public health, safety and welfare.

Photo 3: Failed Carport

What constitutes a structural failure? The term "structural failure" refers to the loss of the load-carrying capacity of a component or member within a structure, or of the structure itself. Structural failure is initiated when a member or its connection is stressed to its strength limit, thus causing fracture or excessive deformation. Beyond the strength limit, the load-bearing capacity is permanently reduced and excessive member deflection and/or collapse can occur suddenly.

Structural failures might include separated connections, broken, cracked or split members, and buckled columns or compression members. Collapsed members are generally replaced while sagging members can be repaired or replaced. Only members which required replacement or repair are considered to have experienced a structural failure.

As members are loaded in their elastic range, they deflect much like a spring. If the loads are removed, the members return to their original position. It was not uncommon for deflecting members to result in cracked interior drywall, or "sticky" doors and windows. As the snow melted, most members returned to their original position. Because no repair or replacement of the roof members was necessary, these instances do not constitute a structural failure.

Observations

Data were collected and inventoried for 108 structures in Spokane and Kootenai counties. These structures were reviewed by structural engineering firms in the area or were reported to local building departments. Not all sites were visited by structural engineers, and not all damaged structures were available for viewing. In several instances, repair or demolition was under way soon after the damage or failure occurred.

Of these 108 structures, 95 were noted as sustaining some form of structural failure resulting from the snow event. The remaining 13 structures inventoried exhibited roof deflections sufficient to cause concern for occupants, or were structures visited as a preventative measure at the direction of building owners.

Photo 4: Sliding Snow on Lower Roof

It is important to note that most of the structural failures occurred prior to the roofs receiving the city or county required minimum basic roof snow load, thus other factors led to these failures. Therefore, properly designed and constructed structures in good condition should have been adequate to resist the loading from the 2008-2009 snow event.

Structural Systems

The 95 failures evaluated for this report included a broad array of structure types and building ages. The collected data are found in the Appendix and are categorized in Table 3.

Table 3. Summary of Reported/Observed Structural Failure Types

Type of Structure	Number of Structures
Primary Structures	
Plate Connector Wood Trusses	24
Heavy Timber Trusses with Purlins	15
Beam and Joist Framing	13
Agricultural Pole Buildings	3
Other Wood Framed Structures	2
Total Wood Framed Structures	*57*
Pre-Engineered Steel Structures	11
Total Primary Structures	**68**
Secondary Structures	
Carports and Canopies	15
Residential Garages	9
Sheds/Utility Buildings	3
Total Secondary Structures	**27**
Total Reported/Observed Failures	***95***

As shown in Table 3, there were a variety of structural systems that experiences failures. The committee has made the following observations of the various structural systems:

- *Plate Connector Wood Truss Structures*

Plate connector wood truss structures represented the single most prevalent system exhibiting failures during the 2008-2009 snow event. The 24 reported failures for this building type constitute 35% of the 68 primary structure failures evaluated. Failures included member fractures and joint failures, as well as lateral buckling type failures resulting from improper installation of stability bracing. At several of the failure sites, it appeared that the failure of a single truss resulted in load being transferred to the adjacent trusses. These trusses then become overloaded and the failure propagated along the roof line. These failures are often sudden and provide occupants with little or no advanced warning to vacate the structure.

Photo 5: Failed Trusses at Retail Building

Photo 6: Failed Trusses Over Indoor Pool

- *Heavy Timber Truss Construction*

Fifteen (15) failures evaluated were of heavy timber truss construction with sawn-lumber purlins spanning between the trusses. This represents 22% of the primary structure failures observed. Observed failures were primarily caused by broken or split truss members and/or failure of truss connections.

Photo 7: Failed Bowstring Truss Heel Connection

These types of structures were very common in the 1930's through the 1960's, but are not common in more contemporary structures. The number of structures of this type has diminished over time, and their numbers will continue to decrease as they reach the end of their useful life. All of the heavy timber truss failures evaluated from the 2008-2009 snow event were older buildings; 40 to 100 years old.

At least two of the buildings had been renovated in recent years to provide better insulation and ventilation of the attic space. The better-insulated roofs resulted in less snow melt from interior heat transmission, and consequently more snow was retained on the roof than in previous winters.

- *<u>Wood Beam and Joist Framing Systems</u>*

  Failures in wood beam and joist framing systems were also a significant portion of the total evaluated. Thirteen (13) such wood framing systems were evaluated representing 19% of the primary structure failures, with a wide variety of configurations and modes of failure. Several appear to have failed due to a single weak point, such as a knot or split in a sawn lumber component, or an inadequate ledger connection.

Photo 8: Failed Glue Laminated Beam

The majority of the wood beam and joist framing systems were low-slope roofs, most having slopes of ¼" per foot or less. These roofs are more susceptible to drainage and ponding issues.

- *<u>Steel Framed Structures</u>*

  As indicated in Table 3, conventional steel framed structures generally performed well during the 2008-2009 snow event. An exception to this performance record is pre-engineered steel structures, 11 of which exhibited failures.

Photo 9: Buckled Column

Pre-engineered steel structures are designed by the supplier. Most often, they employ rigid moment-resisting frames with cold rolled steel roof purlins and wall girts. Bracing of column and beam flanges is often critical in order for the structure to support the design loads. Flange bracing was observed missing on three of the structural failures and had presumably either not been installed or had been removed at some point.

Photo 10: Buckled/Twisted Beam and Column

- *Secondary Structures*

Secondary structures evaluated were of both wood and metal construction. Carports were typically steel framed or aluminum framed; garages most often wood framed. Most of the secondary structures were estimated to be between 30 and 50 years old, although 3 of the carport structures were reported to be only a few years old.

Photo 11: Failed Garage Trusses

- *Flat or Low-Slope Roofs*

Flat or low-slope roofs (1/4" per foot or less) constituted 47% of the 68 primary structure failures evaluated. The observed failure mechanisms included member overstress, connection failure and ledger failure. Evidence of inadequate drainage was also observed.

Photo 12: Collapsed Low-Slope Roof

Low slope roofs do not always drain properly with heavy snow loads. Under normal conditions, rainwater or snow-melt flows to the low spot in the roof, where drains are located. Heavy snow loads can cause the joists to deflect to the extent that the middle of the joist becomes the low spot, thus collecting water away from a drain. As water collects at this location it results in increased load on the joist, which in turn results in further joist deflection. This increased deflection allows for collection of more water becoming a vicious cycle until the joist becomes overstressed and fails. This phenomenon is known as "ponding" and it is an issue specific to low-slope roofs.

Building Age

The 95 primary and secondary failures evaluated for this report were categorized into three age groups: 0-19 years old, 20-39 years old, and 40 and older as shown in Table 4. The ages of several of the structures were estimated as the exact age was unknown.

Table 4. Summary of Building Ages for Reported/Observed Structural Failures

Age	Number	Percent
0-19 years old	8	9%
20-39 years old	46	48%
40 years and older	41	43%
Total Number of Failures Evaluated	***95***	***100%***

The majority of failures occurred in structures over 20 years old. Recent building codes have more adequately provided design provisions for snow drifting, sliding and unbalanced loading conditions.

Older buildings are also more likely to have been modified during their service life. Modifications might include the application of additional layers of roofing materials, the addition of equipment loads, and non-engineered alterations of structural members or bracing. Added loads, whether they are roofing, equipment, or otherwise, diminish the structural capacity remaining for snow loads.

Over time, wood members are susceptible to creep, shrinkage and checking. Defects such as knots often become more brittle when subjected to seasonal moisture and thermal cycles.

Older building codes did not require as much site inspection and testing as current codes. This may have allowed more construction errors or omissions to go unnoticed. The purpose for the current level of inspection and testing is to insure that the quality, workmanship and material properties meet the designer's intent.

Recommendations

Based on evaluation of the data gathered, the Ad-Hoc Committee of the Spokane Chapter of Structural Engineers Association of Washington recommends retaining minimum design roof snow loads currently adopted by jurisdictions in the Spokane and Coeur d'Alene area. The committee encourages improved communication among design professionals, building officials/inspectors, and contractors to ensure that the built structure conforms to the design intent. It is the duty of the design professional to correctly implement the code design provisions for the building type and location. For structures constructed without design professional involvement, this responsibility rests with the permit-issuing government agency.

Specific recommendations are as follows:

- *Plate Connector Wood Truss Structures*
  Plate connector wood trusses are an efficient and common component of roof structures in contemporary construction. They are typically designed by the truss supplier for prescribed roof snow loads. Bracing of these truss framing systems must also be properly designed and installed. To achieve the design performance required, manufacturing, delivery, installation, and inspection must follow the IBC 2006 and the current Truss Plate Institute recommendations.

- *Heavy Timber Truss Construction*
  The structural design community is aware of the poor historical performance of this type of structure and its potential for sudden collapse. Recent codes have also recognized that unbalanced snow loads can cause stress reversals in web members and have provided design provisions to address this issue. Properly renovated and strengthened, heavy timber trusses can provide safe and stable continued use.

- *Wood Beam and Joist Framing Systems*
  The committee recommends that care is taken by the design professional to account for any low-slope areas where ponding could occur.

- *Steel Framed Structures*
  Of steel framed structures, pre-engineered buildings were the most problematic. Current methods of design, manufacturing, permitting, installation, and inspection should be reviewed. Inadequate bracing resulted in a number of the failures observed during the snow event. Better communication between all parties would result in a better performing structure.

- *Secondary Structures*
  Many of the failed wood-framed secondary structures observed were likely not designed. Of these structures, most were garages or outbuildings, and most were more than 20 years old. For structures of this nature, not required to be designed by a design professional, proper inspection is paramount to insure that good construction practices are being incorporated.

  Metal framed carports with long cantilevered roof decks did not perform well. Proper design, considering unbalanced loads will reduce the number of future failures.

- *Flat or Low-Slope Roofs*
  For new buildings, designers should give serious consideration to increasing roof slopes to 3/8” per foot or more to avoid ponding.

  It is imperative in a low-slope roof to keep roof drains cleared and unobstructed. Unfortunately, this is often overlooked by building owners and the buildup of ice, snow, or debris around a drain can prevent the roof from draining properly.

- *Miscellaneous*
  Some of the failures observed were due to additions or changes in roof geometry resulting in additional loads due to drifting and sliding snow. Proper evaluation of affected existing structures could reduce the number of structures that perform unsatisfactorily.

  Any repair to a damaged member must be designed to meet the requirements of the current building code. It should be noted that in a well-designed system, a localized failure should not cause immediate or progressive collapse of the entire structure.

APPENDIX

					COLOR KEY:		Steel Construction					**COLOR KEY:**		Secondary Structure	
							Wood Construction							No Structural Failure	
#	**Building Name**	**Street Address**	**City**	**State**	**Date of Collapse**	**Age of Building (years)**	**Structural System**	**Roof Slope (in/ft)**	**Measured Roof Snow at Time of Collapse (psf)**	**Approx. Building Size (LxW)**	**Is Engineering Report Available? (yes/no)**	**Is roof ponding suspected (yes/no)?**	**Was snow drifting observed (yes/no)?**	**Conclusions on Failure Mechanism**	**General Comments**
1	Distribution center	Coeur d'Alene	Coeur d'Alene	ID	Jan 2, 2009	10	Open-web steel joists and joist girders	1/4"/ft.	40 psf measured 1/2/09	221'x226'	Yes, Coffman Engineers	no	no	No failure occurred other than non-structural gyp walls with cracks	Building was evacuated while snow was removed, reoccupied after snow removal, no structural failures occurred
2	Federal courthouse	Coeur d'Alene	Coeur d'Alene	ID	Jan 2, 2009	1	Steel beams with metal deck	1/4"/ft.	40 psf measured 1/2/09	180'x160'	no	no	no	No failure occurred	Snow was removed from roof
3	Ice rink	Coeur d'Alene	Coeur d'Alene	ID	12/29/2008 & 1/2/2009	--	Rigid wood frames w/ 2x purlins	0.1333	Not measured	110x191	Yes, Coffman Engineers	No	No	Frame failure at center splice connection	
4	Barn	Deer Park	Deer Park	WA	late Dec 2008	1	Pre-engineered steel building	1/12	35 psf (approx)	150'x300'	No	No	No		Total Bldg Collapse - Due to form exclusion in permitting improper design was not checked.
5	Horse Arena	Deer Park	Deer Park	WA	late Dec 2008	4	Fabric Covered Frames	-	15 psf (approx)	80'x150'	No	No	No		Total Bldg Collapse - Due to form exclusion in permitting improper design was not checked.
6	Medical Center	Downtown	Spokane	WA	late Dec 2008/early Jan 2009	Various	Steel joists and concrete pan joists.	1/4"/ft.	30 psf	Varies	No	No	Slightly around mech units	No failure	Steel framed and concrete roofs were performing well with 30 psf load.
7	Retail store	Downtown	Spokane	WA	Jan 2, 2009	--	Parallel chord press-plate wood trusses	.25:12	Not measured	40x86	Yes, Coffman Engineers	No	No	One truss failed, causing 'zipper' effect.	CMU sufferend significant damage as it was ungrouted/unreinforced
8	Office building	Downtown Spokane	Spokane	WA	late Dec 2008/early Jan 2009				30 psf - measured	12000 sf	No	No	No	No failure	
9	School	East Central Spokane	Spokane	WA	late Dec 2008/early Jan 2009	--	Varied		No collapse - measured 30 psf on 1/2/09		No	No	No		
10	Warehouse	Fairchild AFB	Fairchild AFB	WA	Jan 2, 2009	57	Steel trusses and columns, wood 6x14 purlins	1/4"/ft.	23 psf measured 1/2/09	200'x300'	Yes, Coffman Engineers	no	no	existing purlins failed under snow load	Purlins repaired by adding steel channels each side
11	Warehouse	Fairchild AFB	Fairchild AFB	WA	Jan 2, 2009	67	Heavy-timber wood trusses with 2x12 purlins	1/4"/ft.	not measured; approx 25" depth based on verbal reports	160'x180'	Yes, Coffman Engineers	no	no	Existing wood trusses failed near the bottom chord splice locations where split ring connectors were used. During WWII, many large warehouse buildings such as this one were erected quickly using green timber trusses that subsequently dried and had bolted splice connections that shrank and split the wood in cross-grain tension, weakening the connection. The bottom chord members were also undersized based on an overestimation of the allowable tensile stress of the wood, causing failures of the bottom chord under less than the design snow loading.	Repairs were made by adding high-strength steel tension rods to each side of the bottom chords of the failed trusses.

					COLOR KEY:		Steel Construction					**COLOR KEY:**		Secondary Structure	
							Wood Construction							No Structural Failure	
#	**Building Name**	**Street Address**	**City**	**State**	**Date of Collapse**	**Age of Building (years)**	**Structural System**	**Roof Slope (in/ft)**	**Measured Roof Snow at Time of Collapse (psf)**	**Approx. Building Size (LxW)**	**Is Engineering Report Available? (yes/no)**	**Is roof ponding suspected (yes/no)?**	**Was snow drifting observed (yes/no)?**	**Conclusions on Failure Mechanism**	**General Comments**
12	Warehouse	Fairchild AFB	Fairchild AFB	WA	Jan 3, 2009	58	Heavy-timber wood trusses with 2x10 purlins	1/4"/ft.	31 psf	200'x192'	Yes, Coffman Engineers	no	no	Existing wood trusses failed near the bottom chord splice locations where split ring connectors were used. During WWII, many large warehouse buildings such as this one were erected quickly using green timber trusses that subsequently dried and had bolted splice connections that shrank and split the wood in cross-grain tension, weakening the connection. The bottom chord members were also undersized based on an overestimation of the allowable tensile stress of the wood, causing failures of the bottom chord under less than the design snow loading.	Repairs are to be made by adding high-strength steel tension rods to each side of the bottom chords of the failed trusses.
13	Warehouse	North Spokane County	Spokane	WA	late Dec 2008	40	2x6 rafters with heavy timber trusses at 10 feet on center	1/4"/ft	snow had been removed	36'x50'	Yes, Coffman Engineers	no	snow had been removed	Failre of tension chord of heavy timber truss	Poor design of heavy timber truss
14	Schools	North Spokane County	Spokane	WA	late Dec 2008/early Jan 2009	Various	Steel bar joists	1/4"/ft.	32 psf - measured	Varies	Yes	No	No	No failures	
15	Athletic club	Sandpoint	Sandpoint	ID	late Dec 2008	25	Wood steel plated trusses at 24 feet on center	3/12	30 psf (approx)	70'x150'	Yes, Coffman Engineers	No	No	Trusses were failing @ pressed plates; large vertical deflection.	Poor quality in construction of trusses.
16	Retail store	South Hill	Spokane	WA	late Dec 2008	30	Pre-engineered wood trusses, parallel chord	1/4"/ft.	25" high, approx 30 psf	35'x100'	Yes, Coffman Engineers	no	no	Some trusses supporting a mech unit had bottom chords that completely broke (gross tension failure), most likely due to the combined weight of snow and the mechanical unit.	Trusses may not have been designed for the mech. Unit + snow loading
18	Warehouse	Spokane	Spokane	WA	late Dec 2008	25	Pre-engineered steel building	1/12	30 psf (approx)	70'x200'	Yes, Coffman Engineers	No	No	Improper snow load design	Total Bldg Collapse - Due to form exclusion in permitting improper design was not checked.
19	Waerehouse (730 N. Hamilton??)	Spokane	Spokane	WA	late Dec 2008/early Jan 2009	~55	bowstring trusses on cmu shear/bearing walls		not measured	80'-x180'	Yes, Coffman Engineers	no	unbalanced snow load was observed	Typical bowstring truss issues (under-designed elements and consideration of uniform load only) coupled with sliding snow that created severe unbalanced snow load condition.	Most trusses showed signs of damage, some severe. Widespread cracking prompted use of repair concept on all trusses as a strengthening measure to upgrade the building. Facility has been well-maintained.
21	Warehouse	Spokane Valley	Spokane	WA	Jan 2, 2009	55	2x rafters with glulam beams at 20 ft on center	1/4"/ft	snow had been removed	90'x120'	Yes, Coffman Engineers	yes	snow had been removed	Failure of two glulam beams due to severe ponding at ineffective roof drain	Building was sandwiched between two adjacent structures
22	Warehouse	Spokane Valley	Spokane	WA	late Dec 2008/early Jan 2009	65	3x12 rafters with bowstring trusses at 20 feet on center	--	snow had been removed	70'x200'	No	no	Snow drift had been observed by owner	Failure of tension chord of bowstring truss	Bowstring truss failure due to snow drift

#	Building Name	Street Address	City	State	Date of Collapse	Age of Building (years)	Structural System	Roof Slope (in/ft)	Measured Roof Snow at Time of Collapse (psf)	Approx. Building Size (LxW)	Is Engineering Report Available? (yes/no)	Is roof ponding suspected (yes/no)?	Was snow drifting observed (yes/no)?	Conclusions on Failure Mechanism	General Comments
					COLOR KEY:		Steel Construction					COLOR KEY:		Secondary Structure	
							Wood Construction							No Structural Failure	
24	Exhibition building	Spokane Valley	Spokane	WA	late Dec 2008	~30	Pre-engineered steel trusses, parallel chord	0.175	not measured; approx 30 psf	24'x114'	No	no	Not observed, but sliding snow may have occurred	Sliding snow from upper roof collected on eave of lean-to structure precipitating failure of the lean-to.	Rebuild underway - See also #77
25	Retail store	Spokane Valley	Spokane Valley	WA	late Dec 2008/early Jan 2009	40	TJI's spanning to interior steel framing lines and exterior CMU	.25:12	22 psf on adjoining roof on date of first collapse	100x90	Yes, Coffman Engineers	No	Yes - on adjacent roof	TJI's appeared to be the first member to fail.	Potential reroof with ballast
26	Storage	Spokane Valley	Spokane	WA	late Dec 2008/early Jan 2009	--	Pre-engineered metal bldg with multiple additions	0.1333	Not measured	Odd shaped - includes appx 80,000sf	No	Yes	No	Multiple areas of failure - purlins in two locations, rigid frames in another	Excessive deflection in purlins appeared to cause ponding
27	School	Spokane Valley	Spokane Valley	WA	late Dec 2008/early Jan 2009	--	Varied	Varied	No collapse - measured 38, 34, and 28 psf on three different schools on 1/6/09	Varies	Yes, Coffman Engineers	No	No	NA	
31			Fairchild AFB	WA	39815	52	Steel trusses and columns, wood 6x14 purlins	1/4"/ft.	not measured; approx 25" depth based on verbal reports	200'x300'	Yes, Coffman Engineers	no	no	Some existing wood 6x14 purlins split due to snow load.	Roof snow removed and purlins repaired using steel channels both sides
32	The Village on Broadway	12623 E Broadway	Spokane Valley	WA	12/28/2008	20	Carport with corrugated metal roof, cold-formed purlins and cantilievered columns	0.25		18'x72'	Baja Construction	no	no	Roof deck buckling at supports and mid-span and excessive deflections	1 1/2" deckx4' cantilevers+10' span on 10"x2 1/2" purlins with cantilever 1 column bents
33	River Rock Apartments	12721 E Shannon	Spokane Valley	WA	12/29/2008	1	Carport with corrugated metal roof, cold-formed purlins and wood columns	0.25		18'x90'	Wyatt Archiects?	no	yes	Roof deck buckling at supports and mid-span and excessive deflections	2" deckx4' cantilevers+10' span on 10"x3 1/4" purlins with two wood column bents
34	Value Village	13112 E Sprague	Spokane Valley	WA	12/31/2008	50	dimensional lumber purlins on bowstring wood trusses on cmu walls	Arch		120'x140'	Yes, 425-462-1515	no	no	Sagging, leaks	Declared safe by engineer
35	Vacant Space	13118 E Sprague	Spokane Valley	WA	12/31/2008	30	TJL trusses and pressed plate trusses on glulam beams on cmu walls	0.25		120'x120'	No	no	no	Leaks. No sagging	Declared safe by engineer
36	Motion Auto Supply	13124 E Sprague	Spokane Valley	WA	12/31/2008	30	TJL trusses and pressed plate trusses on glulam beams on cmu walls	0.25		120'x120'	No	no	no	Leaks. No sagging	Declared safe by engineer
37	Dollar Tree	15520 E Sprague	Spokane Valley	WA	12/27/2008									Collapse	
38	Fred Meyer	15609 E Sprague	Spokane Valley	WA	12/27/2008										Sagging
39	Eagle Rock Apartments	2410 N Cherry	Spokane Valley	WA	12/29/2008	9	Carport with corrugated metal roof, cold-formed purlins and cantilievered columns	0.25	28	18'x18'-72'	Baja Construction	yes	no	Roof deck buckling at supports and mid-span and excessive deflections	1 1/2" deckx4' cantilevers+10' span on 10"x2 1/2" purlins with cantilever 1 column bents
42	Mieneke Muffler	523 N Pines	Spokane Valley	WA	1/5/2009	10	Pressed-plate trusses supported on glulam beams and CMU walls	0.25		45'x220'	Third Ave Properties, Green Ridge Fund?	no	no	Excessive deflection, cracked gypsum	Restored after shovelling

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					COLOR KEY:		Steel Construction					COLOR KEY:		Secondary Structure	
							Wood Construction							No Structural Failure	
43	Oak Club	726 N McDonald	Spokane Valley	WA	12/29/2008	28	Carport with corrugated metal roof, cold-formed purlins and tube steel columns	0.25	16	18'x90'	Baja Construction	no	no	Roof deck buckling at supports and mid-span and excessive deflections	1 1/4" deckx4' cantilevers+10' span on 10"x2 1/2" purlins with two steel column bents
44	American Thrift	1010 N. Atlantic	Spokane	WA	1/21/2009	30	Pressed plate trusses supported on CMU	4	33	40' x 100'	limited	no	no	truss failed possibly bottom chord	unheated structure
45	American Thrift	1010 N. Atlantic	Spokane	WA	unknown	70+	Long span multi-ply trusses and joists	0	unknown	50' x 70'	limited	no	no	unsure-possible column failure	
46	Hancock Fabrics	1020 W Francis	Spokane	WA	12/31/2008	27	Pressed-plate trusses clear-spanning between wood stud bearing walls.	0.25	unknown (28-30 MKA)	65' x 230'	Yes, DCI	no (yes-MKA)	unknown	Possible failure of truss due to unbraced top chord	Partial failure of approx. 70' of building on south end
47	Spokane Sporthorse Riding Arena	10710 S. Sherman Road	Spokane	WA	1/5/2009	20	Pre-engineered metal building	3	unknown	216' x 122'	no	no	no	Column buckling followed by progressive collapse	Total collapse, snow load did not appear to be near design capacity
48	Rosauers-5 Mile	1724 W Francis Ave.	Spokane	WA	12/29/2008	52	Wood bow string trusses	Barrel	22	Original collapse portion 13,200	no	no	unknown	Bowstring trusses, bolt pull through in bottom chord	
50	3229 Ferry Warehouse	3229 E Ferry Ave.	Spokane	WA	1/10/2009	48	Long-span wood bow string truss supporting solid sawn purlins	Arch		100' x 128'	limited calcs for fix, DCI	no	no	Failure of supporting column caused collapse. Added canopy also collected snow	Kickers @ truss and did not allow truss to deflect
51	Evergreen Parking	707 W 2nd	Spokane	WA	12/25/2008	approx. 80	Bow string trusses supporting solid sawn purlins	Arch	Unknown	50' x 140'	DCI Calcs	no	unknown	Likely tension failure in bottom chord	One truss out of 10 failed, others show signs of distress
52	Rocker Arm Supply Building, RAS Properties	815 N Lincoln	Spokane	WA	Approx. 1/2/09	approx. 90	Wood post and beam, 2-story supported by URM Walls	0	unknown	67' x 75'	Limited Calcs, DCI	no	no	Failure of Main Roof Support Beams in (2) locations, damange to URM wall occurred	Beams were made up of (5) 2 x 12's and were not sufficient for span under code loads. Columns maybe removed at some point
53	Mel's Nursery	8800 N Division	Spokane	WA	unknown	approx. 20	Press-plate trusses, wood stud bearing walls	4	unknown	91' x 58'	No	no	no	Failure	
54	Fisher/Mow Residence	1016 S Madison	Spokane	WA	12/27/2008	50	Conventional wood framing	4		40'x26'	No, Debris removed before site visit	no	no	Failure of leanto carport roof ledger.	
55	Tranny Shack	1401 N Division Street	Spokane	WA	12/26/2008	30	Pressed-plate trusses supported on glulam beams and CMU walls	0.5	25	148'x60'	Yes, Inland Northwest Engineering	no	no	Failure of pressed plates not centered on connections and inadequately designed for strength and deflection.	
56	Ash Street Plaza	2223 North Ash Street	Spokane	WA	1/2/2009	30	Pressed-plate trusses supported on glulam beams and wood framed walls	0.25	27	120'x49'	Yes, Inland Northwest Engineering	yes	no	Failure of pressed plates not centered on connections.	
57	Thrifty Supply Company	3210 E Trent Ave	Spokane	WA	12/29/2008	30	Pressed-plate trusses supported on glulam beams and CMU walls	0.25	25	120'x180'	Yes, Inland Northwest Engineering	no	no	Failure of pressed plates not centered on connections.	
58	Willaims Barn	8901 S Hangman Valley Road	Spokane	WA	12/30/2008	20	Pressed-plate trusses supported on dimensional lumber beams and wood framed walls	4		97'x68'	No, Debris removed before site visit	no	yes		
59	Global Fitness	110 W Price Ave	Spokane	WA	12/30/2008	+/-30	Parallel chord, pressed plate trusses on steel beams	0	na	50'x50'	Yes, Integrus	yes	no	Severed tension chord	minor moisture damage observed throughout
60	Inland Empire Drywall	5113 E Railroad Ave	Spokane Valley	WA	12/23/2008	50	Pressed plate wood trusses supported on exterior concrete walls	3		100'x50'	Yes, Integrus	no	no	Failure of wood trusses	
61	Abadan Reprographics	2615 4th Street	Coeur d'Alene	ID	Jan. 2009	30 est.	Pressed plate wood trusses supported on wood framed walls	0.25	30 est.		no	no	no	Failure of wood trusses	
62	Coeur d'Alene Siding Supply	500 Dalton Ave.	Coeur d'Alene	ID	Jan. 2009	30 est.	Pressed plate wood trusses supported on steel beams and concrete tilt-up walls	0.25	30 est.		no	no	no	Failure of wood trusses	

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							Wood Construction							No Structural Failure	
63	Redinger Horse Arena	995 Neufele Lane	Colburn	ID	2/8/2008	1	Pressed plate wood trusses supported on wood posts embedded into the ground	3	31	70'x144'	yes	no	no	Wood post instability	Supporting posts were too slender for the combination of load and unbraced length
64	Coeur d'Alene Tractor	W 1112 Appleway	Coeur d'Alene	ID	2/4/2008	30 est	Pressed plate wood trusses supported on CMU walls	0.25	25 est.	40'x80'	no	no	no	Failure of wood trusses	
65	Spokane Hardware Supply	2001 E Trent Avenue	Spokane	WA	1/2/2009	40-50	2x joists bearing spanning to glulam beams	0.25	not taken	80' x 140'	yes	yes	no	2 glulam beams failed	failure occurred near a roof drain that may not have been working
66	Wren Pierson Center	609 2nd Street	Cheny	WA	1/5/2009	50-60	2x joists spanning to multi-ply wood trusses, cmu perimeter walls	.25-.50	not taken	40' x 80'	yes	no	no	multi-ply wood truss failed at bottom chord	See also #75
67	Trinity Baptist Church	6528 N Monroe	Spokane	WA	12/30/2008	27	Pressed plate trusses supported on 2x wood framed walls	0.25	28	50'x80'	Yes, MKA	Yes	No	Rotation due to lack of lateral bracing	Collapsed 2 walls as well
68	Barn	+/- 15000 N. Muzzy	Newman Lake	WA	1/4/2009	+/- 50	Site fabricated wood trusses on wood beams and posts	3:12	38	60'x120'	No	No	No	Member overstress	
69	Spokane Raceway Park-Warehouse	102 N Hayford Rd	Spokane	WA	Unknown	+/- 40	Steel Truss Frame	2:12	Unknown	50'x60'	Yes, MKA	No	No	Frame overstressed	
70	Commercial Building	126 N Crestline	Spokane	WA	12/24/2008	35	Pressed plate trusses supported on 2x wood framed walls	4:12	15-20	80'x80'	Yes, MKA	No	No	Buckling of web members due to lack of bracing	
71	Commercial Building	1403 N Greene	Spokane	WA	12/29/2008	25	Pressed plate trusses supported on 2x wood framed walls	1:12	20-Est	80'x120'	Yes, MKA	No	No	Rotation due to lack of lateral bracing	Only 1/5 of roof collapsed. Remaining trusses had several loose press plates
72	Simson Lumber	1680 W Prairie	Hauser	ID	12/30/2008	40	Wood framed 3-hinge arch	Curved	25-30	50'x115'	Yes, MKA	No	no	Underdesigned	
73	Hangman Valley CC	2210 E Hangman Valley Rd	Spokane	WA	Damaged-Unknown	+/- 40	Heavy timber trusses	Varies	Unknown	Unknown	Yes, MKA	No	Yes	Sliding snow on step roof landing on flat roof	Not collapsed- Broken beams
74	Reliance Corp	3807 E Central	Spokane	WA	Damaged-12/31/2008	30	Pole Bldg- wood trusses	4:12	Unknown	90'x120'	Yes, MKA	No	No	Overstress of truss/ inadequate bracing	Not collapsed- Damaged trusses
78	Strip Mall	Country Homes & Division	Spokane	WA	1/1/2009		Pressed-plate trusses supported on glulam beams and CMU walls	.25 Est	30 Est	40'x60' Est	No	yes	No	Collapse	
81	Metal Building	1327 E Joseph	Spokane	WA	Unknown	Old	Metal Bldg. Had been removed & replaced with new metal bldg.	Unknown	Unknown	Unknown	No	No	No	Did not see failure	
83	Quonset Hut	142 E Illinois	Spokane	WA	Unknown	Unknown	Carved metal/plastic roof with CMU stem wall	Curved	Unknown	30' or 40' X 60' +/-	No	No	No	One end of structure collapsed	Very old looking structure
85	Residential Garage	1523 E Wellesley	Spokane	WA	Unknown	40+/-	Wood frame	3:12+/-	Unknown	15'x20' +/-	No	No	No		
86	Apartment Carport	1604-1610 W. Fairview	Spokane	WA	Unknown	30+/-		Flat	Unknown	Unknown	No	No	No		
87	Apartment Carport	1711 W 7th Ave.	Spokane	WA	Unknown	50+/-		Unknown	Unknown	Unknown	No	No	No	Unknown	Could not view
88	Residential Garage	2102 E 1st Ave.	Spokane	WA	Unknown	50+/-	Assume wood frame- demo had been removed	Probably 3:12 or 4:12	Unknown	Single car garage 15'x25'+/-	No	No	No	Unknown	Demo had been removed
89	Apartment Walkway	2126 E Boone	Spokane	WA	Unknown	40-50		Unknown	Unknown	10'x50'+/-	No	Could have		Flat roof awning, sliging snow possible	
90	Residential Garage	2305 W Gardner	Spokane	WA	Unknown	50-60	Probably 2x wood frame	3:12+/-	Unknown	15'x26' +/-	No	No	No	wood member or nailed joint failed	
93	Residential Garage	2529 W Gardner	Spokane	WA	Unknown	50-60	Probably 2x wood frame	3:12+/-	Unknown	Unknown	No	No	No	wood member or nailed joint failed	
95	Industrial	3117 E Ferry	Spokane	WA	Unknown	30-40	Wood frame heavy timber-Metal roof	2:12 or 3:12	Unknown	Unknown	No	No		Possible sliding snow from adjacent higher metal roof building	Roof totally destroyed but building not totally collapsed
96	Apartment Carport	3141 E 37th Ave.	Spokane	WA	Unknown	40-50	Looked like wood decking-beam and post	Very low pitch	Unknown	Unknown	No	No	No	Unknown	Damage had been removed
97	Residential Garage	322 S Freya	Spokane	WA	Unknown	Unknown	Roof probably wood frame	3:12+/-	Unknown	15'x26' +/-	No	No	No	All damage had been removed	

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98	Residential Garage	325 E North	Spokane	WA	Unknown	40-50	2x wood framed roof to wood stud bearing wall	3:12+/-	Unknown	25'x25'	No	No	No		
100	Residential Garage	3501 W Kiernan	Spokane	WA	Unknown	Unknown	2x wood framing	3:12+/-	Unknown	Unknown	No	No	No	2x wood framing or nailed joint failure	
102	Commercial	3801 E Sprague	Spokane	WA	Unknown	30+/-	2x framing to 2x wood stud wall with metal roof	1:12 or 2:12	Unknown	20'x20'	No	No	No	Wood member or nailed connection failure	
103	Commercial Warehouse	3857 E Olive	Spokane	WA	Unknown	40-50	Unreinforced brick masonry bearing wall with built-up wood trusses and stick framing	Flat or very low pitch	Unknown	50' or 100'	No	Could have	No	Possible deflection of roof causing brick wall to bow outward and collapse	
106	Residential Garage	4028 N Elm	Spokane	WA	Unknown	40-50	Wood 2x framing was not professionally designed	3:12+/-	Unknown	Single car garage 15'x25'+/-	No	No	No	Members and/or connections failed	Very old and appeared to be in poor condition
107	Commercial	406 E Rowan	Spokane	WA	Unknown	20+/-	Wood	Low pitch or flat	Unknown	50' or 100'	Unknown	Could have	No	Did not see failure	
109	Residential Garage	4507 N Adams	Spokane Valley	WA	Unknown	50+/-	Wood stick frame	Unknown	Unknown	Single car garage 15'x25'+/-	No	No	No	Failed nail connection and 2x member	Very old and appeared to be in poor condition
111	Storage Shed	507 N Howard	Spokane	WA	Unknown	Unknown	Steel or aluminum storage shed	3:12+/-	Unknown	8' X 12' +/-	No	No	No		Looked like "off the shelf" metal storage building
112	Apartment Building	511 E Indiana	Spokane	WA	No collapse	20+/-	Wood frame walkway canopy & stair roof	Flat	Unknown	10'x50'+/-	No	No	No	No failure- just deformation	
113	Metal Building Storage Shed	6619 N Cedar Rd.	Spokane	WA	Unknown	Unknown	Metal bldg. Gable frame steel metal roof	Unknown	Unknown	Unknown	No		Could have been between ridges on gable roof		All debris had been removed
115	Commercial Space	7011 N Division	Spokane	WA	Unknown	30+/-	Wood	Flat or very low pitch	Unknown	30' or 70'+/-	No	Could have	No	Did not see the collapsed structure	Commercial space
117	Residential Carport	704 S Ash	Spokane	WA	Unknown	40-50	Assume wood stick frame- could not see collapse	Unknown	Unknown	Unknown	No			Could not view	Older structure, not well maintained
120	Quonset Hut	915 E Rosewood	Spokane	WA	Unknown	Unknown	Collapsed Quonset hut had been removed & site was fenced off	Curved	Unknown	50' or 100'	No	No	No	Old age	Site cleaned-up
121	Storage Building	916 S Hatch	Spokane	WA	Unknown	Unknown	CMU walls & flat roof	Flat	Unknown	Unknown	No	Could have	No	Wood members failed	Ripley's Plumbing
122	Commercial	918 W Mallon	Spokane	WA	Unknown	40-50	Press plate truss- masonry bearing wall	Flat	Unknown	20' or 50'+/-	No	Possible	No	Probably failure of metal plate connectors	Building was completely rebuilt
123	Mead School District Transportation Bldg.	Market St.	Mead	WA	1/5/2009	50+	Sawn lumber roof joists supported by bowstring wood trusses and unreinforce masonry walls and pilasters	curved	25	56'x144'				Collapse	See also #79
124	Residence	610 W Bradford Ct.	Spokane	WA	Unknown	20+/-	Front porch canopy 4x wood framed column and knee brace beam	4:12	Unknown	Section of collapse 24'x8'	Yes, evaluation	No	Yes, some	Inadequate design	Knee brace forced base of column to push into house- not a complete collapse
125	New Heights Church	708 W Nora Ave.	Spokane	WA	Unknown	100+	1x sheathing, 4x purlin to 4x wood truss	3 or 4:12	Unknown	large- Not measured	Yes, evaluation	Yes	No	Inadequate design	Wood purlin split at knot in bottom of beam. May have been from snow falling from nearby tree.
126	Sunshine Disposal	2407 North University	Spokane Valley	WA	1/8/2009	40	Metal Systems Frames	0.25:12	?	60x100	?	no	no	damaged frame bending	Frame columns detached from piers during use.
128	University Apartments	3205 South University	Spokane Valley	WA	12/29/2008	25	Light gage metal canopy	0.25:12	?	20x60	no	no	no	Bending of light gage metal carport	Roof deck, column and beams failed.

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129	Pheasant Ridge Apartments	601 South Woodruff	Spokane Valley	WA	12/29/2008	3	Light gage metal canopy	0.25:12	24"	20x200	no	no	no	Bending of light gage metal carport	Deck overhang bending only.
130	Amberwood Club Apartments	3020 South Clinton	Spokane Valley	WA	1/7/2009	25	Light gage metal canopy	0.25:12	?	20x200	no	no	no	Bending of light gage metal carport	Roof deck, column and beams failed.
131	Private Residence	3904 South Skipworth	Spokane Valley	WA	12/29/2008	20	Pressed plate scissor trusses	4:12	48"	30x40	no	no	yes	Bottom chord tension	Walls pushed when trusses failed.
133	Unoccupied Commercial Building	509 North Ella	Spokane Valley	WA	12/29/2008	30	Metal building with steel trusses	0.5:12	24"	50x60	?	no	no	Steel truss failure	Unheated at failure-nearby identical buildings ok.
134	Capel Rugs	1321 North Mullan	Spokane Valley	WA	12/31/2008	30	Pressed plate trusses on steel joist girders	0.25:12	?	200x100	?	yes	no	Wood truss failure	Bending and end shear top chord failure.
135	Carwash	11409 East Sprague Avenue	Spokane Valley	WA	12/31/2008	25	Light gage metal canopy	3:12	?	30x50	no	no	yes	Bending in roof decking	Minor damage.
136	Buck's Tire	918 W Mallon Ave	Spokane	WA			Wood Trusses on CMU bearing walls	.25:12		60x100		yes	no	Wood Ledger Failure	
137	Church		Spokane	WA	12/25-1/1		Wood Trusses on Wood Bearing Walls	3:12		80X80	yes	no	no	Truss failure/Improper compression bracing	
138	Warehouse		Spokane	WA	12/25-1/1	50+	bowstring trusses on cmu shear/bearing walls	arch			yes	no	no	Shed roof failed. Connection to main building pulled wall out from under bowstring trusses.	
139	Spokane Seed	6015 East Alki	Spokane Valley	WA	1/5/2009	30	Wood truss pole building	3:12	12"	200x50	no	no	no	Wood truss failure	Owner said trusses were damaged before snow load.