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Frame Building Expo

Snow Loading Patterns Observed During the 2009/2010 Winter

timbertech ENGINEERING

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Overview

- Weather Events
- Code requirements
- Building Description
- Snow Damage
- Snow Distribution Observed
- Snow Loading
- Contributing Factors to Failure
- Rebuilding
- Recommendations

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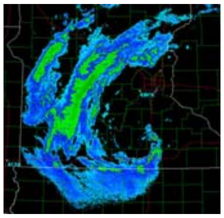
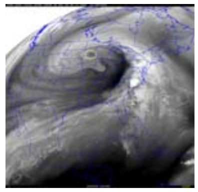
Midwest Blizzard December 25-27, 2009





Blizzard Paralyzes Much of Midwest

Ground Snow Load for Midwestern United States per IBC 2009

Snow Load per ASCE7-05

Chapter 7
SNOW LOADS

7.2 GROUND SNOW LOADS, p_g

Ground snow loads, p_g, to be used in the determination of design snow loads for roofs shall be as set forth in Fig. 7-1 for the contiguous United States and Table 7-1 for Alaska. Site-specific case studies shall be made to determine ground snow loads in areas designated CS in Fig. 7-1. Ground snow loads for sites at elevations above the limits indicated in Fig. 7-1 and for all sites within the CS areas shall be approved by the authority having jurisdiction. Ground snow load determination for such sites shall be based on an extreme value statistical analysis of data available in the vicinity of the site using a value with a 2 percent annual probability of being exceeded (50-year mean recurrence interval).

Snow loads are zero for Hawaii, except in mountainous regions as determined by the authority having jurisdiction.

7.3 FLAT ROOF SNOW LOADS, p_f

The snow load, p_f, on a roof with a slope equal to or less than 5° (1 in./ft = 4.76°) shall be calculated in lb/ft² (kN/m²) using the following formula:

$$p_f = 0.7 C_e C_t I p_g \quad (7\text{-}1)$$

but not less than the following minimum values for low slope roofs as defined in Section 7.3.4:

where p_g is 20 lb/ft² (0.96 kN/m²) or less,

$p_f = (I)\, p_g$ (Importance factor times p_g)

where p_g exceeds 20 lb/ft² (0.96 kN/m²),

$p_f = 20(I)$ (20 lb/ft² times Importance factor)

7.3.1 Exposure Factor, C_e. The value for C_e shall be determined from Table 7-2.

7.3.2 Thermal Factor, C_t. The value for C_t shall be determined from Table 7-3.

7.3.3 Importance Factor, I. The value for I shall be determined from Table 7-4.

7.3.4 Minimum Values of p_f for Low-Slope Roofs. Minimum values of p_f shall apply to monoslope roofs with slopes less than 15°, hip and gable roofs with slopes less than the larger of 2.38° (1/2 on 12) and (70/W) + 0.5 with W in ft (in SI: 21.3/W + 0.5, with W in m), and curved roofs where the vertical angle from the eaves to the crown is less than 10°.

Snow Load per ASCE7-05

7.4 SLOPED ROOF SNOW LOADS, p_s

Snow loads acting on a sloping surface shall be assumed to act on the horizontal projection of that surface. The sloped roof snow load, p_s, shall be obtained by multiplying the flat roof snow load, p_f, by the roof slope factor, C_s:

$$p_s = C_s p_f \quad (7\text{-}2)$$

7.4.1 Warm Roof Slope Factor, C_s. **7.4.2 Cold Roof Slope Factor, C_s.**

7.6 UNBALANCED ROOF SNOW LOADS

Balanced and unbalanced loads shall be analyzed separately. Winds from all directions shall be accounted for when establishing unbalanced loads.

7.6.1 Unbalanced Snow Loads for Hip and Gable Roofs. For hip and gable roofs with a slope exceeding 70° or with a slope less than the larger of $70/W + 0.5$ with W in ft (in SI: $21.3/W + 0.5$, with W in m) and 2.38° (1/2 on 12) unbalanced snow loads are not required to be applied. Roofs with an eave to ridge distance, W, of 20 ft (6.1 m) or less, having simply supported prismatic members spanning from ridge to eave shall be designed to resist an unbalanced uniform snow load on the leeward side equal to Ip_g. For these roofs the windward side shall be unloaded. For all other gable roofs, the unbalanced load shall consist of $0.3p_s$ on the windward side, p_s on the leeward side plus a rectangular surcharge with magnitude $h_d\gamma/\sqrt{S}$ and horizontal extent from the ridge $8\sqrt{S}h_d/3$ where h_d is the drift height from Fig. 7-9 with ℓ_u equal to the eave to ridge distance for the windward portion of the roof, W. Balanced and unbalanced loading diagrams are presented in Fig. 7-5.

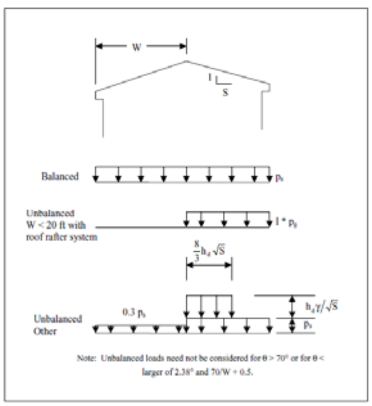


FIGURE 7-5 BALANCED AND UNBALANCED SNOW LOADS FOR HIP AND GABLE ROOFS

7.7 DRIFTS ON LOWER ROOFS (AERODYNAMIC SHADE)

Roofs shall be designed to sustain localized loads from that form in the wind shadow of (1) higher portions structure and (2) adjacent structures and terrain featu

7.7.1 Lower Roof of a Structure. Snow that forms drifts comes from a higher roof or, with the wind from the opposite direction, from the roof on which the drift is located. These two kinds of drifts ("leeward" and "windward" respectively) are shown in Fig. 7-7. The geometry of the surcharge load due to snow drifting shall be approximated by a triangle as shown in Fig. 7-8. Drift loads shall be superimposed on the balanced snow load. If h_c/h_b is less than 0.2, drift loads are not required to be applied.

For leeward drifts, the drift height h_d shall be determined directly from Fig. 7-9 using the length of the upper roof. For windward drifts, the drift height shall be determined by substituting the length of the lower roof for ℓ_u in Fig. 7-9 and using three-quarters of h_d as determined from Fig. 7-9 as the drift height. The larger of these two heights shall be used in design. If this height is to or less than h_c, the drift width, w, shall equal $4h_d$ and the height shall equal h_d. If this height exceeds h_c, the drift wid shall equal $4h_d^2/h_c$ and the drift height shall equal h_c. How the drift width, w, shall not be greater than $8h_c$. If the drift w, exceeds the width of the lower roof, the drift shall be trun at the far edge of the roof, not reduced to zero there. The mum intensity of the drift surcharge load, p_d, equals $h_d\gamma$ snow density, γ, is defined in Eq. 7-3:

$$\gamma = 0.13p_g + 14 \text{ but not more than 30 pcf}$$

(in SI: $\gamma = 0.426p_g + 2.2$, but not more than 4.7 kN/m³)

This density shall also be used to determine h_b by dividing p_s by γ (in SI: also multiply by 102 to get the depth in m).

7.7.2 Adjacent Structures and Terrain Features. The requirements in Section 7.7.1 shall also be used to determine drift loads caused by a higher structure or terrain feature within 20 ft (6.1 m) of a roof. The separation distance, s, between the roof and adjacent structure or terrain feature shall reduce applied drift loads on the lower roof by the factor (20-s)/20 where s is in ft ([6.1-s]/6.1 where s is in m).

7.8 ROOF PROJECTIONS

7.9 SLIDING SNOW

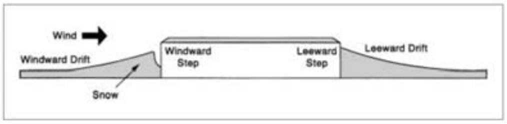


FIGURE 7-7 DRIFTS FORMED AT WINDWARD AND LEEWARD STEPS

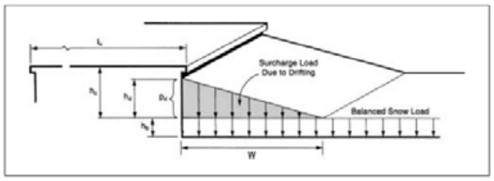


FIGURE 7-8 CONFIGURATION OF SNOW DRIFTS ON LOWER ROOFS

STRUCTURE

November, 2008 Lessons Learned - Issues and solutions encountered by practicing structural engineers

Structural Collapse from Snow Loads

Michael O'Rourke, Ph.D., P.E.

Every winter brings with it a unique collection of snow related building collapses. Although each collapse is different - different structural engineer, different contractor - there are certain elements, roof geometry being one, that are similar and that can be used to categorize the collapses.

This article presents such a categorization based upon roof collapse case histories from the author's forensic consulting practice. The hope is that an improved understanding of the circumstances that have led to structural performance problems in the past will result in fewer collapses and headaches for structural engineers in the future.

Although there are exceptions, it is generally the case that snow related roof collapses are due to larger than average loads on a small portion of roof, as opposed to nominally uniform loads over the whole roof. As evidenced by the percentages in Table 1, the most common of these "larger than average" snow loads are drift loads of one kind or another, and to a much lesser extent, sliding snow loads or ice dams at the eave of a roof.

Parapet Walls **Open Air and Cold Buildings**

Combined Drifts **Ice Dams** **Rain-on-Snow**

Building Description

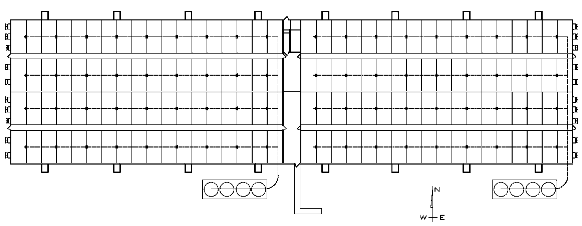
102'x396' Hog finishing barn located in north central Iowa constructed in 2006

Building Description

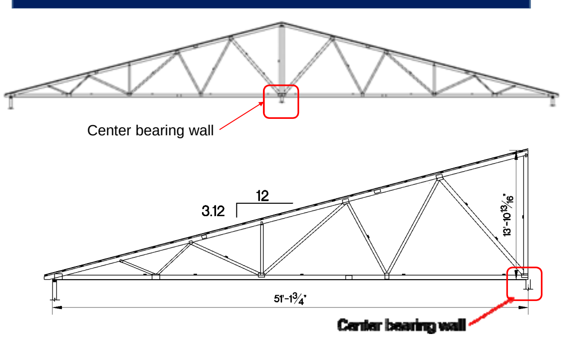
102’x396’ Hog finishing barn located in north central Iowa

Building Description

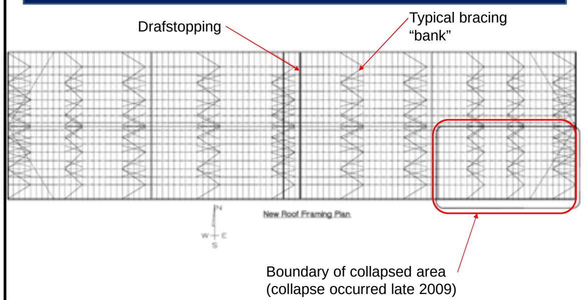
102’x396’ Hog finishing barn floor plan



Center bearing mono trusses 4’ o/c



Roof Framing Plan (shown with repairs)



Snow Damage

Snow Damage

Snow Damage

Snow Damage

Snow Damage

Snow Damage

Snow Damage

Snow Damage

Snow Distribution Observed

Snow Distribution Observed

Snow Distribution Observed

Layers from multiple snow events

Snow Distribution Observed

Snow Distribution Observed

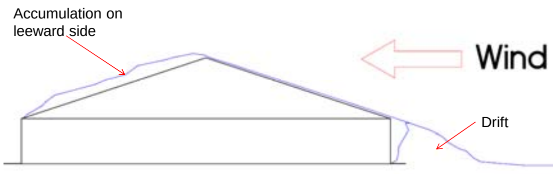
Snow Distribution Observed

Snow Distribution Observed

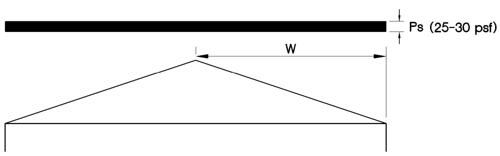
Snow Distribution Observed

Snow Distribution Observed

Observed Snow Drifting

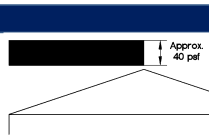


Balanced Snow Loads for Gable Roofs Per the IBC 2009

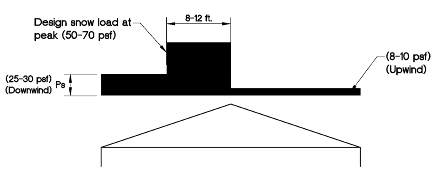


Design without wind effects (balanced)

Unbalanced Snow Loads for Gable Roofs Per the IBC 2009

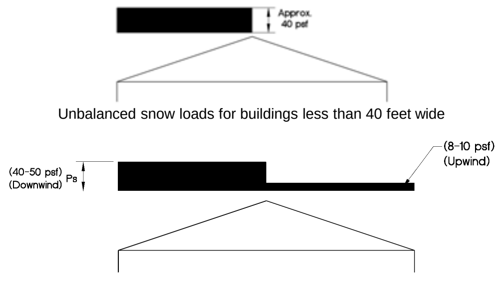


Unbalanced snow loads for buildings less than 40 feet wide



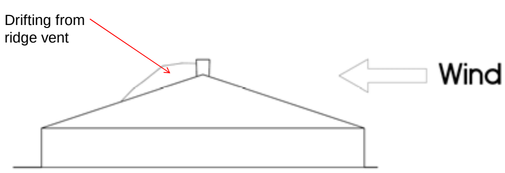
Unbalanced snow loads for buildings greater than 40 feet wide

Unbalanced Snow Loads for Gable Roofs Per the IBC 2003



Unbalanced snow loads for buildings greater than 40 feet wide

Design Snow Load



High Profile Ridge Vent Snow Load

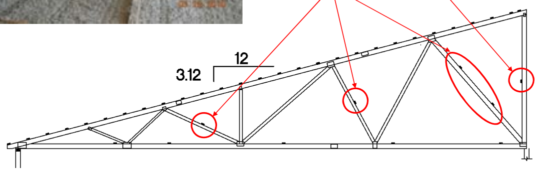
Contributing Factors to Failure

- Lack of bracing
- Inadequate design load
- Broken truss members
- Bowed or out of plumb trusses
- Inadequate truss bearing area
- Decay

Lack of Bracing

Lateral braces installed on tension webs

Required lateral braces on compression webs



Lack of Bracing

No “X” bracing on critical compression web

Bowed web

Lack of Bracing

Butt jointed lateral bracing with toe nail connection

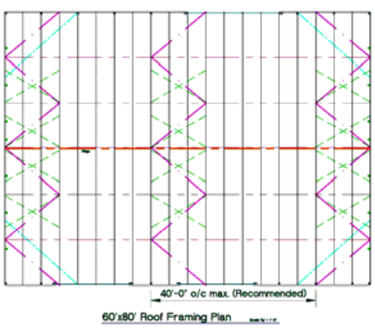
Splices in lateral bracing occur at same truss

Lack of Bracing

X bracing does not extend to truss panel point

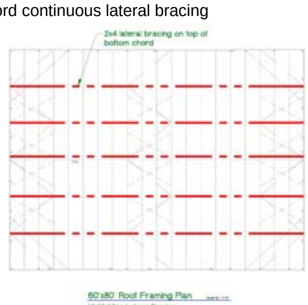
Bottom chord diagonal bracing does not join at lateral brace

Truss Bracing Concepts



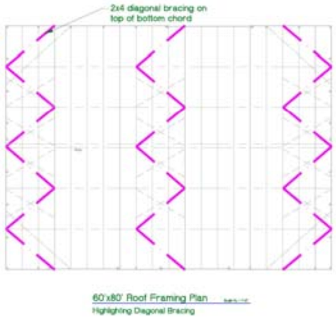
Truss Bracing Concepts

Bottom chord continuous lateral bracing

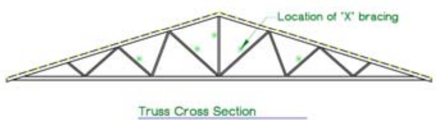


Truss Bracing Concepts

Bottom chord diagonal bracing

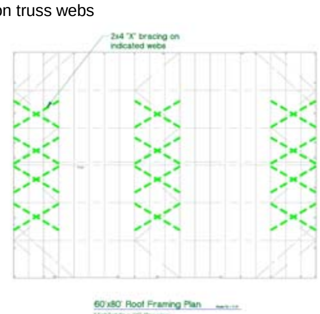


Truss Bracing Concepts



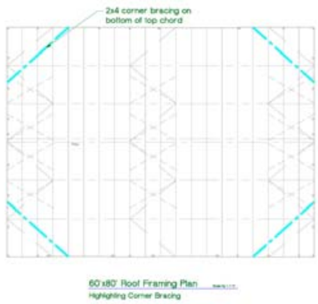
Truss Bracing Concepts

"X" Bracing on truss webs

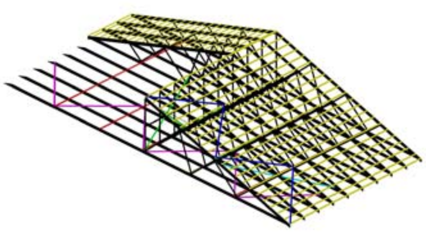


Truss Bracing Concepts

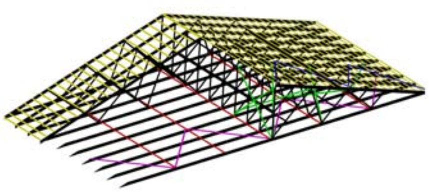
Top Chord Corner Bracing



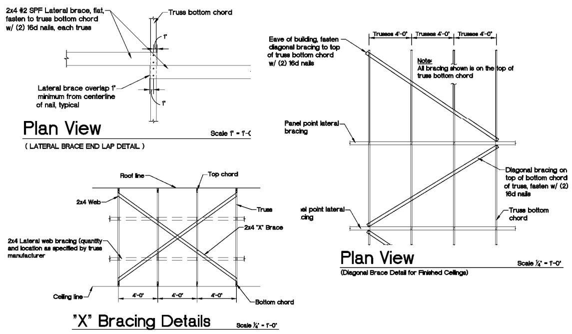
Truss Bracing Concepts



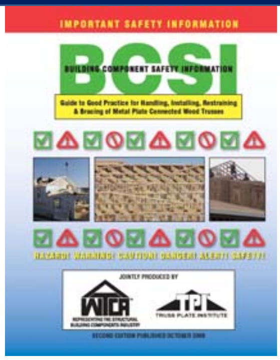
Truss Bracing Concepts



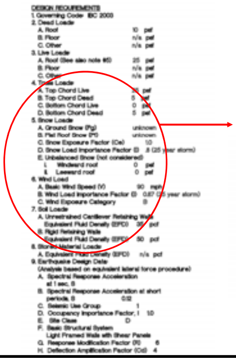
Truss Bracing Concepts



Truss Bracing Concepts

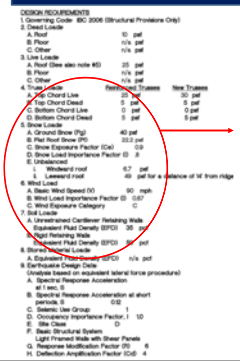


Design Loads (Original) Per IBC 2003



4. Truss Loads:
   - A. Top Chord Live 25 psf
   - B. Top Chord Dead 5 psf
   - C. Bottom Chord Live 0 psf
   - D. Bottom Chord Dead 5 psf
5. Snow Loads:
   - A. Ground Snow (Pg) unknown
   - B. Flat Roof Snow (Pf) unknown
   - C. Snow Exposure Factor (Ce) 1.0
   - D. Snow Load Importance Factor (I) .8 (25 year storm)
   - E. Unbalanced Snow (not considered)
     - i. Windward roof 0 psf
     - ii. Leeward roof 0 psf
6. Wind Load
   - A. Basic Wind Speed (V) 90 mph
   - B. Wind Load Importance Factor (I) 0.87 (25 year storm)
   - C. Wind Exposure Category B

Design Loads (Rebuilds) Per IBC 2006


DESIGN REQUIREMENTS
1. Governing Code: IBC 2006 (Structural Provisions Only)
2. Dead Loads
A. Roof 10 psf
B. Floor n/a psf
C. Other n/a psf
3. Live Loads
A. Roof (See also note #5) 25 psf
B. Floor n/a psf
C. Other n/a psf
4. Truss Loads Reinforced Trusses New Trusses
A. Top Chord Live 25 psf 30 psf
B. Top Chord Dead 5 psf 5 psf
C. Bottom Chord Live 0 psf 0 psf
D. Bottom Chord Dead 5 psf 5 psf
5. Snow Loads
A. Ground Snow (Pg) 40 psf
B. Flat Roof Snow (Pf) 22.2 psf
C. Snow Exposure Factor (Ce) 0.9
D. Snow Load Importance Factor (I) .8
E. Unbalanced
i. Windward roof 6.7 psf
ii. Leeward roof 49 psf for a distance of 14' from ridge
6. Wind Load
A. Basic Wind Speed (V) 90 mph
B. Wind Load Importance Factor (I) 0.87
C. Wind Exposure Category C
7. Soil Loads
A. Unrestrained Cantilever Retaining Walls
Equivalent Fluid Density (EFD) 35 pcf
B. Rigid Retaining Walls
Equivalent Fluid Density (EFD) 50 pcf
8. Stored Material Loads
A. Equivalent Fluid Density (EFD) n/a pcf
9. Earthquake Design Data
(Analysis based on equivalent lateral force procedure)
A. Spectral Response Acceleration at 1 sec, S
B. Spectral Response Acceleration at short periods, S 0.12
C. Seismic Use Group 1
D. Occupancy Importance Factor, I 1.0
E. Site Class D
F. Basic Structural System
Light Framed Walls with Shear Panels
G. Response Modification Factor (R) 6
H. Deflection Amplification Factor (Cd) 4

4. Truss Loads:	Reinforced Trusses	New Trusses
A. Top Chord Live	25 psf	30 psf
B. Top Chord Dead	5 psf	5 psf
C. Bottom Chord Live	0 psf	0 psf
D. Bottom Chord Dead	5 psf	5 psf

5. Snow Loads:
- A. Ground Snow (Pg) 40 psf
- B. Flat Roof Snow (Pf) 22.2 psf
- C. Snow Exposure Factor (Ce) 0.9
- D. Snow Load Importance Factor (I) .8
- E. Unbalanced
  - i. Windward roof 6.7 psf
  - ii. Leeward roof 49 psf for a distance of 14' from ridge

6. Wind Load
- A. Basic Wind Speed (V) 90 mph
- B. Wind Load Importance Factor (I) 0.87
- C. Wind Exposure Category C

Broken Truss Members

Inadequate field repair

Broken Truss Members

Inadequate field repair

Bowed or Out of Plumb Trusses

NFBA Accepted Practices for Post Frame Building Construction: Framing Tolerances

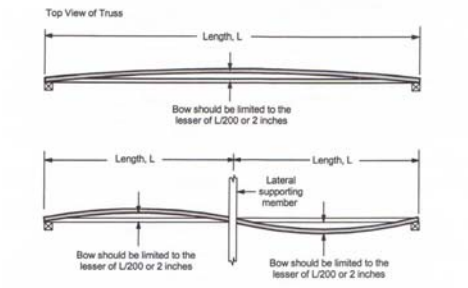


Figure 8 - Restrictions on overall truss bow and bow in truss members.

Bowed or Out of Plumb Trusses

NFBA Accepted Practices for Post Frame Building Construction: Framing Tolerances

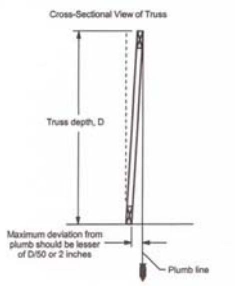


Figure 9 - Requirements for truss plumbness.

Inadequate Truss Bearing Area

Decay

Wood decay

Decay

Plate Corrosion

Decay

Possible source of corrosion

Pit Fans

Rebuilding

Rebuilding

New truss design drawing

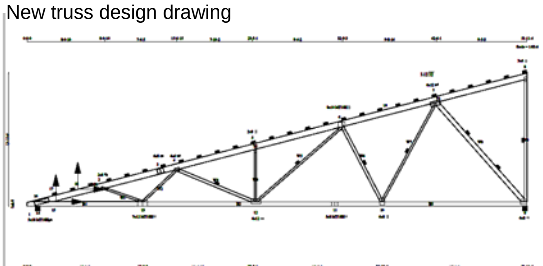


Plate Offsets (X,Y): [6:0-5-12,0-2-8], [7:0-4-12,0-2-0], [10:0-3-12,0-2-8], [12:0-4-0,0-2-4], [13:0-5-12,0-5-4]

LOADING(psf)		SPACING	4-0-0	CSI		DEFL	in	(loc)	l/defl	L/d	PLATES	GRIP
TCLL	30.0	Plates Increase	1.15	TC	0.78	Vert(LL)	-0.97	12-13	>637	240	MT20	185/144
TCDL	5.0	Lumber Increase	1.15	BC	0.97	Vert(TL)	-1.35	12-13	>458	180	MT18H	185/144
BCLL	0.0	Rep Stress Incr	NO	WB	0.89	Horz(TL)	0.31	9	n/a	n/a		
BCDL	5.0	Code IBC2006/TPI2002		(Matrix-M)							Weight: 350 lb	

Rebuilding

New lateral brace connection

Rebuilding

New bottom chord diagonal braces connected at lateral brace

New bracing connections

Rebuilding

New X bracing installed

X braces attached at panel point

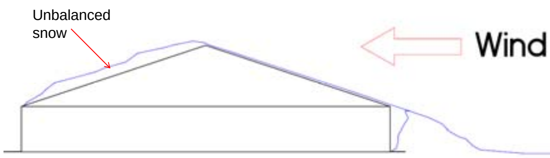
Rebuilding

New joint reinforcement of existing truss

New top chord reinforcement of existing truss

Recommendations

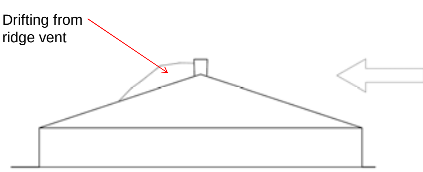
Design Snow Load



Observed Snow Load

Recommendations

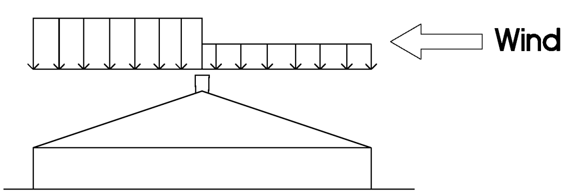
Design Snow Load



High Profile Ridge Vent Snow Load

Recommendations

Design Snow Load



ASCE 7-02 Unbalanced Load

Recommendations

Summary

- Use correct loading for geographical area and building use
- Include unbalanced snow loading in the design
- If continuous obstruction is used at ridge, consider more conservative unbalanced load profile extending from ridge to eave
- Consider wind exposure condition (Exposure category C-open terrain vs. Exposure category B- closely spaced obstructions)
- Consider using normal loading (50 yr. recurrence) rather than "low occupancy" loading (25 yr. recurrence) for new buildings even if they are for agricultural use
- Understand truss bracing concepts
- Follow the bracing and bearing length requirements on the truss design drawings
- Provide additional diagonal and X bracing per BCSI or an engineer designed bracing plan
- Be careful to install trusses within tolerance for plumbness and bow

Recommendations

Summary

- Secure an engineer certified truss repair from the truss company for any broken trusses
- Provide regular maintenance to prevent snow from building up against building walls
- Perform inspection of existing building roof systems looking for:
  - Bowed or broken trusses
  - Loose, broken, or bowed bracing members
  - Quantity and type of bracing (is there enough?)
  - Moisture or ammonia build-up
- If something seems wrong, contact an engineer for an evaluation