Applying IBC 2000 wind and snow loads to post-frame building posts

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Introduction

The International Building Code 2000 edition (IBC, 2000) is a compilation and consolidation of three major building codes into one. The IBC has already been adopted, or is in the process of being adopted, by most jurisdictions throughout the United States. IBC Section 2306.1 adopts by reference the American Society of Agricultural Engineers standards ASAE EP484.2, "Diaphragm Design of Metal-Clad, Post-Frame Rectangular Buildings" and ASAE EP559, "Design Requirements and Bending Properties for Mechanically Laminated Columns." The purpose of this article is to demonstrate how the loads and load combinations specified by the IBC 2000 may be systematically applied to the structural design of typical post-frame building bearing wall posts, including the methodology underlying these ASAE Standards.

For purposes of simplicity, in this article it is assumed that wind rather than seismic loads will govern the design, and that snow loads will control rather than roof live loads. Since IBC Section 2306.1 applies only to allowable stress design (ASD), this paper assumes ASD structural design methodology. We will discuss the basis for load calculations in the IBC, highlight the wind and snow load design procedures, and present a design example.

ASCE 7-98

Minimum load requirements per the IBC 2000 are based on American Society of Civil Engineers Standard ASCE 7-98, "Minimum Design Loads for Buildings and Other Structures." (ASCE, 1998) In fact, this publication is needed to calculate the design snow and wind loads. This article discusses the ASCE 7-98 loads and appropriate load combinations only in general terms, as calculation of design wind and snow loads using ASCE 7-98 is beyond the scope of this article.

Wind loads

ASCE 7-98 provides design wind pressures for the Main Wind Force Resisting System (MWFRS) and Components and Cladding. Because of its nature, Component and Cladding wind pressures are generally not applied in combination with other loads, thus this article will not focus on them.

The MWFRS of post-frame buildings less than 60 feet tall may be designed using ASCE 7-98, Section 6.5.12.2.2 and Figure 6-4. A post-frame is a structural building frame consisting of a wood roof truss or rafters connected to vertical timber columns or sidewall posts. Wind load design provisions are given for wind acting primarily perpendicular to the ridge, as well as parallel to the ridge. Since we are focusing on bearing wall posts, we will consider perpendicular wind loading only. It is necessary to calculate and consider four separate sets of wind pressures:

1. External wind pressures in "End Zones" (designated 1E, 2E, 3E, and 4E in ASCE 7-98 Figure 6-4).
2. External wind pressures in "Interior Zones" (designated 1, 2, 3, and 4 in ASCE 7-98 Figure 6-4).
3. Internal positive pressure.
4. Internal negative pressure.

A schematic of wind forces is in Figure 1. Negative internal pressure tends to create a vacuum inside the building and cause it to contract. Positive internal wind pressure causes the building to expand. That is, positive internal pressure acts toward the building's inside surface; negative internal pressure acts away from the inside surface.

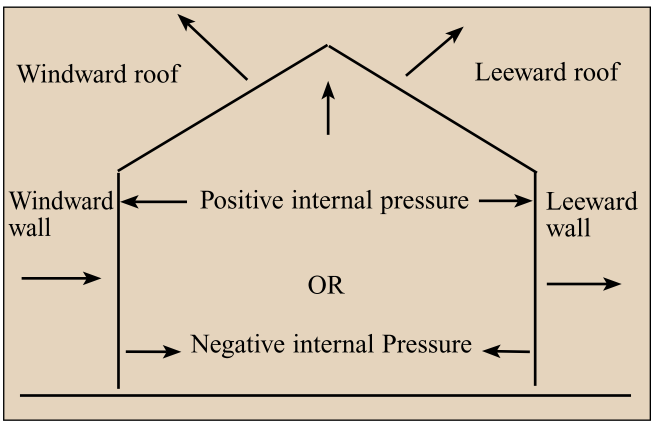

Figure 1. External & Internal Wind Pressures (Wind blowing from left to right)

Internal wind pressure acts equally in all directions and thus balances at each post-frame. External wind pressure tends to push the entire building over, and does not balance. Roof and enclosed wall diaphragms provide structural rigidity and resist overturning forces at each post-frame. Thus external wind pressure gives rise to shear in the diaphragms. Since internal wind pressure counteracts itself "internally," the load it imposes upon the diaphragms and its contribution to eave deflections can be neglected. Methods to determine distribution of the forces among post-frames and diaphragms are presented in ASAE EP484.2, (ASAE, 2001).

The "Post-Frame Building Design Manual" (PFBDM, NFBA, 2000) lists the following design steps for the MWFRS:

1. Model the roof diaphragm and frame segments;

2. Determine frame stiffness for a preliminary post-frame;

3. Determine diaphragm stiffness for preliminary roof and end wall diaphragms;

4. Determine eave loads;

5. Finally, determine the distribution of wind loads among the post-frame and diaphragm segments using methods consistent with ASAE EP 484.2.

These steps, in essence, determine the deflection at the eaves of the post-frames. Once this deflection is determined, post forces may be calculated. The two basic methods for determining post forces given in the PFBDM are:

1. Analyze the frame with a plane-frame structural analysis program.

2. Neglect that part of the eave deflection caused by internal truss deflections (assume a rigid truss), and then use the formulae presented in the PFBDM based on the principles of engineering mechanics.

The "distribution of the wind forces", as used in the context of the PFBDM and ASAE EP484.2, refers to how much of the total external lateral wind pressure is resisted by each post-frame and how much is resisted by each diaphragm component. The distribution of wind forces among frames and diaphragms is not unique to post-frame buildings. However, post-frame structures are the only buildings that are typically designed using this sophisticated, three dimensional design technique.

It is necessary to calculate the eave deflection at each critical post-frame. The post-frame with the greatest eave deflection will typically be in the interior wind zone (zone 1, 2, 3, and 4 in ASCE 7-98 Figure 6-4). The post-frame subjected to end zone pressures (zone 1E, 2E, 3E and 4E) will typically have a very small calculated eave deflection, because it is located close to the relatively stiff end wall. The PFBDM presents formulae and examples of this process.

Since there are two wind pressure zones, the designer must either solve for the eave deflections by using a computer program such as DAFI (Bohnhoff, 1992a,b), or by making some reasonable engineering judgments. For example, in a typical post-frame building with relatively stiff end walls, the increased wind pressures in the end zone will have a very small effect on the eave deflections. A designer may reasonably decide that the effect of the increased "end zone" pressure on eave deflections is negligible and calculate eave deflections based on interior zone external wind forces only. Of course, the added end zone pressures cannot be neglected when calculating shear in roof and end wall diaphragms, nor when designing posts that receive wind pressure from this zone.

Designers will find that for most post-frame buildings with typical roof slopes from 3:12 to 5:12, external windward roof wind pressures will be greater than external leeward roof wind pressures. In accordance with ASCE 7-98, these net windward forces on the roof should be neglected when calculating eave deflections.

Snow loads

The IBC specifies snow load maps and rules for determining the design roof snow loads by referencing ASCE 7-98. On post-frame buildings with typical roof slopes from 3:12 to 5:12, there are two design load conditions: balanced and unbalanced.

Balanced snow load conditions model situations where snow falls and accumulates uniformly. Unbalanced snow load conditions model situations where wind causes snow from windward roof slopes to be deposited on leeward roof slopes. Wind will blow some snow entirely off the roof, so the total amount of snow on the roof is less for the unbalanced case (O'Rourke, 1997). This leads to two recommendations for applying the IBC-specified snow loads to the design of post-frame building posts:

1. The worst-case snow load reaction for windward post design is the balanced load case.

2. The worst-case snow load reaction for leeward post design is the greater of the balanced load case and the unbalanced load case. Most often, it will be the unbalanced load case reaction.

Example

Chapter 9 of the PFBDM presents a design example that uses the structural

Table 1: Sample Building Specifications	
Width (truss length)	36 ft
Length (along ridge)	60 ft
Height at truss bearing	12 ft
Roof slope	4:12 (18.43°)
Bay spacing	10 ft
Number of frames (including end walls)	7
Post Embedment depth	4 ft
Post grade & species	No. 2 S. Pine
Post size	Nom. 6 x 6 in
Roof dead load	5 psf
Concrete slab?	Yes
Ceiling?	No

parameters shown in Table 1.

Table 2 presents the wind load design parameters and Table 3 presents the wind pressures determined from ASCE 7-98 Low Rise Building Procedure.

Table 4 presents the snow load design parameters and the snow load pressures determined from ASCE 7-98.

Load Combinations

The basic load combinations for allowable stress design are given in IBC 1605.3, (IBC, 2000). The specific load combinations for this example building are shown in Table 5. The first load condition is the dead load, IBC Formula 16-7. The second applicable set of load cases is IBC Formula 16-9, dead load plus snow load. To properly evaluate this condition, the designer must account for both the balanced and unbalanced snow load cases (load combinations 2 and 3).

Of course since wind can blow from either direction, all bearing posts must be checked for the greater leeward load.

The third applicable set of load cases (IBC Formula 16-10) is dead plus snow plus wind. IBC Section 1605.3.1.1 permits the combined effect of two or more transient loads to be multiplied by 0.75 and added to the effect of the dead load. Formula 16-10 can then be re-written in the form D + 0.75(W + S) as shown in Table 5. Finally, IBC Formula 16-11 is used to check dead plus wind.

Four sets of wind pressures and two sets of snow loads make this more of an accounting problem. Since negative internal wind pressure will add to the windward wall external wind pressure, this will be the worst-case wind pressure combination for the windward column. The negative internal wind pressure will also be added to the vertical dead and snow loads.

Positive internal pressure will add to the leeward wall external wind pressure, and will tend to counteract the effect of dead and snow loads. In most cases, the effect of the combined lateral load will be worst-case; however, the designer must be cautious for circumstances where this may not be true. Table 6 presents the summation of load combi-

Table 2. Wind Load Parameters	
Wind speed	90 mph
Wind exposure	B
Building use	Normal
Importance factor	1.0
Topography	Flat
Topographic factor	1.0
Enclosure classification	Enclosed
Mean roof height	16 ft
2a, length of end zone (as defined in ASCE 7-98 Fig. 6-4)	7.2 ft

Table 3. Design Wind Pressures & Post Reactions	Interior bays	End bay
External Pressures		
Windward wall (surface 1)	6.42 psf	9.69 psf
Windward roof (surface 2)	-8.52 psf	-13.21 psf
Leeward roof (surface 3)	-5.82 psf	- 8.36 psf
Leeward wall (surface 4)	-5.17 psf	- 7.71 psf
Internal Pressures		
Positive internal pressure	2.22 psf	2.22 psf
Negative internal pressure	-2.22 psf	-2.22 psf

Table 4. Snow Load Design Parameters & Loads	
Ground snow	30 psf
Terrain category (wind exposure)	B
Roof exposure	partially exposed
Exposure factor	1.0
Unheated building Thermal factor	1.2
Importance factor	1.0
Flat roof snow load	25.2 psf
Roof slope factor	0.94
Sloped roof snow load (balanced)	23.6 psf

Table 5. Load Combinations

		IBC Formula
1.	D	16-7
2.	$D + S_{BAL}$	16-9
3.	$D + S_{UNBAL}$	16-9
4.	$D + .75(W_{EXT} + W_{POS.\ INT} + S_{BAL})$	16-10
5.	$D + .75(W_{EXT} + W_{NEG.\ INT} + S_{BAL})$	16-10
6.	$D + .75(W_{EXT} + W_{POS.\ INT} + S_{UNBAL})$	16-10
7.	$D + .75(W_{EXT} + W_{NEG.\ INT} + S_{UNBAL})$	16-10
8.	$0.6D + W_{EXT} + W_{POS.\ INT}$	16-11
9.	$0.6D + W_{EXT} + W_{NEG.\ INT}$	16-11

Table 6. Dead + Unbalanced Snow + Wind + Pos Internal (Interior Frame)

	Windward		Leeward	
Vertical Loads Interior Frames	Wall (psf)	Roof ($psf_{projected\ area}$)	Wall (psf)	Roof ($psf_{projected\ area}$)
Dead	-	5.00	-	5.00
Worst-case snow x .75	-	0.00	-	26.60
External wind x .75	-	-6.40	-	-4.37
Pos internal wind x .75	-	-1.67	-	-1.67
Design Vertical Load	0	-3.10	0	25.60
Lateral Loads Interior Frames	Wall (psf)	Roof ($psf_{projected\ area}$)	Wall (psf)	Roof ($psf_{projected\ area}$)
External wind x .75	4.82	-6.40	3.88	4.37
Pos internal wind x .75	-1.67	-1.67	1.67	1.67
Design Lateral Load	3.15	-8.10	5.55	6.00

nation 6 in Table 5. These loads are for the interior frame only; the end bay is not included, but must also be checked.

Post Design

Posts can be designed utilizing benefits of diaphragm action, in accordance with ASAE EP484.2. For diaphragm action to effectively resist wind loading in a post-frame building, the sidewalls and endwalls need to be enclosed or partially enclosed. Benefits of diaphragm strength and stiffness as a building's length-to-width ratio increases. Other stiffening methods such as internal shearwalls need to be used in post-frame buildings for situations where the diaphragm system can not adequately resist the design lateral loading.

In this example, we used the frame analysis approach to calculating post forces. A two-dimensional frame analog is created to reflect the geometry of the building frame and the loading that must be resisted (see Figure 2). The design loading is placed on the analog according to the appropriate tributary width for each frame, and the load combinations in Table 5.

A fictitious force, F_F, is included at the windward eave to counteract the net windward force on the roof. F_F is the resultant roof wind force acting on the frame tributary width. In addition, the Sidesway Restraining Force, Q, is included on the analog at the leeward eave to represent the resistance provided by the diaphragm system. This restraining force is multiplied by 0.75 for load combinations four through seven (see Table 5), to be consistent with IBC Section 1605.3.1.1. The Q force is determined from the diaphragm factor, mD, and the eave load, R, as per ASAE EP 484.2. The diaphragm factor, mD, is determined from ASAE EP484.2 Table 2 using the ratio of diaphragm to frame stiffness (Ch/k) and ratio of endwall to frame stiffness (ke/k). Since mD equals 1.0, eave deflection is zero and posts could be designed as propped cantilever beam columns without the aid of a frame analog. The eave load, R, is the eave restraining force assuming the eave is totally restrained, as with a vertical roller support. The post fixity factor, f, comes from the assumption that the post is a propped cantilever. Five-eighths (5/8) of the tributary wind load is taken at the fixed base, and 3/8 is resisted by the roller reaction at the eave.

1. Diaphragm Factor, mD

C_h=horizontal shear stiffness from ASAE EP484
k=frame stiffness from ASAE EP484
Ke=endwall stiffness from ASAE EP484

$$\frac{C_h}{k} = 1567$$

$$\frac{k_e}{k} = 10000$$

Number of frames = 7
By interpolation of values in ASAE EP484, Table 2
mD = 1.0

2. Eave Load, R

$$R = (s)[(h_r)(qwr - q_{lr}) + h_w f(q_{ww} - q_{lw})]$$

R = eave restraining force assuming the eave is fully restrained, as with a vertical roller support
s = frame spacing=10 ft.
h_r = roof height at ridge line (distance between lower cord and peak) = 6ft.
h_w = wall height = 12 ft.
q_{wr} = windward roof pressure = -8.52 psf (see Table 3)
q_{lr} = leeward roof pressure = -5.82 psf (see Table 3)
q_{ww} = windward wall pressure =6.42 psf (see Table 3)
q_{lr} = leeward wall pressure = -5.17 psf (see Table 3)
f = post fixity factor = 0.375
R = 360 lb

3. Sidesway Restraining Force, Q

$$Q = -1(mD)(R) = -1(1.0)360 = -360 \text{ lb}$$

4. Fictitious Force, F_F(Resultant of net roof wind load acting on tributary roof area between posts).

$$F_F = (-1)(q_{wr} - q_{lr})(h_r)(s)$$

The support conditions of the frame analog are represented as a fixed condition. Several other structural analogs modeling post behavior below grade are described in the PFBDM. The fixed condition is a simplified model which may produce conservative values for post base moments, and non-conservative diaphragm forces. For this example

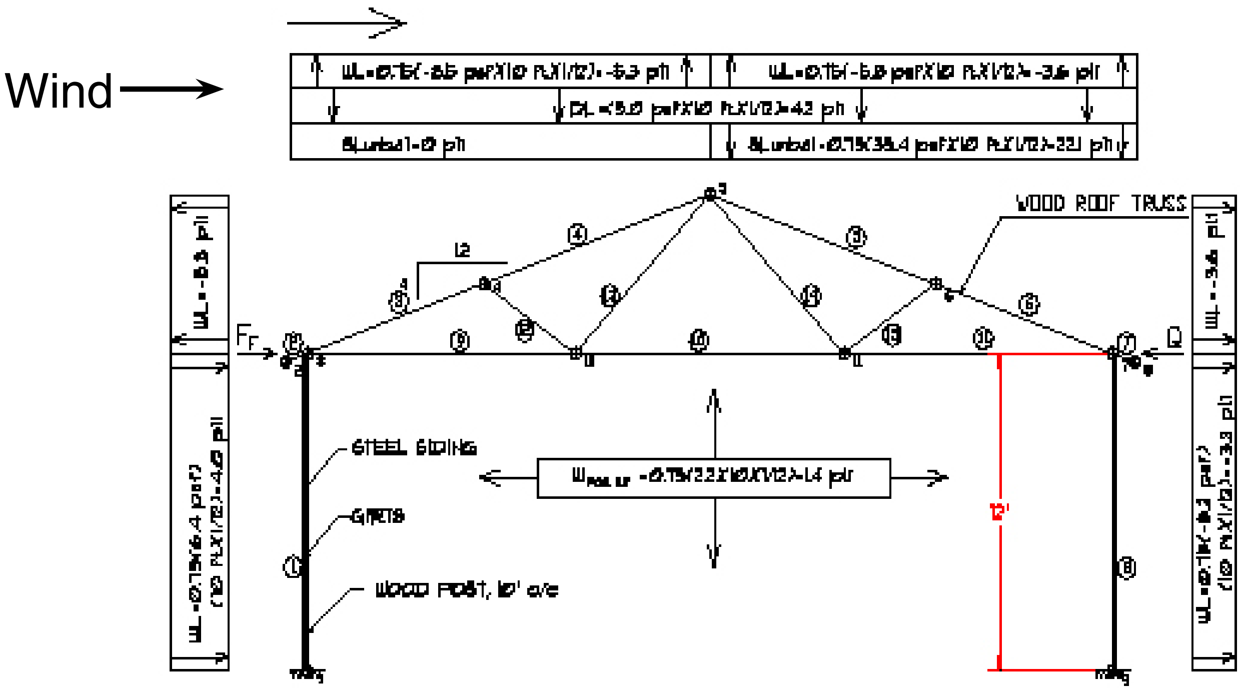

Figure 2. Frame Analog (Load Combination 6, Table 5)

building, mD equals 1.0 and the posts can be designed as propped cantilever beam columns. The fixed base analog is similar to this propped cantilever condition.

After post forces have been calculated, post size, grade and embedment can be checked. Post design is completed using the "National Design Specification for Wood Construction" (NDS, 2001) by the American Forest and Paper Association. Mechanically laminated columns should be designed according to ASAE EP559 (ASAE, 2001).

Conclusion

Structural design of post-frame building bearing wall posts in accordance with IBC 2000 requires the use of ASCE 7-98 to calculate design loadings. There are two methods for determining post forces, and the designer can choose which one is appropriate for the situation.

Creating a frame analog is a more general approach, which will apply to many different frame geometries. Within ASCE 7-98 four sets of wind loads (external "end zone", external "interior zone", internal positive, and internal negative pressure) and two sets of design roof snow loads (balanced and unbalanced) need to be analyzed. It is also necessary to design the posts for both the windward and leeward wind load conditions. This presents the designer with the complex task of tracking all of these loads and combining them in accordance with IBC provisions.

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