Simplified wind load provisions of the 2003 International Building Code

By T. Eric Stafford, P.E.

Wind load criteria specified in codes and standards have been refined significantly, particularly in recent years. Our knowledge of how wind affects buildings and structures has expanded because of better technology and advanced research. As a result, code development professionals have been asked to refine the methodologies used to determine wind loads. Greater accuracy in predicting wind loads greatly benefits manufacturers, designers, and the general public, who all want designs that will satisfy anticipated loads without unwelcome conservatism that may result in a more costly building than necessary.

The 1973 Standard Building Code contained only a page and a half of wind load requirements, and wind pressures were based on whether or not a structure was located in a coastal area. However, recent editions of the American Society of Civil Engineers 7, "Minimum Design Loads for Buildings and Other Structures," contains more than 40 pages of text, figures, and tables to predict wind loads for a particular structure. Naturally, new research has been incorporated into new codes.

Simplification of the design criteria in the 2002 edition of ASCE 7 is a welcome development to structural engineers. For small projects it also expedites the design process, which may discourage engineers from rushing through a design. Simplified procedures tend to result in a reduced number of variables or equations, which invariably assumes some conservatism. However, code professionals who have been charged with refining the design process have worked to align the solution's complexity with the problem's complexity — with minimal penalties in the final design. The result of their efforts is the Simplified Wind Load Provisions of the International Building Code and ASCE 7.

Simplification concepts

Before looking at the background and application of the simplified method of Section 1609.6 of the IBC, some important points should be noted. ASCE 7-98 contained four methods for determining winds:

- A simplified method,
- The buildings-of-all-heights method,
- The low-rise buildings (height less than or equal to 60 feet) method, and
- The wind tunnel tests.

The 2000 IBC provisions were based on low-rise buildings methodology. The ASCE 7-98 simplified method was based on the buildings-of-all-heights method; it was much more limited in scope than the IBC provisions. However, with the finalization of the 2002 ASCE 7 standard and the 2003 edition of the IBC, the simplified methods found in both are essentially the same, and are similar to the simplified procedure set forth in the 2000 IBC but with further refinements for ease of application.

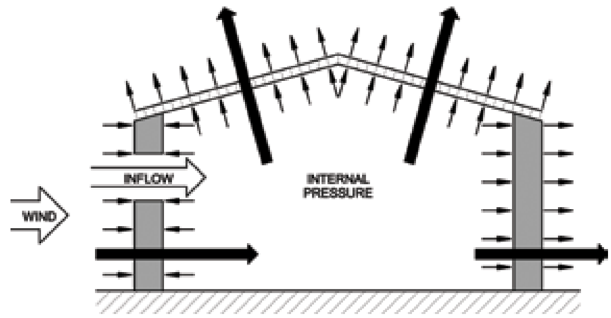


Figure 1. Partially enclosed building with an opening on the windward wall.

How and where did the IBC originally simplify the wind load calculations and keep the conservatism to a minimum? To answer this question, let's first examine the scope of the simplification and the controlling equations. The IBC provisions were developed using the following set of rules and scope:

- Reduce the number of variables and equations to simpler forms,
- Determine the controlling load cases for certain buildings,
- Tabulate wind pressures for applicable locations on buildings based on basic wind speed, and
- Arrange for a single factor to be applied to account for different heights and different exposures.

Fundamental equations

The controlling equations require calculating the velocity pressure, q_z, and the design pressure, p. The velocity pressure represents the stagnation pressure and is calculated by using the following equation:

$q_z = 0.002567 K_z K_{zt} K_d V^2 I$

The stagnation pressure is then inserted into the following equation for the design pressure, which accounts for gusts, internal pressure, and aerodynamic properties of the element under consideration:

$p = q_h(GC_p - GC_{pi})$

K_z = velocity pressure exposure coefficient dependent upon mean roof height and surrounding terrain (accounted for in Table 1609.6.2.1(4))

K_{zt} = topographic factor (assuming no topographic effects and equal to 1.0 for simplification)

K_d = directionality factor (0.85 for buildings)

V = basic wind speed (determined from Figure 1609)

I = importance factor (determined from Table 1604.5)

$q_z = q_h$ = velocity pressure, at mean roof height required for the low-rise method (accounted for by application of Table 1609.6.2.1(4))

GC_p = external pressure coefficients, combined for the low-rise methodology (accounted for by determining the controlling load cases for the main-wind-force resisting system in Table 1609.6.2.1(1) and based on effective wind area for components and cladding (C&C) in Tables 1609.6.2.1(2) and 1609.6.2.1(3)

GC_{pi} = internal pressure coefficient (± 0.18 for enclosed buildings)

Using these assumptions, the simplification reduces the number of unknown variables to three (K_z, V, and I), all of which are incorporated easily into the simplified equations. By contrast, using the low-rise buildings analytical procedure in ASCE 7 and applying it to the simplest buildings requires the use of up to eight variables (11 if topographic effects are considered).

Additionally, the calculations have to be performed twice to account for positive and negative internal pressures. Also, the building must be rotated with each corner as the reference corner while considering the two separate load cases.

Enclosure classifications

The IBC's Section 1609.1.1 requires wind loads to be determined in accordance with these controlling equations found in Section 6 of ASCE 7. The simplified method of Section 1609.6 applies to "the design of enclosed buildings with flat, gabled, and hipped roofs and having a mean roof height not exceeding the least horizontal dimension or 60 feet ..."

Limiting the simplified provisions to those described in this way by Section 1609.6.1 is necessary to maintain the method's simplicity. During its development, the question was posed: "Using the low-rise methodology, for what buildings can the controlling load case be determined in advance?" The most obvious answer is buildings that transfer wind loads to the vertical main-wind-force resisting system (MWFRS) through floor and roof diaphragms. For these buildings, the MWFRS is not sensitive to the proportion of the load on the windward or leeward sides. The floor and/or roof diaphragms are assumed to collect the wind load and to transfer it uniformly to the vertical MWFRS below. Therefore, the simplified method applies to simple diaphragm buildings meeting the following criteria:

- It is an enclosed building;
- Its mean roof height is less than or equal to 60 feet;
- Its mean roof height does not exceed the least horizontal dimension;
- It has an approximately symmetrical cross-section;
- It does not have expansion joints or structural separations;
- It has wind loads transmitted through floor and roof diaphragms to the vertical MWFRS;
- It does not have unusual response characteristics or a site location which would subject it to unusual wind effects; and
- It has roof slopes that do not exceed 45 degrees and hip roofs not exceeding 27 degrees when designing components and cladding.

Most criteria relate to limitations associated with the low-rise methodology. The enclosed building criterion pertains to the enclosure classification of the building: enclosed, partially enclosed, or open. A building classified as partially enclosed assumes that a large opening is on one side of a building and no (or minimal) openings are on the other walls. Depending upon the wind's direction, this type of situation allows two conditions to develop: internal pressure or internal suction. Internal pressure occurs when air enters a building opening on the windward wall and becomes trapped, exerting an additional force on the interior elements of the building. These internal forces act in the same direction as the external forces on all walls but the windward wall. As openings on one wall reach a certain size with respect to openings on the other walls, the building is classified as partially enclosed.

Partially enclosed buildings allow more air to enter, creating larger internal forces. The additional forces produced by this type of pressurization are characterized by requiring an internal pressure coefficient that is more than three times greater than that required for an enclosed building. An illustration of this scenario is shown in Figure 1.

Internal suction is a condition that exists when there is an opening on the leeward wall allowing air to be pulled out of the building. The scenario results in the internal forces acting in the same direction as the external forces on the windward wall.

Requiring buildings to be classified as enclosed usually necessitates the use of glazing that is impact-resistant, or protected with an impact-resistant covering for buildings located in wind-borne debris regions (as defined in the IBC). This obviously assumes that the glazing on a windward wall is large enough such that the condition shown in Figure 1 could occur, which would require investigation. The option of assuming the glazing to be an opening in wind-borne debris regions is not permitted when using the IBC simplified provisions.

Because post-frame buildings often include large openings, special provisions may apply. According to ASCE-7 there are three classifications of design for wind resistance: "Open," "Enclosed," and "Partially enclosed."

Post-frame buildings are considered "Open" if each wall is at least 80 percent open. These conditions are expressed in a series of equations, which may be found in section 6.2 of ASCE 7-98. Common examples include sheds and open-sided structures.

The requirements for "partially enclosed" structures are more complex. Common examples of partially enclosed structures include warehouse facilities with many overhead doors installed. Both of the following conditions must apply to consider a building partially enclosed:

1. The total area of openings in the wall that receives positive external pres-

sure must exceed the sum of the areas of openings in the balance of the building envelope (siding and roofing) by more than 10 percent; and

2. The total area of openings in a wall that receives positive external pressure must exceed 4 square feet or 1 percent of the area of that wall, whichever is smaller; and the percentage of openings in the balance of the building envelope must not exceed 20 percent.

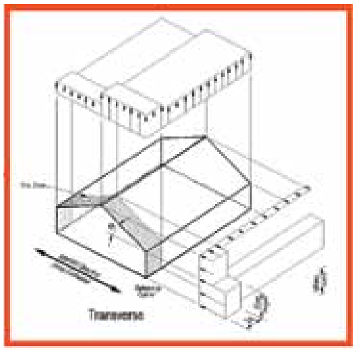
These conditions are expressed in a series of equations, which may be found in section 6.2 of ASCE 7-98.

If a building does not fit into the open or partially enclosed categories, it will fall into the "enclosed" category. Most residential structures are considered "enclosed," as are most retail and commercial buildings.

Coverings for openings, such as windows and doors, may influence the wind loading requirements. If the coverings are designed to resist the wind pressures, the building can meet the overall wind rating requirements for an enclosed building. Since partially enclosed buildings require the highest design pressures, they are typically the most expensive ones to design.

Exposure classifications

Another criterion that significantly affects the magnitude of the wind pressures is the site's exposure category, which provides a way to define the relative roughness of the boundary layer at the site. The IBC defines four exposure categories: A, B, C, and D. In the 2000 IBC and ASCE 7-98, exposure A is the roughest, and D is the smoothest. Consequently, when all other conditions are equal, calculated wind loads are less as the exposure category moves from D to A. The 2002 edition of ASCE 7 no longer uses Category A, and so therefore the previous description of Category A does not appear in the 2003 edition of the IBC. Exposure B is the most common category, consisting primarily of terrain associated with a suburban site. Accordingly, it is the default exposure category in the IBC. Exposure C consists primarily of open terrain with scattered obstructions but also includes shorelines in hurricane-prone regions. Specific def-



HORIZONTAL LOADS[a]				VERTICAL LOADS					
End zone		Interior zone		End zone		Interior zone		Windward Overhang	
Wall	Roof	Wall	Roof	Windward roof	Leeward roof	Windward roof	Leeward roof	End zone	Interior zone
15.9	-8.2	10.5	-4.9	-19.1	-10.8	-13.3	-8.4	-26.7	-20.9
22.0	-5.8	14.6	-3.2	-19.1	-13.3	-13.3	-10.1	-26.7	-20.9
17.8	12.2	14.2	9.8	6.9	-10.8	5.9	-9.3	-6.3	-7.2
15.9	-8.2	10.5	-4.9	-19.1	-10.8	-13.3	-8.4	-26.7	-20.9

Figure 2. Main-wind-force resisting system loads for a building with mean roof height of 30 feet located in exposure B.

initions for the four categories are given in Section 1609. For the IBC simplified provisions, a single exposure category, based on the exposure yielding the highest wind loads for any wind direction, is used.

Buildings must also be classified based on their importance. The wind factor, IW, in Table 1604.5 of the IBC is used to adjust the return period for a structure based on its relative level of importance. For example, the importance factor for structures housing critical national defense functions is 1.15. Alternatively, the importance factor for an agricultural building is 0.87.

Risk classifications

Risk calculations are based upon the following four categories:

Category I — Low hazard to human life in the event of failure (e.g., agricultural, temporary facilities, and minor storage facilities)

Category II — Medium risk; includes residential and buildings with only small gathering areas

Category III — Substantial hazard to human life (e.g., churches and other buildings where more than 300 people may congregate; buildings with day-care facilities with capacity greater than 250; primary and secondary school structures with a capacity greater than 250; college or adult education facilities with a capacity greater than 500; structures containing toxic, explosive, or other substances that may be hazardous to the public if released; and other public utility facilitates not included in Category IV).

Category IV — Structures designated as essential facilities (e.g., hospitals and other health care facilities having surgery or emergency treatment facilities; fire, rescue, and police stations and emergency vehicle garages; designated emergency shelters; communications centers; public utility facilities required in an emergency and ancillary structures required for their operation during an emergency; aviation control towers, water storage facilities, and other structures having critical national defense functions).

Post-frame construction is used for a variety of other types of buildings, in addition to agricultural buildings. Importance factors for some common post-frame building types in non-hurricane prone regions and hurricane-prone regions with a basic wind speed of only 85 to 100 mph include:

Residential homes — 1.00

Warehouses without hazardous substances and a low risk to human life — 0.85

Warehouses with hazardous substances — 1.15

Churches, retail facilities, and other buildings where less than 300 people congregate — 1.00

Churches, retail facilities, and other buildings where more than 300 people congregate — 1.15

Essential facilities such as police stations, fire stations, emergency vehicle garages, and ancillary structures —1.15

Conclusion

The IBC provisions greatly simplify the determination of wind loads for low-rise enclosed simple diaphragm buildings. As we continue to improve our knowledge of environmental loads, and the performance of buildings and structures subjected to these loads, code developing organizations (such as the International Code Council) will continue to provide a means for the refinement to thrive in the field, as well as a methodology for applying the latest research to the design and construction of buildings resistant to these loads. ■

T. Eric Stafford, P.E., is the vice president of technical services for the Federal Alliance for Safe Homes - FLASH, Inc. He is the former manager of codes and standards for the International Code Council and director of code development for Southern Building Code Congress International. He is a member of the ASCE 7 Task Committee on Wind Loads, ASCE Committee 7 on Minimum Design Loads, the National Hurricane Conference Planning Committee, and the National Hurricane Conference Engineering Topic Committee. He may be reached via e-mail at testafford@charter.net.

Editor's Note: Post-frame buildings which do not have posts embedded in the earth are typically modeled as pin connected to the foundations and resist wind forces through ceiling, floor, and roof diaphragms (MWFRS). The simplified methods described in this article and in the sidebar are applicable to this type of post-frame building.

Simplified calculations of wind load requirements

By John Henry, P.E.

The procedure given in IBC Section 1609.6 is a simplified version of the ASCE 7-02 analytical procedure. Perhaps the most simplifying aspect of the IBC procedure is that for the main-wind-force resisting system, it employs a projected area method involving (net) horizontal and vertical pressures acting on the external projected area of the structure. In addition, all design loads (pressures) are determined directly from tables — Table 1609.6.2.1(1) for the MWFRS and Table 1609.6.2.1(3) for C&C. The pressures given in these tables are based on Exposure B, mean roof height h = 30 feet and importance factor $I_w = 1.0$. These pressures must be adjusted for the actual mean roof height and exposure category of the structure being designed; the adjustment facλor, , is given in Table 1609.6.2.1(4). Finally, the adjusted pressures are applied to the building projected area for the MWFRS or building surfaces for C&C in accordance with the pressure diagrams illustrated, respectively, by Figure 1609.6.2.1 and Figure 1609.6.2.2.

The step-by-step procedure given by Section 1609.6 for determining the design loads on MWFRS can be summarized as follows:

Step 1 — Determine the basic design 3-second gust wind speed from the maps shown in IBC Figure 1609.

Step 2 — Determine the importance factor, I_w, for the building in accordance with Section 1609.5 and Table 1604.5. As with snow and seismic loads, I_w is intended to improve the level of structural reliability and reflects the degree of hazard to human life and property as a function of building use.

Step 3 — Determine the exposure category of the structure for each wind direction based on Section 1609.4. The exposure category accounts for variations in the upwind surface roughness for different site conditions. Exposure A has been deleted from the 2003 IBC (see ASCE 7-02 Commentary, Section C6.5.6); Exposure B represents urban and suburban areas; Exposure C represents generally open, flat terrain, and shorelines in hurricane-prone regions; and Exposure D represents flat, unobstructed areas exposed to open water. Section 1609.4 shows detailed exposure category descriptions.

Step 4 — Determine the height and exposure adjustment coefficient, , from Table 1609.6.2.1(4). The adjuλ-ment coefficient depends on the mean roof height of a building and the exposure category for the given wind direction.

Step 5 — Determine the width of the end zone for the MWFRS, which is equal to 2a. The dimension of a is the lesser of 0.010 times the least horizontal dimension of the structure or 0.4h, but not less than 0.04 times the least horizontal dimension of a building or 3 feet (see Table 1609.6.2.1, Footnote 10).

Step 6 — For both transverse and longitudinal directions, determine the simplified design wind pressures, p_{s30}, for the MWFRS from Table 1609.6.2.1(1). The wind pressures in this table are for Exposure B, mean roof height h = 30 feet and importance factor $I_w = 1.0$. The horizontal pressures are determined for zones A, B, C, and D. Zones A and B are end zones, and zones C and D are interior zones. The vertical pressures are determined for zones E, F, G, and H. Zones E and F are end zones, and G and H are interior zones. Asymmetrical loading because of higher pressure acting on the edge zones must be considered.

Step 7 — Determine the adjusted, simplified design wind pressure for the MWFRS in accordance with the equation: $p_s = \ \ I_w p_{s30}$.

Step 8λ— Apply the adjusted horizontal and vertical design wind pressures for the transverse and longitudinal directions to the various zones in accordance with Figure 1609.6.2.1.

Section 1609.6.2.1.1 requires a minimum design wind load such that the load effects resulting from application of the above procedure are not less than the load resulting from using 10 pounds per square foot of horizontal pressure on zones A, B, C, and D with 0 pounds-per-square-foot vertical pressure on zones E, F, G, and H. ■

John R. Henry, P.E., is a senior staff engineer and instructor with Professional Development Services of the ICC. He can be reached at jhenry@iccsafe.org.