

Wind Loads

Guide to the Wind Load Provisions of ASCE 7-22

T. Eric Stafford, P.E.
Timothy Reinhold, Ph.D., P.E.

ASCE PRESS

Wind Loads

Other Titles of Interest

Minimum Design Loads and Associated Criteria for Buildings and Other Structures, by the American Society of Civil Engineers (ASCE/SEI 2022). Standard ASCE/SEI 7-22 provides requirements for general structural design and includes means for determining various loads and their combinations, which are suitable for inclusion in building codes and other documents. (ISBN 978-0-7844-1578-8)

Wind Loads: Guide to the Wind Load Provisions of ASCE 7-16, by William L. Coulbourne and T. Eric Stafford (ASCE Press 2020). Authors Coulbourne and Stafford provide a comprehensive overview of the wind load provisions in *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*, ASCE/SEI 7-16, focusing on the provisions that affect the planning, design, and construction of buildings for residential and commercial purposes. (ISBN 978-0-7844-1526-9)

Wind Engineering for Natural Hazards: Modeling, Simulation, and Mitigation of Windstorm Impact on Critical Infrastructure, edited by Aly Mousaad Aly and Elena Dragomirescu. (ASCE/EMI 2018). TEMPS (Trends in Engineering Mechanics Special Publication) 3 contains selected papers from the EMI 2016 conference which address the challenges of understanding and mitigating windstorm impact on critical infrastructure. (ISBN 978-0-7844-1515-3)

Wind-Induced Motion of Tall Buildings: Designing for Habitability, by Kenny C. S. Kwok, Melissa D. Burton, and Ahmad K. Abdelrazaq (ASCE/SEI 2015). This state-of-the-art report describes various facets of the human response to wind-induced motion in tall buildings and identifies design strategies to mitigate the effects of such motion on building occupants. (ISBN 978-0-7844-1385-2)

Urban Aerodynamics: Wind Engineering for Urban Planners and Designers, by the Task Committee on Urban Aerodynamics. (ASCE/Technical Council on Wind Engineering 2011). This report introduces the basic tools and technology used by engineers to determine the effects of wind on city streets and structures. (ISBN 978-0-7844-1179-7)

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Preface

This guide is designed to assist professionals in using the wind load provisions of *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*, ASCE/SEI 7-22, published by ASCE. The guide represents a major revision of *Wind Loads: Guide to the Wind Load Provisions of ASCE 7-16*. It has been reorganized to follow the flow of ASCE 7-22 provisions and reflects significant changes made to the wind load provisions from the previous version of the standard, ASCE/SEI 7-16.

The guide contains 19 example problems worked out in detail, which can provide direction to practicing professionals in assessing wind loads on a variety of buildings and other structures. Every effort has been made to make these illustrative example problems correct and accurate.

The authors welcome comments regarding inaccuracies, errors, or different interpretations. The views expressed and interpretation of the wind load provisions made in this guide are those of the authors and not of the ASCE 7 Standards Committee or ASCE.

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The authors express their deepest gratitude and thanks to Dr. Kishor C. Mehta, who was an author of this guide from its inception in 1995 through the 2010 edition. Dr. Mehta has been a guiding force in the development of wind engineering practice in the United States for 45 years. The authors also want to express their gratitude and thanks to the other authors who have worked with Dr. Mehta over the years in producing various editions of this guide. They include Dr. Richard D. Marshall, Dr. Dale C. Perry, James M. Delahay, and William C. Coulbourne. This guide would not be the same without their leadership and counsel on the types of information the practice can most use and what design issues are the most misunderstood.

Unit Abbreviations

SI Unit Abbreviations	*Customary Unit Abbreviations*
°C = degrees Celsius	°F = degrees Fahrenheit
cm = centimeter	in. = inch
day	day
g = gram	oz = ounce
h = hour	h = hour
ha = hectare	ac = acre
J = joule	Btu = British thermal unit
kg = kilogram (SI base unit of mass)	slug or pounds-mass (lbm)
N/m – newton per meter	plf = pound-force per foot (lbf/ft)
km = kilometer	mi = mile
kPa = kilopascal	psf = pounds-force/square foot
kW = kilowatt	hp = horsepower
L = liter (SI base unit of volume)	gal. = gallon
m = meter (SI base unit of length)	yd = yard
min = minute	min = minute
ml = milliliter	pt = pint
N = newton ($m \times kg/s^2$)	lbf = pound-force
Pa = pascal (N/m^2)	psi = pounds per square inch
ppm = parts per million	ppm = parts per million
s = second (SI base unit of time)	s = second
W = watt	Btu/h = British thermal unit per hour

1

Introduction

ASCE's publication, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*, ASCE/SEI 7-22, is a consensus standard. It originated in 1972 when the American National Standards Institute (ANSI) published a standard with the same title (ANSI A58.1-1972). That 1972 standard was revised 10 years later, and ANSI A58.1-1982 contained an innovative approach to wind loads for Components and Cladding (C&C) of buildings (ANSI 1982). Wind load criteria were based on the understanding of the aerodynamics of wind pressures in building corners, eaves, and ridge areas, as well as the effects of area averaging on pressures.

Note that for all chapters, sections, tables, figures, and appendixes from ASCE 7-22, "ASCE 7-22" is added where needed for clarification and should be assumed by the reader thereafter for table and equation numbering that matches ASCE 7-22 numbering.

In the mid-1980s, ASCE assumed responsibility for the Minimum Design Loads for Buildings and Other Structures Standards Committee, which establishes design loads. The document published by ASCE, ASCE 7-88 (ASCE 1990) contained design load criteria for live loads, snow loads, wind loads, earthquake loads, and other environmental loads, as well as load combinations. The ASCE 7 Standards Committee consists of voting membership representing all aspects of the building construction industry. The criteria for each of the environmental loads are developed by respective subcommittees.

The wind load criteria of ASCE 7-88 (ASCE 1990) were essentially the same as ANSI A58.1-1982. In 1996, ASCE published ASCE 7-95 (ASCE 1996). This version contained major changes in wind load criteria: The basic wind speed averaging time was changed from the fastest mile to a 3 s gust. This in turn necessitated significant changes in boundary layer profile parameters, gust effect factor, and some pressure coefficients. A *Guide to the Use of the Wind Load Provisions of*

ASCE 7-95 (Mehta and Marshall 1998) was published by ASCE to assist practicing professionals in the use of wind load provisions of ASCE 7-95.

In 2000, ASCE published a revision of ASCE 7-95 with updated wind load provisions. The document is ASCE 7-98 and has the same title as the previous version (ASCE 2000). The *International Building Code* (ICC 2000) adopted the wind load criteria of ASCE 7-98 by reference. This was a major milestone because it had the potential to establish a single wind load criterion for the design of all buildings and structures for the entire United States. A *Guide to the Use of the Wind Load Provisions of ASCE 7-98* (Mehta and Perry 2000) was published soon after the publication of ASCE 7-98. After each revision of the ASCE/SEI standard in 2002, 2005, 2010, and 2017, a *Guide to the Use of the Wind Load Provisions* has been published by ASCE (Mehta and Delahay 2004; Mehta and Coulbourne 2010, 2013; Coulbourne and Stafford 2020).

A revised standard, ASCE 7-22, was published by ASCE (ASCE 2022). It contains updates in wind speed maps for areas near the hurricane-prone coastline of the US mainland and a significant change in its reliance on the ASCE 7 Hazard Tool for defining wind speeds at specific locations and in certain areas. Specifically, basic design wind speed maps for the US Virgin Islands and Puerto Rico that include topographic effects have been developed. These maps, including those already developed for the Hawaii Islands that were included in ASCE 7-16 (ASCE 2017), are not directly included in the ASCE 7-22 standards document. They are only accessed through the ASCE 7 Hazard Tool (https://asce7hazardtool.online). In addition, some site-specific values for special wind regions in Colorado and California have been developed and can be accessed through the ASCE 7 Hazard Tool. ASCE 7-22 also includes the following major revisions and additions:

1. Simplifications to external C&C roof pressure coefficients for steep slope roofs;
2. Updated drawings for wind pressure zones on multilevel flat roofs;
3. Wind load provisions for elevated buildings;
4. Wind load provisions for ground-mounted solar arrays;
5. Extension of the application of wind load provisions for canopies attached to buildings taller than 60 ft; and
6. Addition of an entirely new chapter dealing with tornado loads.

The chapter on tornado wind loads mimics the methodologies used for nontornado wind loads. However, it includes new design wind speed maps that are a function of building/facility effective plan area and includes modifications to nontornado wind provisions, parameters, and coefficients.

Examples provided in previous guides have been well received by practitioners and are expanded and updated in this guide.

1.1 Objectives of the Guide

The objectives of this guide are to provide direction in the use of wind load provisions of ASCE 7-22 (referred to as *the standard*) and to provide some background that can help when applying the provisions to more complex structural shapes. ASCE 7 wind load provisions are generally presented for simple rectangular-shaped building plans with simple roof shapes. However, many buildings are being designed with complex plan shapes and roofs. This guide contains background information about the analytical provisions and examples that are intended to help the user think about how to use engineering judgment in applying the wind load provisions to more complex shapes. The commentary of ASCE 7-22 (Chapters C26 through C32) contains helpful background information and discussion of the wind load criteria; that information is not repeated in this document.

The guide contains 19 worked examples. Sufficient details of the calculation of wind loads are provided to help the reader properly interpret the wind load provisions of the standard. Sections of the standard, as well as the figures and tables of the standard, are cited liberally in the examples. *It is necessary to have a copy of ASCE 7-22 to follow the examples and work with this guide.* A copy of ASCE 7-22 can be ordered by calling 1-800-548-ASCE or ordering online at www.asce.org/publications.

1.2 Overview, Changes, and Additions

The wind load provisions of ASCE 7-22 are similar in appearance to those found in the 2010 and 2016 versions of the standard. A major change in the format occurred for the ASCE 7-10 version (ASCE 2010). Wind load provisions contained in one chapter (Chapter 6) in versions prior to ASCE 7-10 were expanded into six chapters (Chapter 26 through Chapter 31) in ASCE 7-10. Wind loads can be determined through analytical methods and code provisions or by conducting a boundary layer wind tunnel (BLWT) study. Chapters 26 through 30 provide information and provisions necessary for the use of the analytical procedures, whereas Chapter 31 describes the requirements for an acceptable wind tunnel study.

Analytical procedures all begin with the establishment of basic reference design pressure(s) to be used in the analysis. Chapter 26 provides the general requirements and parameters for determining the basic design wind reference pressures used in other chapters to calculate wind loads or wind pressures. The provisions for determining specific design wind pressures or loads are organized by the type of loading and the type of building, building feature, or structure under consideration in Chapters 27 through 30. Types of loading include main wind force resisting system (MWFRS) and C&C loads. Each chapter contains all the equations, tables, and figures needed, other than basic reference design pressure(s) and reference material contained in Chapter 26, to calculate the specific wind pressures or loads for the building structure, element, or feature under consideration.

For the 2022 edition, an additional chapter (Chapter 32) was added to provide specific basic tornado speed maps and wind load provisions for tornado-related loads. Tornado loads have been intentionally separated from wind loads in the standard, rather than being treated as a subset, because their characteristics are significantly different from other types of windstorms. Tornado load provisions apply only to Risk Categories III and IV buildings and other structures located in the tornado-prone region shown in Figure 32.1-1 of ASCE 7-22. The intent is that these risk category buildings would be designed for the higher wind loads obtained from Chapters 26 through 31 or tornado loads from Chapter 32, using the load factors from Chapter 2 of ASCE 7-22.

The basic approach to assessing wind loading has not changed. This is true even for tornado design loads where the approach is maintained, but parameters and coefficients are adjusted. However, there are a couple of important issues to keep in mind when using either the tornado provisions or the wind speed maps that include topographic effects.

- For tornado design, basic design tornado speeds are dependent on the effective plan area of the building or facility. This is because of the relatively narrow path of tornadoes compared to other types of wind events. Consequently, larger plan dimension buildings or facilities have a nontrivial greater probability of being struck by a tornado.
- When basic design wind speed maps that include topographic effects are used, adjustments need to be considered for buildings and structures taller than about 100 to 200 ft. Without adjustments, the wind loads will likely be overly conservative on the top portions of these buildings and structures.

Chapter 26 does contain some significant changes to the basic design wind speed, from the 2016 version. These include tweaks to basic design wind speed map contours along the hurricane coastline, the integration of topographic effects in basic design wind speeds for Puerto Rico and the US Virgin Islands, and the adoption of design wind speed contours in some of the Special Wind Regions of Colorado and California. These more detailed determinations of basic design wind speeds, including maps for the Hawaiian Islands which were included in ASCE 7-16, are now only available through the ASCE 7 Hazard Tool (https://asce7hazardtool.online).

One specific change that has been made relative to the determination of the basic reference wind pressure in Chapter 26 is the removal of the directionality factor, K_d, from Equation (26.10-1). Nevertheless, Chapter 26 still retains the table listing appropriate K_d factors for various building shapes, structure types, and types of loading. The K_d factor has simply been moved to the various pressure and load calculation equations in Chapters 27 through 30. General requirements for calculating the reference design pressure for buildings and structures now include basic design wind speed (V), exposure category and height above grade (K_z), topographic effect (K_{zt}) by calculation or through the map when available, and ground elevation factor (K_e).

Chapter 26 also addresses the gust effect factor, enclosure classification, windborne debris regions, internal pressure coefficient, symbols, and definitions.

Decisions about these factors, classifications, and coefficients can be made before proceeding with wind load calculations in Chapters 27 through 30. Changes in velocity pressure with height and exposure category now extend to much higher elevations than in previous editions of the standard. The largest changes in K_z values for heights below 500 ft are reductions in values for Exposure B. The option for using performance-based wind design procedures is now specifically recognized. Conditions that trigger addressing topographical effects have been revised.

Chapter 27 contains new provisions for determining the MWFRS loads on elevated buildings including loads on the structure and elements below the elevated portion of the building and on the bottom surface of the elevated building. It also includes improved figures that more clearly describe the loading patterns on buildings with various roof shapes (Figure 27.3-1 of ASCE 7-22) and the requirements for including roof pressures in the load cases. Circumstances when sidewall pressures should be considered (Figure 27.3-8), have been clearly defined in the revised notes. The directionality factor K_d now appears in all the wind load equations in this chapter. The Part 2 simplified methods provided in ASCE 7-16 have been removed from the standard.

In Chapter 28, conditions and limitations have been revised to better prescribe when the provisions should not be used. Load case figures have been improved and the directionality factor K_d now appears in all the wind load equations in this chapter. This chapter provides the only provisions in ASCE 7 for determining lateral wind loads parallel to the ridge for open and partially enclosed buildings with transverse frames and pitched roofs. Equations are provided for both wind pressure on the end walls and the total longitudinal force. The provisions are applicable to open-end walls and those that are fully or partially enclosed with cladding. The Part 2 simplified methods provided in ASCE 7-16 have been removed from the standard.

Chapter 29 contains wind loads criteria for MWFRS of other structures and building appurtenances. Other structures include freestanding walls and solid signs; chimneys, tanks, and similar structures; open signs and single-plane open frames; trussed towers; and circular bins, silos, and tanks. Building appurtenances include rooftop structures and equipment. For wind loads on parapets and overhangs, Chapter 29 refers to appropriate sections in other chapters. Provisions for determining wind forces on rooftop solar arrays were added in 2016 and the 2022 version includes provisions for determining wind loads on ground-mounted fixed-tilt solar panel arrays. The directionality factor K_d now appears in all the wind pressure and wind load equations in this chapter.

Chapter 30 contains wind load criteria for C&C. The complex pressure coefficient charts for steep slope roofs in ASCE 7-16, which were characterized by varying tributary area limits and many zones, have been simplified. Except for flat roofs, the treatment of loads on roof overhangs has been simplified in most cases to a simple addition of the wall design pressure at the bottom side of the overhang. For flat roofs, separate overhang charts are still provided. Zones with similar coefficient values have been combined. Wind load provisions for the flat bottom surface of elevated buildings have been added. Wind pressure zones for

flat roofs on low-rise buildings with stepped roofs (Figure 30.3-3 of ASCE 7-22) have been aligned with the basic wind pressure zones for flat roofs on low-rise buildings. Provisions for determining C&C surface wind loads as well as net loads on canopies attached to buildings with heights less than or equal to 60 ft were added in ASCE 7-16. Additional provisions for canopies attached to buildings of all heights have been added in ASCE 7-22. C&C pressures on silos, bins, and tanks are included in this chapter. The directionality factor K_d now appears in all the wind pressure equations in this chapter. Part 2 and Part 4 simplified methods provided in ASCE 7-16 have been removed from the standard.

Chapter 31 now references the 2020 edition of ASCE 49 for wind tunnel test conditions.

Chapter 32 provides provisions for determining tornado design loads and applies only to Risk Category III and IV buildings and structures. However, it can be used to determine tornado design loads for any building or structure where the owner wants to consider a higher level of design (i.e., 1,700- or 3,000-year return period tornado wind loads). Nevertheless, a building designed for tornado loads should not be confused with a building or areas of a building designed as ICC 500 compatible storm shelters or FEMA Tornado Safe Rooms. The provisions in Chapter 32 follow similar procedures to those laid out for MWFRS and C&C loads in Chapters 26 through 30, excluding Chapter 28. However, Chapter 32 provides substitute coefficients, parameters, and modifiers that address the current understanding of the differences in loading between tornadoes and other types of windstorms.

For owners or designers wishing to address even more extreme windstorm-related loads, Appendix F provides wind hazard maps for long return periods (10,000 years through 1,000,000 years) for straight-line winds associated with frontal systems, thunderstorms, and hurricanes. Similarly, Appendix G provides long return period maps for tornado hazards with the same 10,000-year through 1,000,000-year probabilities. Nevertheless, it should be pointed out that these long return period hazard estimates are based on models developed using historical data and do not account for potential variations associated with climate change.

The changes found in the wind-related chapters of ASCE 7-22 are reflected in the example problems provided in this guide.

1.3 Reliability of Wind Loads Developed Using Provisions in the Standard

The analytical procedures used to determine design wind loads typically involve the selection of a basic design wind speed that reflects a certain annual probability of exceedance at the site, modified by terrain roughness-related factors, topographic factors if any, and air density considerations to produce a reference velocity pressure(s) that is site specific and appropriate for use with

other factors that are specific to the building or structure being designed. These additional building-related factors can be described in a general way as pressure or force coefficients that incorporate a peak factor or are coupled with a gust effect factor. The overarching goal is to provide designs that meet the reliability targets expressed in Chapter 1 of the standard. Evaluation of the overall reliability requires an assessment of uncertainties involved in all these parameters. Achieving different target reliabilities associated with potential consequences of failure or collapse is generally achieved by selecting basic design wind speeds with different annual probabilities of exceedance. The following sections provide a background discussion of the relative importance of the various parameters, procedures, and provisions used to determine wind loads.

1.3.1 Assessment of Wind Climate

As wind pressures and wind loads vary with the square of the wind speed, estimation of the design wind speed is a critical component of any design wind pressure or wind load calculation. A 5% increase or decrease in the design wind speed results in approximately a 10% increase or decrease in the wind pressure or wind load, respectively. The basic design wind speed maps contained in ASCE 7-22 and further refined to produce site-specific values in the ASCE 7 Hazard Tool represent the best available overall modeling of wind risks for the United States and its associated territories and commonwealths. Hurricane-related design wind speeds were significantly improved in the 2010 edition and further adjusted to account for more recent data on storm tracks and trends in the 2022 edition. Similarly, design wind speeds away from the hurricane-prone coastal areas were the subject of significant modeling efforts that were completed in time for the new mapping to be included in the 2016 version of the standard.

Versions of the standard before 2010 used importance factors to increase or decrease design wind loads for buildings and structures depending on the consequences of failure or collapse. However, research into hurricane wind-related risks clearly demonstrated that a single importance factor did not adequately reflect the variations in risk throughout hurricane-prone regions. Consequently, starting with the 2010 version of the standard, different basic design wind speed maps corresponding to different annual probabilities of exceedance [one divided by the annual probability of exceedance provides what is generally referred to as the mean recurrence interval (MRI) in years] have been provided instead of importance factors. Research to align design wind loads with reliability targets achieved using the load combinations in Chapter 2 resulted in separate maps for each of the four risk categories assigned to buildings and structures. The corresponding annual probabilities of exceedance for Risk Categories I, II, III, and IV buildings and structures are 0.0033, 0.0014, 0.00059, and 0.00033 (MRI = 300, 700, 1,700, and 3,000 years), respectively.

Although there have been significant improvements in the analysis and mapping of basic design wind speeds across the United States, there continue to be areas that are identified simply as special wind regions on the maps. These special wind regions typically include mountain ranges, gorges, or river valleys. Unusual winds may be encountered in these regions because of topographic effects or

the channeling of wind. The standard permits climatological studies using regional climatic data and consultation with a wind engineer and/or a meteorologist. However, the standard does specify two specific requirements that must be met when regional data are used. In some cases, local building officials may have established design wind speeds for these areas. While location-specific wind speeds can be found using the ASCE 7 Hazard Tool (https://asce7hazardtool.online/), if the site falls into one of the special wind regions other than the few areas in Colorado and California that have been mapped, the program will return that the location is in a special wind region.

Tornado winds are not included in the development of the Chapter 26 basic wind speed maps (Figure 26.5-1 of the standard) because these wind events have very different wind characteristics from those of the other types of storms included in the database. Furthermore, until recent investigations of tornado strike probabilities were completed, it was expected that tornadoes did not affect the wind risks for MRIs below 5,000 years. Recent in-depth analyses of tornado risks have shown that in certain parts of the country, tornados do contribute to wind risks at 1,700-year and 3,000-year MRIs. To address this risk, a new chapter (Chapter 32) has been added to provide guidance for the design of Risk Categories III and IV buildings and structures against tornado loads expected at those MRIs.

1.3.2 Adjustment Factors for Exposure, Height, and Elevation

Earlier versions of the standard that used fastest-mile wind speeds also used equations to describe the variation of wind speed with height in the different identified exposures that were based on mean hourly wind speeds. The result was large variations in calculated wind pressures and loads for the same building or structure located in different wind exposures. The shift to basic wind speeds based on 3 s gust wind speeds instead of fastest-mile wind speeds and the use of gust velocity profiles significantly reduced the differences associated with exposure factors because the ratio of gust wind speeds to mean wind speeds close to the ground is higher in rougher terrain. The standard also allows for the determination of intermediate exposures in a transition zone between the standard exposures provided it is determined using a rational analysis method defined in recognized literature.

1.3.3 Peak Factors and Gust Effect Factors

The standard defines factors G and G_f that appear in wind pressure and wind load equations throughout Chapters 27 through 30 as gust effect factors. Most people would likely think that a gust effect factor would be directly associated with a gust in the approaching wind. This association of the gust effect factor with gusts in the approaching wind tends to ring true for pressures on the windward wall of a building when that face is perpendicular to the wind direction. In these cases, pressure fluctuations on the windward wall can be related to the gusts in the approaching wind flow. Because the directional method for determining the MWFRS loads (Chapter 27) specifically addresses wind loads in the along-wind direction and these loads tend to be dominated by pressures applied to the windward face, the gust effect factor description is also a reasonable description for this case.

However, all bluff bodies (buildings) shed a variety of vortexes that can create high local peak negative surface pressures (suctions). Flow separation at corners and edges of buildings, as well as separation because of turbulent flow around streamlined structures such as circular cylinders, generates shear layers and vortexes that produce large surface pressure fluctuations. Typically, these pressure fluctuations are not directly correlated to gusts in the wind approaching the building but instead are affected by complex interactions between the approach flow and the disturbance caused by the building. The term *wake effects* is sometimes used as a general description of these effects on surface pressures. Consequently, the GC_p used to calculate peak negative design pressures is derived by dividing the measured peak negative pressure by the maximum expected 3 s gust velocity at an appropriate reference height, usually the mean roof height. When the GC_p approaches -2 or -3 and is based on a 3 s gust velocity, it is not possible to relate that kind of peak pressure to a gust in the approaching wind. From a code development perspective, it could be possible to define positive surface pressures in terms of mean pressure coefficients to be multiplied by a gust effect factor. Unfortunately, as noted above, that is not possible when it comes to defining negative surface pressures. Consequently, the standard uses a combined gust effect factor and pressure coefficient (GC_p) to define C&C pressures and does not allow them to be separated.

When it comes to the MWFRS load provisions in Chapter 27 (Directional method), the provisions provide separate values for the gust effect factor, G or G_f, and pressure coefficients, C_p. For all low-rise buildings and other structures with a fundamental natural frequency greater than 1.0 Hz, a gust effect factor, $G = 0.85$, is specified in the standard. For dynamically sensitive buildings and other structures, a gust effect factor, G_f, is to be determined using provisions in the standard. The formulation of the gust effect factor, G_f, is for buildings (it is not always applicable to other structures), and it should be noted that G_f is based on the along-wind buffeting response. Consequently, the MWFRS loads produced using Chapter 27 only represent the unidirectional along-wind loading of the building when the wind is blowing perpendicular to the face of the building. Furthermore, the analysis method works best when the cross-sectional shape of the building is square or rectangular. While the MWFRS loads calculated using Chapter 27 are unidirectional, they are to be computed for each principal direction, aligned with the length and width of the plan cross section. The boundary layer wind tunnel investigations to determine the MWFRS loads have demonstrated that significant loads can occur simultaneously in both principal directions when winds approach at an angle to one of the faces. Consequently, Chapter 27 includes a series of design wind load cases that include combinations of reduced lateral loads in both principal directions, roof loads, and in some cases torsional moments. This approach has worked well for the design of rigid buildings as well as many somewhat flexible buildings provided across-wind loading because of vortex shedding is not significant.

Chapter 28 provides an alternate set of provisions that can be used to determine the MWFRS loads for buildings that meet certain requirements. These requirements include height less than 60 ft, height divided by minimum width less than or equal to 1.0, and a regular cross-sectional shape with a flat, gable, or hip roof. This chapter takes a different approach to specifying wind loads. Instead of

basing its loads on cases where winds are blowing directly at one of the building faces as is done in Chapter 27 with the directional method, the load cases provided envelope the critical wind loading effects (structural actions such as uplift, horizontal shear, and bending moments) generated by winds from all directions. Similar to C&C loads, the gust effect factor and force coefficients (GC_{pf}) provided in Chapter 28 envelope the loads and cannot be separated. This method has been used extensively by the metal building industry as well as in developing guidance for light-frame construction found in prescriptive standards such as the American Wood Council's *Wood Frame Construction Manual* (AWC 2018), American Iron and Steel Institute's *Standard for Cold-Formed Steel Framing—Prescriptive Method for One- and Two-Family Dwellings* (AISI S230) (AISI 2019), and the International Code Council's *Standard for Residential Construction in High-Wind Regions* (ICC 600) (ICC 2020b).

As noted earlier, all buildings and structures (bluff bodies) shed vortexes. The vortexes associated with the phenomenon commonly referred to as *vortex shedding excitation* are created by shear layers formed at the upwind corners or surface of a bluff body where the flow separates from the surface of the building or structure. Within the shear layer and next to the building, the wind rolls up into a vortex with an axis aligned with the edge of the structure and this vortex then rolls off the building and into the wake. These vortexes generate strong negative (outward-acting) surface pressures on the side of the building or structure downwind of the edge. This produces an across-wind force on the building or structure. Typically, vortexes are shed alternately from opposite sides of the building creating a nearly sinusoidal across-wind force on the building or structure. As buildings or structures become taller or a structure becomes longer, while maintaining a somewhat uniform cross-sectional shape, the vortex shedding-induced forces will become larger. Vortex shedding can become a problem when the frequency of shedding is close or equal to the frequency of the first or second transverse modes of the structure. The intensity of excitation increases with aspect ratio (height-to-width or length-to-breadth) and decreases with increasing structural damping. Structures with low damping and an aspect ratio of 6 or more may well experience vortex shedding across-wind loading that exceeds the along-wind loading determined using code provisions.

For certain cross-sectional shapes, such as D or H, wind-induced motion may generate increasingly larger forces in the direction of motion resulting in motion that continues to increase if the wind continues to blow at or above the speed needed to initiate the motion. For some building shapes and wind directions, torsional excitation can also be important. This is particularly true for structural systems where the center of stiffness is offset from the center of aerodynamic forces. If across-wind or torsional excitation appears to be a possibility, expert advice should be obtained because a more complex analysis or a wind tunnel test may be needed.

Although the standard does not specify limiting values for serviceability, a discussion of serviceability is given in the Appendix C commentary of the standard. The user of the standard is encouraged to review this appendix to obtain guidelines for the drift of walls and frames and vibrations.

Pressure and Force Coefficients

The pressure and force coefficients given in the standard have largely been derived from the BLWT tests of rectangular buildings. The main wind force resisting system lateral force coefficients included in Chapter 27 have not changed much since the 1982 edition of the standard and trace their roots back to approaches used in the 1960s. The force coefficients for roofs of varying pitch in Chapter 27 have received minor tweaks over the years to better address internal pressures and provide values for interpolation but have remained largely unchanged since the 1995 edition of the standard. Chapter 28 MWFRS load provisions for low-rise buildings were added to the standard in 1995 and have largely remained unchanged through the 2022 version. Specific guidance for applying provisions to buildings with complex plan shapes (e.g., Y, T, and L shapes) or buildings with stepped elevations are not included (except as shown in Figure 30.3-3 of ASCE 7-22). Because MWFRS in Chapter 27 is uniformly applied across the surfaces of the building, it is easier to rationalize methods for applying the pressures to more complex building shapes than for Chapter 28 provisions. Nevertheless, common methods used for either set of provisions involve either creating a rectangular shape that circumscribes the building's cross section or breaking the building into rectangular sections for the purposes of calculating wind loads on each section. The sectional loads on the pieces are then combined to develop overall loads for structural analysis. Additional information and guidance may be found in other sources (**Table G1-1**).

As noted earlier, C&C pressure coefficients represent an enveloping of the highest wind pressures regardless of wind direction and the combination of gust effect factors and pressure coefficients cannot be separated. These coefficients have once again largely been developed from the BLWT tests of rectangular buildings. The diagrams provided in the standard envelope the highest peak pressure coefficients obtained regardless of wind direction. All these peak values cannot physically occur at the same time. While this is not a problem when the resulting loads are used to design fasteners, in other cases such as in the design of rafters, care needs to be taken to ensure that unrealistic load distributions are not used in design. Typically, the highest negative pressures occur at corners and along edges. This is true for roof edges and corners as well as along roof ridges. For walls, peak negative pressures occur at corners where wind flow around the building cannot negotiate the corner (exterior corners) and will separate from the downwind wall surface. These peak pressure coefficients are dependent on the geometry of the building.

When coefficients for a specific shape are not given in the standard, the designer is encouraged to use values through interpretation of the intent of the standard (see Examples 3.9 and 6.3 of ASCE 7-22 for an L-shaped building). C&C pressure coefficients provided in the standard can be applied to roofs and walls with similar geometric characteristics even if the building's cross-sectional shape is not square or rectangular. For example, the standard specifically allows C&C pressure coefficients for sloped roofs that were developed from the BLWT tests for low-rise buildings to be used for sloped roofs on buildings of any height.

Table G1-1. **Technical Literature**

Subject	*Selected reference material (see References section of this guide)*
Wind effects on buildings and structures	Newberry and Eaton (1974), Lawson (1980a, b), Cook (1985a, b), Holmes et al. (1990), Simiu and Yeo (2019), Dyrbye and Hansen (1996), Holmes and Bekele (2021), Simiu (2011), Tamura and Kareem (2013)
Codes and standards	NRCC (2016), BSI (2010), CEN (2005), ISO (2009), Standards Australia (2016), Stafford (2010)
Wind tunnel testing	Reinhold (1982), ASCE (2012), ASCE (2021)
General wind research	ASCE (1961), Cermak (1977), Davenport et al. (1977, 1978), Simiu (1981a, b)
Pressure and force coefficients	ASCE (1961, 2020), Hoerner (1965), Kopp and Morrison (2014), Vickery et al. (2011)
Tornadoes, shelter design	Minor et al. (1993), FEMA TR83-A (1980), Minor (1982), McDonald (1983), Coulbourne et al. (2002), FEMA 320 (2021a), FEMA 361 (2021b), ICC 500 (2020a)
Impact resistance protocol	ASTM E1886-19 (2019), ASTM E1996-20 (2020), ICC (2020c, d), DASMA (2017)
Wind load design for petrochemical and other industrial facilities	ASCE (2020)

Pressure and force coefficients available in the literature can also be used. However, the source and method of determination as well as the reference wind speed characteristics used need to be carefully reviewed and the coefficients should be adjusted as needed to align with the basis for ASCE 7-22 coefficients. The following caveats should be addressed:

1. The coefficients should be obtained from proper turbulent BLWT tests that are consistent with the requirements of Chapter 31.
2. The averaging time used should necessarily be considered to determine whether the coefficients are directly applicable to the evaluation of design loads or whether they need to be modified.
3. The reference wind speed (fastest mile, hourly mean, 10 min mean, 3 s gust, and so forth) and exposure category under which the data are generated must be established to properly compute the velocity pressure, q.
4. If an envelope approach is used, the coefficients should be appropriate for all wind directions. If, however, a directional approach is indicated, then the applicability of the coefficients as a function of wind direction needs to be ascertained. A limitation in the use of directional coefficients is that their adequacy for other than normal wind directions may not have been verified.

Although all the issues identified are important considerations when using the information on wind loading from other sources or standards, one of the most critical is assuring that the coefficients and gust factors are appropriate for use