



Resilience is a key component of building design when addressing both seismic and wind design. Properly designed and constructed wood structures that comply with building code requirements are resilient, performing with minimal damage while protecting occupants during both seismic and high wind events.

Photo courtesy of LEVER Architecture

## Resilient Wood Construction: Designing for Earthquakes and High Winds

How wood-frame wind- and seismic-resisting systems can contribute to resilience in the built environment

Sponsored by Think Wood | *By Andrew A. Hunt*

**R**esilience is the capacity of a structure or system to withstand and recover quickly from disruptive events, be they natural or human-caused disasters. High winds, hurricanes, and earthquakes are a harsh reality for much of the United States and designing a building to withstand the potentially devastating forces of high winds or seismic events is a challenge an architect or engineer will likely face.

Properly designed and constructed wood structures that comply with building code requirements are resilient, performing with minimal damage while protecting occupants during both seismic and high wind events.

For example, safe rooms constructed with wood and following prescriptive plans set forth by the Federal Emergency Management Agency (FEMA) are designed to withstand a 250-mph wind force and can pass a 100-mph “missile” impact test.<sup>1</sup>

Such rooms are meant to provide refuge for occupants during extreme weather events.

In another test, a seven-story, wood-frame building constructed at Japan's Hyogo Earthquake Engineering Research Center showed only minor signs of damage after a simulated quake that reached 7.5 on the Richter scale.<sup>2</sup>

Resilience is a key component of building design and should be addressed in every new project.

This continuing education course offers an overview of the benefits of light wood-frame construction, followed by a summary of key considerations in both seismic and wind design. The second half of the course focuses on issues and code provisions relevant to seismic- and wind-resistive design in light wood-frame construction, specifically compliance with the 2021 International Building Code (IBC) and

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#### Learning Objectives

After reading this article, you should be able to:

1. Describe the role that wood's structural configuration and redundancy play in enhancing resilient design.
2. Explain the analysis procedure commonly used for determining wind- and seismic-design loads for wood-frame buildings in accordance with the 2021 International Building Code (2021 IBC) and the American Society of Civil Engineers/Structural Engineering Institute Minimum Design Loads for Buildings and Other Structures (ASCE 7-16).
3. Describe common wood-frame wind- and seismic force-resisting systems, in accordance with the Special Design Provisions for Wind and Seismic (SDPWS) 2021 and the 2021 IBC.
4. Describe the techniques for strengthening wood buildings against high wind forces and seismic loads in accordance with building code requirements.

To receive AIA credit, you are required to read the entire article and pass the quiz. Visit [ce.architecturalrecord.com](http://ce.architecturalrecord.com) for the complete text and to take the quiz for free.

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the American Society of Civil Engineers/ Structural Engineering Institute Minimum Design Loads for Buildings and Other Structures (ASCE 7-16).

**Designing for Continuous Load Path**

Any discussion of designing for seismic and high wind events should begin with an overview of how various forces are transferred within a structure. Engineers and architects use the term “load path” to describe how forces flow through a building’s structure to the final point of resistance at the foundation. A continuous load path is like a chain that ties building elements together from the roof to the foundation, offering seamless transfer of load.

Design forces, including snow loads, wind, or an earthquake, are specified in the building code and referenced standards, and the building must be designed to withstand those forces without failure. For a structure to remain stable, a load applied at any point must have a path allowing transfer of the load through each building part, down to the building foundation and supporting soils.

The concept of a load path can be seen in the exploded diagram of a house in Figure 1, taken from FEMA’s publication, “Homebuilders’ Guide to Earthquake Resistant Design and Construction” (FEMA 232).<sup>3</sup> As this example shows, load transfer occurs via the roof-ceiling system and its connections to the second-story bracing wall system; through the second-story bracing wall system and its connections to the floor-ceiling system; by the floor-ceiling system and its connections to the first-floor bracing wall system; through the first-story bracing wall system and its connections to the foundation; and from the foundation to the supporting soil.

**How Wood Enables Resilience**

The ability of a properly designed and maintained wood building to provide occupant safety in extreme conditions can be attributed to several factors:

- Robust design criteria in applicable codes and standards: Codes and standards governing the design and construction of wood-frame buildings have evolved based on experience from prior earthquakes,

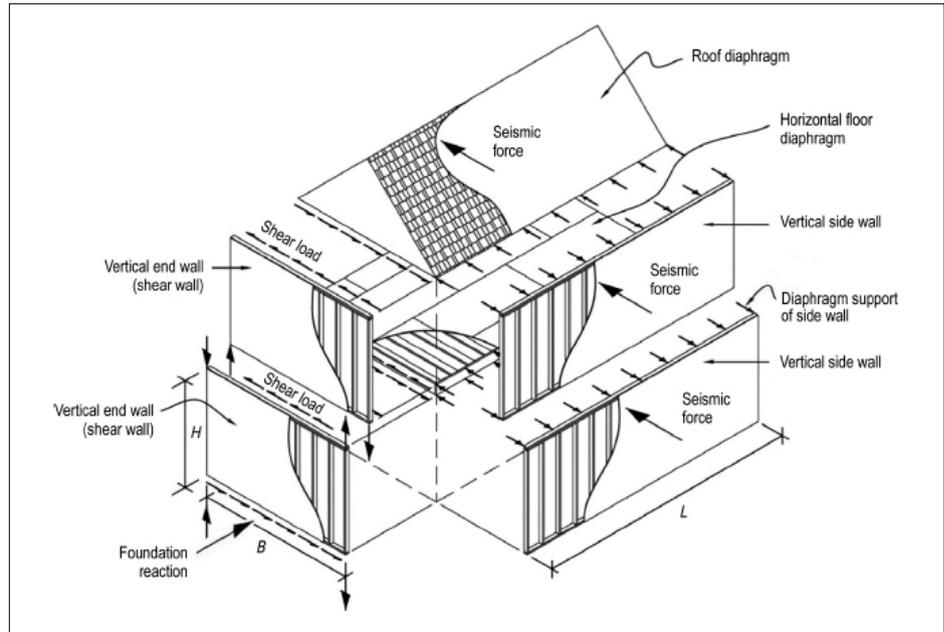


Figure 1: Load transfer between components in a building

hurricanes, wind loads, and related research. Codes also prescribe minimum fastening requirements for the interconnection of wood framing members—requirements that are unique to wood-frame construction and beneficial to a building’s performance.

- Ductile connections: Multiple nailed connections in framing members, shear walls, and diaphragms of wood-frame construction exhibit ductile behavior—the ability to yield and displace without sudden brittle fracture.
- Redundant load paths: Wood-frame buildings tend to be comprised of repetitive framing attached with numerous fasteners and connectors, which provide multiple, and often redundant, load paths for resistance to forces. Plywood or oriented strand board (OSB) diaphragms and shear walls have proven to be exceptionally resistant to these forces.

**RESILIENT DESIGN AND TODAY’S CODES**

Building codes are intended to protect occupants and first responders and, to a

lesser extent, limit property damage. By considering potential hazards together with the building’s intended use, they establish a minimum level of safety for all buildings, regardless of the building material used.

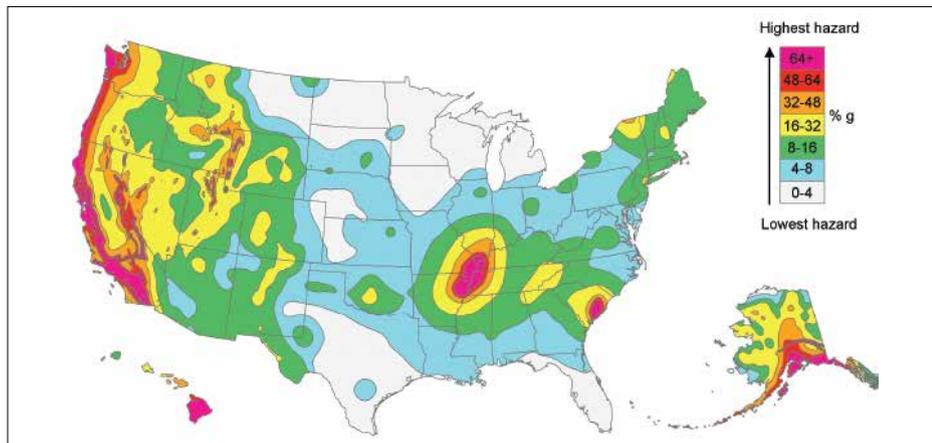
The 2021 IBC references ASCE 7-16, “Minimum Design Loads and Associated Criteria for Buildings and Other Structures.” This document is used to determine dead, live, soil, flood, tsunami, snow, rain, atmospheric ice, earthquake, and wind loads, and any combination thereof for general structural design. Minimum design loads are established to ensure that every building is designed to withstand loads that have a certain probability of occurring in its lifetime.

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Think Wood provides commercial, multifamily, and single-family home design and build resources to architects, developers, and contractors, including education, research, design tools, and innovative project profiles. For additional information, please visit [www.thinkwood.com](http://www.thinkwood.com).



**Figure 2:** This USGS earthquake hazard map shows peak ground accelerations for a firm rock site having a 2 percent probability of being exceeded in 50 years.

## AWC GUIDELINES FOR RESILIENT WOOD CONSTRUCTION

The American Wood Council (AWC) develops codes, standards, and guidelines for wood construction that allow for the appropriate and responsible manufacture and use of wood products. The IBC references several of these publications.

The National Design Specification (NDS) for Wood Construction<sup>4</sup> 2018 includes the necessary design procedures and design value adjustment factors for beams, columns, joists, structural glued-laminated timber (glulam), timber piles, prefabricated I-joists, structural composite lumber, cross-laminated timber, and connections, for lateral (including wind and seismic) and gravity loads and certain special loading conditions. It also contains design procedures for calculating fire resistance of exposed wood members. Reference design values for structural sawn lumber, structural glulam, and round timber poles and piles are contained in the NDS Supplement, a compendium of design values as reported by the grading agencies responsible for their establishment.

The AWC Wood Frame Construction Manual for One- and Two-Family Dwellings (WFCM)<sup>5</sup> 2018 provides engineered and prescriptive design requirements and is referenced by both the IBC and IRC. The provisions of the WFCM are based on dead, live, snow, seismic, and wind loads derived from the provisions of ASCE 7-16. In general, the framing systems described in the WFCM utilize repetitive member wood assemblies. Although intended for one- and two-family dwellings, the WFCM is a useful tool in the design of nonresidential buildings that fit within its scope for building size and assigned loads. The expanded applicability of WFCM design information beyond one- and two-family dwellings is recognized in 2018 and 2021 IBC Section 2309.

Special Design Provisions for Wind and Seismic (SDPWS)<sup>6</sup> 2021 is another AWC standard directly referenced by the IBC. It provides criteria for proportioning, designing, and detailing engineered wood systems, members, and connections in lateral force-resisting systems for the required design of lateral force-resisting systems which resist wind, seismic, or other lateral loads such as nailed wood-frame shear walls and diaphragms and cross-laminated timber (CLT) shear walls and diaphragms. Section 2305 of the IBC contains additional criteria, primarily for stapled shear wall and stapled diaphragm construction.

Important changes were made in the 2021 edition of the SDPWS. These include revisions to the Chapter 3 tables of nominal uniform load capacities for resistance to out-of-plane wind loads and revised organization of requirements in Chapter 4 to differentiate between sheathed wood-frame systems and new CLT systems. Language is added to clarify reference conditions for applicability of design value tables for framing and nail sizes. Provisions are also added for the vertical distribution of seismic force-resisting system (SFRS) strength for structures assigned to Seismic Design Category D, E, or F.

For the wind and seismic hazards, codes address the probability and severity of wind events and earthquakes by providing design requirements that are specific to regional risks. Codes are also intended to ensure the superior performance of essential facilities, such as hospitals and fire stations, relative to other structures.

### Wind- and Seismic Force-Resisting Systems

ASCE 7 recognizes several wood-frame seismic- and wind force-resisting systems. These include sheathed wood-frame diaphragms and shear walls and now, CLT diaphragms and shear walls.

Light wood-frame diaphragms and shear walls include 1) light wood-frame walls with wood structural panels rated for shear resistance; and 2) light wood-frame walls with structural panels made from other materials, including particleboard, structural fiberboard, gypsum wallboard, gypsum base for veneer plaster, water-resistant gypsum backing board, gypsum sheathing board, gypsum lath and plaster, and Portland cement plaster. SDPWS also allows wood-frame shear walls sheathed with wood structural panels to be designed to simultaneously resist shear and uplift from wind forces. The design requirements for wood-frame diaphragms and shear walls used in these systems are contained in Chapter 4 of the 2021 SDPWS.

The increasing popularity of mass timber structures and construction products such as CLT prompted an examination of how these materials, and the resulting taller buildings, may perform during natural disasters. However, until the release of the 2021 SDPWS, use of CLT as diaphragms or shear walls to resist wind and seismic forces had not been codified. The 2021 SDPWS contains new design provisions for CLT diaphragms and CLT shear walls. CLT diaphragm provisions are found in Section 4.5 and CLT shear wall provisions are found in Section 4.6 and Appendix B.

### Risk Category

Before considering provisions specific to wind or seismic hazards, identify the risk category of the building or structure as defined by the IBC. Risk categories are assigned to buildings to account for consequences and risks to human life (building occupants) in the event of a building failure. Risk categories are used to classify buildings and structures based on their importance and take into consideration

occupancy, risk to human life, and societal need of the building or structure to function during and following an extreme event. For example, hospitals and other essential facilities are assigned the highest risk category (Risk Category IV) and therefore must meet more stringent design criteria. Detailed descriptions of buildings and structures associated with Risk Categories I, II, III, and IV are provided in 2021 IBC Table 1604.5.

**SEISMIC DESIGN AND WOOD**

Earthquakes are an unpredictable fact of life in some regions in North America, particularly along the West Coast. The map in Figure 2, prepared by the United States Geological Survey (USGS), illustrates the seismic hazard for the entire country, with areas of greatest risk shown in red.

Although developers of building codes accept that some nonstructural and structural damage will occur, they seek to limit the likelihood of structural collapse and to ensure the superior performance of essential facilities such as hospitals and fire stations. These performance expectations are set in recognition of the fact that it is not economically feasible to prevent all damage in all buildings when designing for infrequent, large-magnitude earthquakes.

Earthquakes cannot be prevented, but proper design and construction—based on compliance with building code requirements—can reduce their negative impacts.

Referencing ASCE 7, building codes address the probability and severity of earthquakes by providing design requirements based on the site-specific seismic hazard and the building’s risk category.

ASCE 7 and model building codes such as the IBC provide maps that identify seismic hazards. Created in cooperation with the USGS and FEMA, these maps are updated regularly and assist engineers in designing buildings, bridges, highways, and utilities that will withstand seismic shaking.

**Calculating Seismic Design Forces**

The IBC establishes the minimum lateral seismic forces for which buildings must be designed, primarily by reference to ASCE 7-16. Base shear refers to the total horizontal force resisted through a structure’s lateral force-resisting system as the mass of the building accelerates due to ground shaking. The equivalent lateral force (ELF) procedure is the most used procedure for determining base shears. This is particularly true for low-rise, short-period, wood-frame buildings.

RISK CATEGORY	NATURE OF OCCUPANCY
I	Buildings and other structures that represent a low hazard to human life in the event of failure, including but not limited to agricultural facilities, certain temporary facilities, and minor storage facilities
II	Buildings and other structures except those listed in Risk Categories I, III, and IV
III	Buildings and other structures that represent a substantial hazard to human life in the event of failure, including but not limited to: <ul style="list-style-type: none"> <li>Buildings and other structures whose primary occupancy is public assembly with an occupied load greater than 300</li> <li>Buildings and other structures containing one or more public assembly spaces, each having an occupant load greater than 300 and a cumulative occupant load of the public assembly spaces of greater than 2,500</li> <li>Buildings and other structures containing Group E or Group 1-4 occupancies or a combination thereof, with an occupant load greater than 250</li> <li>Buildings and other structures containing educational occupancies for students above the 12th grade with an occupant load greater than 500</li> <li>Group I-2, Condition 1 occupancies with 50 or more care recipients</li> <li>Group I-2, Condition 2 occupancies not having emergency surgery or emergency treatment facilities</li> <li>Group I-3 occupancies</li> <li>Any other occupancy with an occupant load greater than 5,000<sup>a</sup></li> <li>Power-generating stations, water treatment facilities for potable water, wastewater treatment facilities, and other public utility facilities not included in Risk Category IV</li> <li>Buildings and other structures not included in Risk Category IV containing quantities of toxic or explosive materials that: exceed minimum allowable quantities per control area as given in Table 307.1(1) or 307.1(2) or per outdoor control area in accordance with the <i>International Fire Code</i>, and are sufficient to post a threat to the public if released<sup>b</sup></li> </ul>
IV	Buildings and other structures designated as essential facilities, including but not limited to: <ul style="list-style-type: none"> <li>Group I-2, Condition 2 occupancies having emergency surgery or emergency treatment facilities</li> <li>Ambulatory care facilities having emergency surgery or emergency treatment facilities</li> <li>Fire, rescue, ambulance, and police stations and emergency vehicle garages</li> <li>Designated earthquake, hurricane, or other emergency shelters</li> <li>Designated emergency preparedness, communications and operations centers, and other facilities required for emergency response</li> <li>Power-generating stations and other public utility facilities required as emergency backup facilities for Risk Category IV structures</li> <li>Buildings and other structures containing quantities of toxic materials that: exceed maximum allowable quantities per control area as given in Table 307.1(2) or per outdoor control area in accordance with the <i>International Fire Code</i>, and are sufficient to pose a threat to the public if released<sup>b</sup></li> <li>Aviation control towers, air traffic control centers, and emergency aircraft hangars</li> <li>Buildings and other structures having critical national defense functions</li> <li>Water storage facilities and pump structures required to maintain water pressure for fire suppression</li> </ul>

<sup>a</sup>For purposes of occupant load calculation, occupancies required by Table 1004.1.2 to use gross floor area calculations shall be permitted to use net floor areas to determine the total occupant load

<sup>b</sup>Where approved by the building official, the classification of buildings and other structures as Risk Category III or IV based on their quantities of toxic, highly toxic or explosive materials is permitted to be reduced to Risk Category II, provided it can be demonstrated by a hazard assessment in accordance with Section 1.5.3 of ASCE 7 that a release of the toxic, highly toxic or explosive materials is not sufficient to pose a threat to the public

**Table 1: Risk categories of the building or structure as defined by the IBC**

Base shear, or *V*, is proportional to the effective seismic weight of the structure and the seismic hazard at the site. The seismic hazard is represented by several variables: the spectral response acceleration parameter, *S*<sub>DS</sub>; response modification coefficient, *R*; and the importance factor, *I*<sub>e</sub>. Effective seismic weight, or *W*, includes both dead load plus some live loads as prescribed in Section 12.7.2 of ASCE 7-16.

**Seismic Design Category**

Once you’ve determined the building’s risk category, the next step is to determine the seismic design category (SDC). SDC is determined based on several factors:

- Soil properties at the site, or site class, classified as A, B, C, D, E, or F: Site class A is associated with the presence of hard rock. Site class F is associated with

peats and/or highly organic clays, very high plasticity clays and very thick, soft/medium stiff clays

- Mapped values of the seismic hazard
- Risk category of the structure

SDCs range from A to F, with A representing the lowest risk and F the highest. The SDC is used to determine permitted seismic force-resisting systems and structural height limitations. It also determines the applicability of special requirements associated with structural redundancy and structural irregularities in the building system.

SDC A represents a very low seismic hazard for which there are no seismic-specific limits (NL) on structural height, system type, structural redundancy, or structural irregularities. Structures located in this category are not subject to design forces determined in accordance with the ELF. Beginning with SDC B, seismic forces in accordance with ELF are applicable and consideration must be given to special requirements for structural irregularities. Special requirements and limitations become increasingly stringent in SDC C and higher. As can be seen in Table 2, as seismic design category increases, structural height limitations apply as well as limitations on the use of some lateral force-resisting systems.

**Calculating SDC for Short-Period Structures**

For short-period structures, such as most wood-frame structures, ASCE 7 allows determination of the seismic design category based on value of SDS (design spectral response acceleration) and risk category alone (see Table 3), provided alternative criteria are met for structure period and diaphragm flexibility and the site’s mapped spectral response acceleration period value (S1) is less than 0.75.

**Structural Redundancy**

Separate from inherent redundancies present in typical wood construction, the code encourages a redundant layout of seismic force-resisting systems throughout the building. The redundancy factor, ρ, which is either 1.0 or 1.3, is applied to the seismic design forces based on lateral force-resisting system configuration. In SDC B and C, the redundancy factor equals 1.0. For wood-frame shear walls in higher seismic design categories, use of a redundancy factor equal to 1.0 can often be accomplished for plans that have a regular layout and where lateral

Seismic Force-Resisting System	Structural system and height, h <sub>n</sub> , limits (ft)						
	R	C <sub>d</sub>	Ω <sub>o</sub>	Seismic Design Category			
				B	C	D	E,F
<b>A. Bearing wall systems</b>							
15. Light-frame (wood) walls sheathed with wood structural panels rated for shear resistance	6½	3	4	NL	NL	65	65
17. Light-frame walls with shear panels of all other materials	2	2½	2	NL	NL	35	NP
<b>B. Building frame systems</b>							
22. Light-frame (wood) walls sheathed with wood structural panels rated for shear resistance	7	2½	4½	NL	NL	65	65
24. Light-frame walls with shear panels of all other materials	2½	2½	2½	NL	NL	35	NP
<b>G. Cantilevered column systems detailed to conform to the requirements for:</b>							
6. Timber frames	1½	1½	1½	35	35	35	NP

NL – Not Limited, NP – Not Permitted  
 \*For wood-frame systems designed in accordance with applicable provisions for ASCE 7, SDPWS, and NDS

Table 2: Wood-frame seismic force-resisting systems, extracted from ASCE 7-16 Table 12.2-1

Value of S <sub>DS</sub>	Risk Category	
	I, II or III	IV
S <sub>DS</sub> < 0.167	A	A
0.167 ≤ S <sub>DS</sub> < 0.33	B	C
0.33 ≤ S <sub>DS</sub> < 0.50	C	D
0.50 ≤ S <sub>DS</sub>	D	D

Table 3: Seismic design category based on short-period response acceleration parameter, adapted from ASCE 7-10, Table 11.6-1

resistance is provided on all sides of the building perimeter by shear walls with aspect ratios (height-to-length) of 1.0 or less, or, for cases where the aspect ratio of individual shear walls is greater than 1.0, the total length of light-frame shear walls equals or exceeds the story height.

**Special Design Conditions: Anchorage of Concrete or Masonry Structural Walls to Wood Diaphragms**

Requirements for anchorage of concrete or masonry structural walls to wood diaphragms, found in both ASCE 7 and SDPWS, were developed to address

instances where these structural walls became detached from supporting roofs, resulting in collapse of walls and supported bays of framing. The intent is to prevent the diaphragm from tearing apart during strong shaking by requiring transfer of wall anchorage forces across the complete depth of the diaphragm.

Minimum out-of-plane wall anchorage design forces are provided in ASCE 7 Section 12.11.2. Additional requirements, applicable in SDCs C, D, E, and F, are provided in Section 12.11.2.2. Provisions include the use of continuous ties between diaphragm chords to distribute wall anchorage forces

into the diaphragm and permitting the use of subdiaphragms to transfer anchorage forces to main continuous cross-ties. Restrictions exist on the use of toe-nailed connections and nails subject to withdrawal, and on framing loaded in cross-grain bending or cross-grain tension. Special detailing provisions for wood diaphragms consistent with those in ASCE 7 were first added to 2015 SDPWS in Section 4.1.5.

**WIND DESIGN AND WOOD**

Many regions of the United States experience high winds, with the accompanying threat of wind-related damage to buildings. According to the Insurance Institute for Business and Home Safety (IBHS), high winds cause billions of dollars of property loss each year.<sup>8</sup> However, damage from wind can be minimized through engineered design which strengthens buildings against wind forces. As with the seismic provisions, codes and standards governing the design and construction of wood-frame buildings have evolved based on field data from prior wind events and related research.

Each building, with its own unique characteristics and site conditions, reacts differently to wind loads. Many complex and interrelated issues must be addressed before a building can be truly considered wind-resistant.

**Structural Wind Loading**

The wind loading requirements in the IBC are determined primarily through reference to ASCE 7-16. The minimum design requirements for wind loads are intended to ensure that every building and structure has sufficient strength to resist these loads without stressing any of its structural elements beyond the material strengths prescribed in the code. The code emphasizes that the loads prescribed in Chapter 16 are minimum loads; in most conditions, the use of these loads will result in a safe building. For this reason, it is important to ensure that wind loads are properly determined. The commentary that accompanies ASCE 7-16 is a good source for additional information, as it outlines conditions which may result in higher loading.

**WIND LOADS ON BUILDINGS**

Buildings and structures are designed and constructed to resist wind loads, or wind pressure, as opposed to wind speeds. Wind speed, although a significant contributor, is only one of several factors that impact wind loads acting on a building. Other factors that affect the calculated design wind loads (pounds per square foot, or psf) include:

- Combined gust factor and external pressure coefficients (GC<sub>pf</sub>)
- Combined gust factor and internal pressure coefficients (GC<sub>pi</sub>)
- Design velocity pressure

Design velocity pressure varies depending on several factors, including mapped wind speed, exposure category, topographic effects, wind directionality, elevation factor, and other specific building characteristics. All of these are covered in the following sections.

**Mapped Wind Speeds and Risk Category**

Mapped wind speeds are based on the probability of winds attaining certain speeds per geographic area. They are developed from an analysis of wind speed data collected during severe wind events and assuming a set of reference conditions. Current wind speed maps include a more comprehensive

analysis of wind speeds for both coastal and non-coastal areas than was previously available. The wind maps in ASCE 7-16 vary substantially from previous versions. In most parts of the country, particularly in the West, winds speeds have decreased.

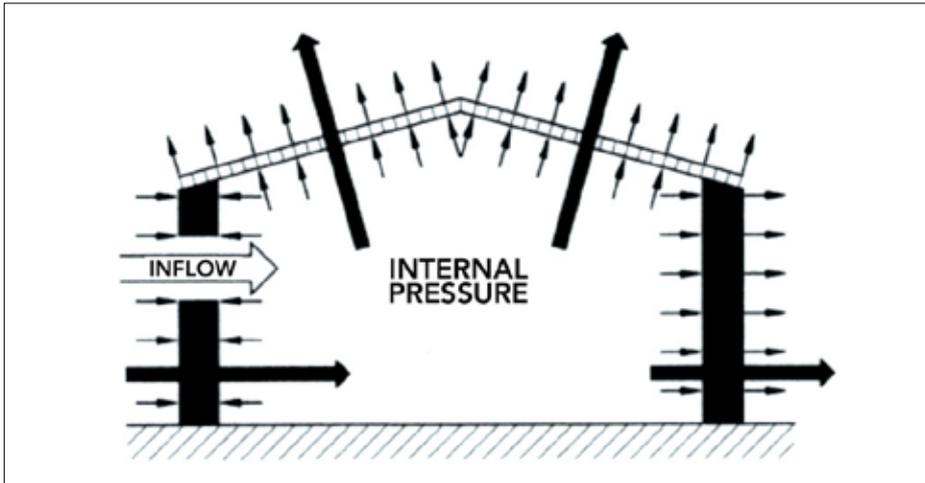
The risk categories introduced earlier also apply when designing for wind loads. Mapped wind speeds for Risk Category III and IV buildings, for which the potential consequences to human life and economic impact are greatest, are higher than mapped wind speeds for Risk Category II buildings. The ultimate design wind speed (V<sub>ult</sub>, in miles per hour) for the establishment of wind loads is determined using wind speed maps contained in three IBC Figures: Figure 1609.3(1) for Risk Category II buildings, Figure 1609.3(2) for Risk Category III buildings, figure 1609.3(3) for Risk Category IV buildings, and Figure 1609.3(4) for Risk Category I buildings.

SURFACE ROUGHNESS CATEGORIES	
<b>SURFACE ROUGHNESS B</b>	Urban and suburban areas, wooded areas, or other terrain with numerous closely spaced obstructions having the size of single-family dwellings or larger.
<b>SURFACE ROUGHNESS C</b>	Open terrain with scattered obstructions having heights generally less than 30 ft. This category includes flat open country and grasslands.
<b>SURFACE ROUGHNESS D</b>	Flat, unobstructed areas and water surfaces. This category includes smooth mud flats, salt flats, and unbroken ice.

**Table 4: Surface Roughness Categories as defined by the IBC**

EXPOSURE CATEGORIES	
<b>EXPOSURE B</b>	For buildings with a mean roof height of less than or equal to 30 ft., Exposure B shall apply where the ground surface roughness, as defined by Surface Roughness B, prevails in the upwind direction for a distance of at least 1,500 ft. For buildings with a mean roof height greater than 30 ft., Exposure B shall apply where Surface Roughness B prevails in the upwind direction for a distance of at least 2,600 ft. or 20 times the height of the building, whichever is greater.
<b>EXPOSURE C</b>	Exposure C shall apply for all cases where Exposures B or D do not apply.
<b>EXPOSURE D</b>	Exposure D shall apply where the ground surface roughness, as defined by Surface Roughness D, prevails in the upwind direction for a distance of at least 5,000 ft. or 20 times the height of the building, whichever is greater. Exposure D shall also apply where the ground surface roughness immediately upwind of the site is B or C, and the site is within 600 ft. or 20 times the building height, whichever is greater, from an Exposure D condition, as defined in the previous sentence.

**Table 5: Exposure Categories as defined by the IBC**



**Figure 3: Effect of openings in a partially enclosed building, courtesy of Florida Building Code Commentary**

### Surface Roughness and Exposure Categories

One of the basic decisions in the design of wind-resistant buildings is determination of exposure category based on the “surface roughness” of nearby terrain. Surface roughness depends on natural topography, vegetation, and existing built structures. Obstructions upwind of the building site can exert a drag force on wind, slowing the flow of air close to the surface of nearby terrain (see Table 4).

For each wind direction considered, an exposure category that reflects the surface irregularities of the terrain must be determined for the site at which the building or structure is to be constructed (see Table 5).

Exposure B is the most common exposure category in the country and is often the default exposure category. However, it is important to recognize that exposure category varies based on conditions at the site and that buildings are often sited on properties which fall under Exposure C and D, with attendant higher wind loading.

### Topographic Effects

Abrupt changes in the landscape can affect wind speeds. For this reason, topographic effects are accounted for when calculating wind loads using the topographic factor, or  $K_{zt}$ .  $K_{zt}$  considers the wind “speed-up” effects that occur when wind encounters an isolated hill, ridge, or escarpment.

### Wind Directionality

For most wood-frame buildings with wind loads determined in accordance with ASCE 7

load combinations, the effect of wind directionality is accounted for by use of a wind directionality factor. This load reduction factor, called  $K_d$ , accounts for two effects: “(1) the reduced probability of maximum winds coming from any given direction and (2) the reduced probability of the maximum pressure coefficient occurring for any given wind direction.” ASCE 7-16 includes a table (Table 26.6-1) which displays the wind directionality factors to be used for each structure type.

### Elevation Factor

A new elevation factor has been added in ASCE 7-16 that accounts for changes in air density at elevations above mean sea level. The revised standard includes a table of factors for elevations up to 6000 feet and a formula that can be used to calculate the factor for any elevation.

### Effect of Openings on Internal Pressure Coefficients

When wind encounters a building, the airflow changes direction and produces several varying effects. Exterior walls and other vertical surfaces facing the wind (windward side) and perpendicular to its path are subjected to positive pressures (loads). Wind continues to flow over and around the building, resulting in suction or negative pressures (loads) on sidewalls, the leeward wall and, depending on geometry, the roof. Wind pressures on a roof vary based on roof slope and location on the roof, with greatest wind pressures occurring at roof edges.

Openings in the building envelope can significantly affect the wind pressures imposed on building elements. Depending on the location and size of openings with respect to wind direction and building porosity, external and internal pressures can act in the same direction to produce higher forces on the walls and roof.

An example of this effect of openings is illustrated in Figure 3. Here, pressures occur on both exterior and interior building surfaces because of a large opening in the windward wall. As this scenario demonstrates, wind enters the building, exerting positive pressures against all interior surfaces. This opening has the net effect of producing high internal pressures that act in the same direction as the external pressures on the roof and leeward walls, adding to the overall pressures on these building elements.

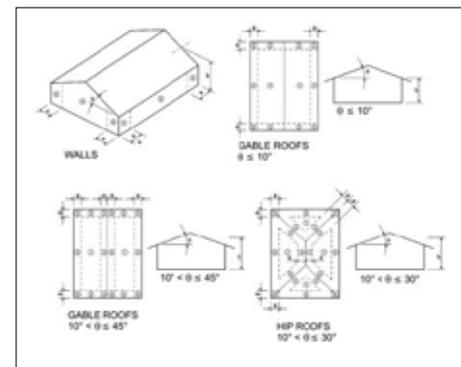
Windows and doors are not considered openings if they are likely to be closed during a design storm event. Therefore, at a minimum, windows and doors need to be rated to resist the positive and negative design wind pressures.

### External Pressure Coefficients

ASCE 7-16 categorizes wind loads according to the building systems they impact. Main wind force-resisting system (MWFRS) wind loads act on the frame and foundation of a building.

Components and cladding (C&C) wind loads act on cladding elements such as shingles, siding, and windows. Loads are calculated differently for each.

For the design of wood-frame buildings 60 feet in height or less, the “envelope procedure” is the most used method for determining MWFRS loads. External pressure coefficients from the envelope procedure have been developed to represent critical loads on the main structural elements, which are “enveloped”



**Figure 4: Roof and wall-sheathing zones for wind design, courtesy of Florida Building Code Commentary**

## CONSTRUCTION HIGHLIGHTS: SEISMIC DESIGN OF PODIUM-STYLE WOOD-FRAME BUILDINGS

“Podium construction” refers to multiple stories of wood framing over one or more stories of another construction type. The top of the podium is often a transfer level where loads from the wood superstructure are redistributed to the supporting levels below. Concrete podiums are the most common, though podiums of other materials are also permitted. As podium construction increases in popularity, so, too, does the need to understand the seismic design considerations for these types of framing systems.

There are two specific considerations for these buildings under lateral loading conditions:

- The inherent differences in lateral-resistance properties of the superstructure above versus the podium below
- A growing tendency to provide fewer lateral-resisting elements at the perimeter of the superstructure, limiting the options for shear walls

To gain additional stories, increase building area, stay within the allowable building heights, and remain within the seismic force-resisting system height limits of light-frame wood shear walls, the IBC and ASCE 7 each have provisions that enable podium designs.<sup>7</sup> Without these provisions, structures of this height and area would have to be constructed using steel or concrete (Type IV construction). The podium provisions enable the continued use of economical light-frame wood construction where it works best—typically multifamily projects. By building light-frame wood structures over one to two stories of concrete or steel, these projects can achieve additional stories and increased building area while staying under the allowable building height and remaining within the seismic force-resisting system height limits of light-frame wood shear walls.

### Two-Stage Seismic Analysis

Structurally, ASCE 7-16 Section 12.2.3.2 provides a two-stage analysis procedure that can be beneficial for seismic design of podium projects. The procedure treats the flexible upper and rigid lower portions of the structure as two distinct structures. Under Section 12.2.3.2, only the weight of the flexible upper portion must be considered in its design, not the entire weight of both portions. The two-stage analysis also allows the seismic base of the upper portion to serve as the top of the lower portion.

### Diaphragm Flexibility

Current practice for light-frame construction commonly assumes that wood diaphragms are flexible for the purpose of distributing horizontal forces to shear walls. Even though diaphragms may be idealized as flexible, they may not always be so. Verifying the diaphragm flexibility is becoming increasingly important given trends toward larger openings in exterior shear walls, shorter wall lengths, and a greater number of wood-frame stories over the podium.

to reflect induced actions on a building from various wind directions for diverse building geometries, roof heights, and roof slopes.

As per ASCE 7, the MWFRS is “an assemblage of structural elements assigned to provide support and stability for the overall structure ... [that] generally receives wind load from more than one surface.” Examples of MWFRS elements include roof trusses, roof and floor diaphragms, and shear walls. Individual elements of the MWFRS may also be subject to C&C load requirements. These include sheathing, cladding, wall studs,

individual roof rafters and elements of a roof truss, and short-span trusses resisting wind loads from cladding.

External pressure coefficients for C&C represent peak pressures which occur over specific areas on the building’s exterior surface. Localized negative pressures associated with C&C loads almost always control design of exterior sheathing and cladding elements, including wall sheathing, wall cladding, roof sheathing, roof cladding, and the attachment of the sheathing and cladding to the building’s structural frame.

### Increased Pressure at Edge Zones

The greatest wind pressures acting on a building are negative pressures (suction), and the locations of the greatest suction pressures occur at wall and roof edge zones, as illustrated in Figure 4. Edge zones at wall corners, roof ridge, and roof perimeter represent locations of potentially high suction forces relative to the central portions of the wall or roof. The extent of increase in suction forces for roofs depends on roof geometry, but increases of two or more times the negative pressures associated with central wall area are possible.

For roof sheathing and roof sheathing attachment, the increase in forces between edge zones and interior zones is larger than that observed for walls. While wood structural panel sheathing of consistent grade and thickness is used over the length of the roof, two fastening schedules are often specified.

One fastening schedule is for roof areas outside of edge zones; fasteners here are spaced farther apart. A second fastening schedule is for higher wind pressure roof areas within the edge zones; fasteners here are more closely spaced. The roof sheathing pressures developed from the external pressure coefficients in ASCE 7-16 are higher than in previous versions of ASCE, and thus require more attention to nailing patterns and to nail types and sizes. In some cases, Roof Sheathing Ring Shank nails, which have higher withdrawal design values than smooth shank nails, are required for attachment of roof sheathing to roof framing for resistance to high wind uplift forces.

The withdrawal design values for Roof Sheathing Ring Shank Nails (RSRN) are generally 1.5 to 2 times greater than those for smooth shank nails. When using Roof Sheathing Ring Shank Nails, care should be taken to ensure that the nails are in fact RSRN nails meeting ASTM F1667, as opposed to another nail with ring shank or other deformations. The 2018 NDS for Wood includes new language for use of Roof Sheathing Ring Shank nails and new provisions for fastener head pull-through. These additions were developed to address the high uplift pressures in ASCE 7-16 and are used in the 2018 Wood Frame Construction Manual.

### Resistance to Uplift

Mechanical connections, sheathing, and the dead load of the building can all be used to resist wind uplift and overturning. Dead load includes the weight of foundations and anchorage; however, only the dead load

likely to be in place during a design wind event is permitted to be used in design. This is accommodated using reduced dead loads for resistance to wind-induced forces and is accomplished through load combinations provided in 2021 IBC 1605.2.

## CONCLUSION

Proper design and construction based on research and compliance with building code requirements can minimize the negative effects of wind and seismic events. Inherently strong and ductile, and with many repetitive members

and multiple connections, wood construction offers several benefits when it comes to seismic- and wind-resistant design. Buildings that protect occupants and can continue to function or recover quickly after a disaster contribute to the overall resilience of communities.

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### Codes and Standards

- 2021 International Building Code (IBC), <https://codes.iccsafe.org/content/IBC2021P1>
- ASCE 7, <https://www.asce.org/publications-and-news/asce-7>
- Special Design Provisions for Wind and Seismic (SDPWS) 2021, <https://awc.org/codes-standards/publications/sdpws-2021>
- National Design Specification® (NDS®) for Wood Construction, <https://awc.org/codes-standards/publications/nds-2018>
- Wood Frame Construction Manual (WFCM) 2018, <https://awc.org/codes-standards/publications/wfcm-2018>.

1 "Build Resilient with Wood." American Wood Council. Web. 13 Sept. 2021. <<https://awc.org/resiliency>>.

2 Merolla, Lisa. "Designing a (Wooden) Earthquake-proof Home." Popular Mechanics. 16 Jul. 2009. Web. <https://www.popularmechanics.com/science/environment/a4388/4324941/>

3 Building Seismic Safety Council. Homebuilders' Guide to Earthquake Resistant Design and Construction. FEMA 232-June 2006. Web. 13 Sept. 2021. <<https://www.wbdg.org/FFC/DHS/fema232.pdf>>.

4 National Design Specification (NDS) for Wood Construction 2018. American Wood Council. Web. 13 Sept. 2021. <<https://www.awc.org/codes-standards/publications/nds-2018>>.

5 Wood Frame Construction Manual for One- and Two-Family Dwellings (WFCM) 2018. American Wood Council. Web. 13 Sept. 2021. <<https://awc.org/codes-standards/publications/wfcm-2018>>.

6 Special Design Provisions for Wind and Seismic (SDPWS) 2021. American Wood Council. Web. 13 Sept. 2021. <<https://awc.org/codes-standards/publications/sdpws-2021>>.

7 "How are podium style wood-frame projects (e.g., 5-over-2) seismically designed to resist lateral forces?" WoodWorks. Web. 13 Sept. 2021. <<https://www.woodworks.org/experttip/podium-style-wood-frame-projects-e-g-5-2-seismically-designed-resist-lateral-forces/>>.

8 "Reduce Losses from Wind." Insurance Institute for Business and Home Safety. Web. 13 Sept. 2021. <<https://iibs.org/risk-research/wind/#:~:text=Severe%20winds%20cause%20billions%20of,mounted%20equipment%2C%20and%20whole%20structures>>.

## QUIZ

1. The function of a continuous load path is to
  - a. Tie building elements together from the roof to the foundation.
  - b. Provide a seamless transfer of load.
  - c. Transfer load from the walls up through the roof.
  - d. **A and B only**
2. A characteristic of wood construction that lends resilience is
  - a. Ductile connections.
  - b. Large mass which provides strength.
  - c. Repetitive elements with multiple fasteners.
  - d. **A and C only**
3. What is the main purpose of building codes?
  - a. To prevent property damage
  - b. To prevent structural collapse
  - c. **To protect occupants and first responders**
  - d. All of the above
4. Which wood-frame seismic- and wind force-resisting systems does ASCE 7 recognize?
  - a. Sheathed wood-frame diaphragms and shear walls
  - b. CLT diaphragms and shear walls
  - c. **Both A and B**
  - d. Wood-frame diaphragms and shear walls sheathed with engineered wood products only
5. A police station is an example of
  - a. Risk Category I.
  - b. Risk Category B.
  - c. Risk Category C.
  - d. **Risk Category IV.**
6. The seismic design requirements in building codes are based on
  - a. The site-specific seismic hazard only.
  - b. The building's risk category only.
  - c. **The site-specific seismic hazard and the building's risk category.**
  - d. The ELF procedure.
7. \_\_\_\_\_ represents a very low seismic hazard for which there are no seismic-specific limits on structural height, system type, structural redundancy, or structural irregularities.
  - a. **SDC A**
  - b. Risk Category I
  - c. SDC B
  - d. Risk Category IV
8. Which is true of podium construction?
  - a. It consists of multiple stories of concrete or steel-framed structure over a wood-framed "podium."
  - b. It allows for buildings of any height.
  - c. **It consists of several stories of wood framing over a concrete or steel "podium."**
  - d. It is not a good choice for multifamily projects.
9. Which is not a factor in design velocity pressure?
  - a. **Seismic design category, SDC**
  - b. Mapped wind speed
  - c. Exposure category
  - d. Topographic effects
10. When wind enters a building, it exerts pressure
  - a. In the opposite direction as the external pressure on the roof.
  - b. In the same direction as the external pressure on the roof.
  - c. **In the same direction as the external pressures on the roof and leeward walls.**
  - d. In the opposite direction as the external pressures on the roof and leeward walls.