Wind Load Determination for Residential Decks

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Introduction

The safety of exterior elevated decks and porches is an important national issue due to numerous documented structural collapses that have resulted in serious injuries and, in some cases, deaths (Shutt 2011; Legacy Services 2010). Many deck and porch failures occur at loads well under design loads and occur without any warning. The primary causes for failures are from (1) deficient connections between the deck ledger and the house rim board, and (2) deficient guardrail systems. Frequently, related decay and corrosion of fasteners also contributed to deck failures (Carradine et al. 2007; Carradine et al. 2008). The 2009 *International Residential Code (IRC)* Section R502.2.1 (ICC 2009b) and the 2009 *International Building Code* (IBC) Section 1604.8.3 (ICC 2009a) state:

> "Where supported by attachment to an exterior wall, decks shall be positively anchored to the primary structure and designed for both vertical and *lateral* loads as applicable." (italics added for emphasis)

Vertical loads on decks, such as occupancy and snow, are straightforward to calculate using the provisions of the 2009 IBC and ASCE/SEI 7-10 *Minimum Design Loads for Building and Other Structures* (ASCE 2010). Determination of lateral loads on decks from seismic, wind, and occupancy is more challenging. Calculation of wind loads using ASCE 7-10 can be complicated and requires engineering judgment.

This paper is part of a larger project to characterize lateral loads on residential decks caused by seismic, wind, and occupancy. In this paper, we focus on wind load determination. Specific objectives of this paper are to highlight the differences between ASCE 7-05 and ASCE 7-10 for wind analysis, illustrate a method and example calculation for determining the wind loads on residential decks, and provide a parameter sensitivity study to demonstrate the relative magnitudes of wind loads in various regions in the US for the example deck.

Overview of Load Determination Using ASCE 7 Load Standard

ASCE 7 is a standard for calculating minimum loads for the design of buildings and other structures as required by building codes. Appropriate load combinations for allowable stress design (ASD) and load and resistance factor design (LRFD) are presented in ASCE 7. ASCE 7 is the primary reference used by designers for load calculation in the US to determine dead, live, flood, snow, ice, rain, wind and seismic loads. This document is cited by the model building code and is revised every five years. The most recent edition is ASCE 7-10.

Changes to ASCE 7-10 (from 2005 edition)

The wind provisions for ASCE 7-10 have been updated and completely reorganized. The wind provisions have been expanded from one chapter to six. The 2010 version provides three new wind speed maps that represent wind events with mean recurrence intervals (MRI) of 300, 700 and 1700 years (ASCE 7-05 had MRI of 50 years). The rationale was to incorporate the risk categories into the wind speeds and to have MRIs that were consistent with strength design format. So, for LRFD design, the load factor for wind changed from 1.6 to 1.0. Similarly for ASD design, the load factor for wind changed from 1.0 to 0.6. After appropriate factoring of wind loads for ASD or LRFD, the resulting loads from ASCE 7-10 are similar as those calculated using ASCE 7-05 for most cases.

One of the analytical procedures permitted by ASCE 7 is the directional procedure for building appurtenances and other structures (such as solid freestanding wall and solid freestanding signs, chimneys, tanks, open signs, lattice framework, and trusses towers). We used this procedure to calculate wind loads on decks. The directional proce-

l – integral length scale factor, ft, from ASCE 7-10 Table 26.9-1

Q – background response factor

q_z – velocity pressure evaluated at height z above the ground

V – basic wind speed, mph

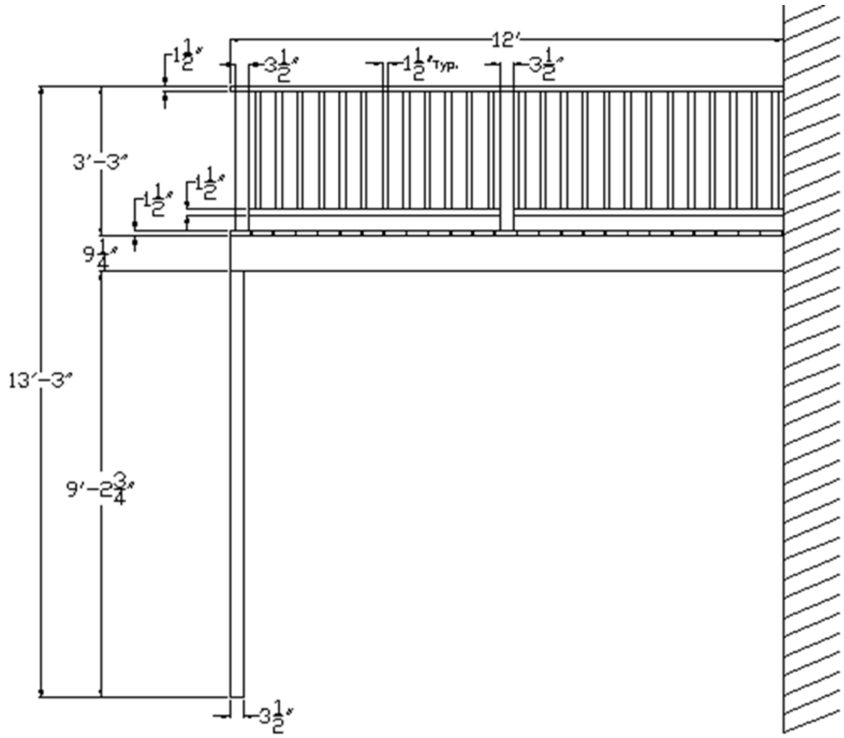
z – height above ground level, ft

z_{min} – exposure constant from ASCE 7-10 Table 26.9-1

ε – ratio of solid area to gross area for deck

ε – integral length scale power law exponent from ASCE 7-10 Table 26.9-1

Appendix – Deck Area Calculations



Deck Area:

$$Joist: \frac{9.25''}{12} x12' = 9.25\,ft^2$$

$$Decking: \frac{1.5''}{12} x12' = 1.5\,ft^2$$

$$Railing: \left(\frac{1.5''}{12}\right)12' + \left(\frac{1.5''}{12}\right)11.29' + 2\left(\frac{3.5''}{12}\right)3' + 25\left(\frac{1.5''}{12}\right)2.54' = 12.6\,ft^2$$

$$Total\ Area = 9.25\,ft^2 + 1.5\,ft^2 + 12.6\,ft^2 = 23.35\,ft^2$$

$$Gross\ Area = \left(\frac{48.25'}{12}\right)12' = 48.25\,ft^2$$

$$\varepsilon = \frac{23.35}{48.25} = 0.48$$

Post Area:

$$Post: \left(\frac{3.5''}{12}\right)9.23' = 2.69\,ft^2$$

Summary and Conclusions

Wind loading can be an important consideration for lateral design of decks. Wind loads were calculated using the directional procedure in ASCE 7. An example was presented to show how to calculate wind loads on residential decks, along with a summary of calculation steps involved. To gain a better understanding of the typical wind loads across the US, the wind loads for different wind speeds were determined using the assumptions from the example presented herein. From the assumptions in the example, the largest ASD wind load was 1,299 lb using ASCE 7-10 methodology and data. The resulting hold-down force for a 12 ft by 12 ft deck would be approximately 650 lb. This load is smaller than the 1,500 lb hold-down requirement in the 2009 IRC, Section 502.2.2.3. From this analysis, the 1,500 lb minimum design capacity is conservatively high for wind lateral loads. An allowable design capacity of 650 lb would be sufficient to resist the wind lateral loads based on the assumptions and calculations given in this paper. Unless you are in a hurricane or special wind region, the hold-down forces will be significantly smaller. Based on the above assumptions, the hold down forces would be approximately 266 lb. By accurately characterizing the lateral loads on decks, design professionals can pursue a range of rational design solutions to resist the loads.

References

American Society of Civil Engineers. 2010. ASCE/SEI 7-10 Minimum Design Loads for Buildings and Other Structures. American Society of Civil Engineers, Reston, Virginia.

Carradine, D.M., Bender, D.A., Woeste, F.E., and Loferski, J.R. 2007. Development of Design Capacities for Residential Deck Ledger Connections. Forest Products Journal 57(3) 39-45.

Carradine, D.M., D.A. Bender, J.R. Loferski and F.E. Woeste. 2008. Lessons learned: residential deck ledger connection testing and design. Structure magazine (May):53-56. www.structuremag.org/Archives/2008-5/C-LessonsLearned-DeckLedger_Carradine-May08.pdf

ICC. 2009a. International Building Code (IBC). http://publicecodes.cyberregs.com/icod/ibc/2009/index.htm

ICC. 2009b. International Residential Code for One-and -Two Family Dwellings (IRC). http://publicecodes.cyberregs.com/icod/irc/2009/index.htm

Legacy Services. 2010. Outdoor deck and porch injury study. http://www.buildingonline.com/news/pdfs/Outdoor-Deck-and-Porch-Injury-Study.pdf

Schutt, C.A. 2011. Improving deck safety. LBM Journal (May/June): 26-28.

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Notation

A – effective wind area, ft^2

A_f – area of deck normal to the wind direction or projected on a plane normal to the wind direction, ft^2

B – horizontal dimension of building measured normal to wind direction, ft

c – turbulence intensity factor from ASCE 7-10 Table 26.9-1

C_f – force coefficient to be used in determination of wind loads for other structures

F_{ad} – allowable stress design load on deck, psi

F_{ap} – allowable stress design load on post, psi

F_D – load on deck including half of post load, lbs

F_d – load on the deck, lbs

F_p – load on the post, lbs

G – gust-effect factor

g_Q – peak factor for background response

g_v – peck factor for wind response

h – height of deck, ft

I_z – intensity of turbulence

K_d – wind directionality factor

K_z – velocity pressure coefficient evaluated at height $z = h$

K_{zt} – topographic factor

L_z – integral length scale of turbulence, ft

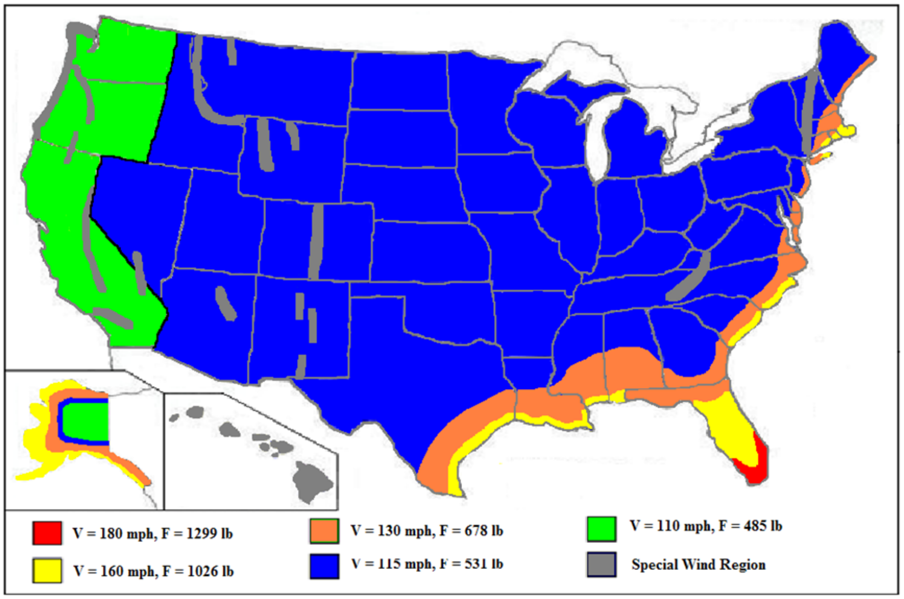

Figure 2. Approximate ASD-factored Wind Loads for Example Deck Using ASCE 7-10

Table 2. Hold-down Forces Due to Maximum ASD Wind Load for Different Deck Ratios

Deck ratio	Hold-down forces (lb)
1.5:1	975
1:1	650
1:1.5	433

Parameter Sensitivity

The example above was performed with the worst-case wind speed. For regions outside of hurricane zones, residential decks will be designed using a much smaller wind speeds. To gain an understanding of wind loads across the US, an investigation of wind loads for different wind speeds, V, using ASCE 7-05 and ASCE 7-10 was performed (Figure 2 and Table 3). The wind forces were calculated using the assumptions from the above example.

There are some differences between the wind loads using ASCE 7-10 compared to ASCE 7-05. At lower wind speeds, the difference between the two versions is minimal but at higher wind speeds, there is up to a 15% difference due to the new ultimate wind speed maps being revised and round-off from the ASD load factor.

It is important to understand wind loads and how these loads are calculated. According to the permitted lateral load connection in the 2009 IRC, Figure R502.2.2.3, at least two hold-down tension devices that have an allowable stress load capacity of not less than 1,500 lbs must be used. The 1,500 lb minimum design capacity was based on judgment. From our wind analyses and deck size with the stated assumptions, and using the directional procedure in ASCE 7-10, hold-down requirements lower than 1,500 lb can be justified if the wind load is the governing load. From our analyses, a maximum ASD-factored wind load of 1,299 lb would be reasonable, resulting in hold-down requirements of approximately 650 lb. This load can be resisted through a variety of hardware solutions.

Most regions in the US use a design wind speed of 115 mph, which results in an ASD-factored wind load of 531 lb for the deck example presented herein. For a deck ratio of one to one, the resulting hold-down forces would be approximately 266 lb.

Table 3: ASD-factored wind loads for different winds speeds assuming Exposure Category

Wind Speed, V (mph)		Velocity Pressure, q_z (psf)		ASD-factored Deck Wind Load, F (lb)	
ASCE7-05	ASCE7-10	ASCE7-05	ASCE7-10	ASCE7-05	ASCE7-10
85	110	13.36	22.38	483	485
90	115	14.98	24.46	541	531
110	130	22.38	31.26	808	677
130	160	31.26	47.35	1127	1025
150	180	41.62	59.93	1500	1299

$$B = 12\text{ ft}$$
$$l = 500\text{ft (Table 26.9-1)}$$
$$\varepsilon = 1/5\text{ (Table 26.9-1)}$$
$$I_Z = l\left(\frac{z_{\min}}{33}\right)^2 = 500\left(\frac{15}{33}\right)^2 = 427.1$$
$$Q = \sqrt{\frac{1}{1+0.63\left(\frac{B+h}{L_z}\right)^{0.63}}} = \sqrt{\frac{1}{1+0.63\left(\frac{12+10}{427.1}\right)^{0.63}}} = 0.96$$
$$g_0 = 3.4$$
$$g_V = 3.4$$
$$G = 0.925\left(\frac{1+1.7g_0 I_Z Q}{1+1.7g_V I_Z}\right)$$
$$= 0.925\left(\frac{1+1.7(3.4)(0.23)(0.96)}{1+1.7(3.4)(0.23)}\right) = 0.9$$

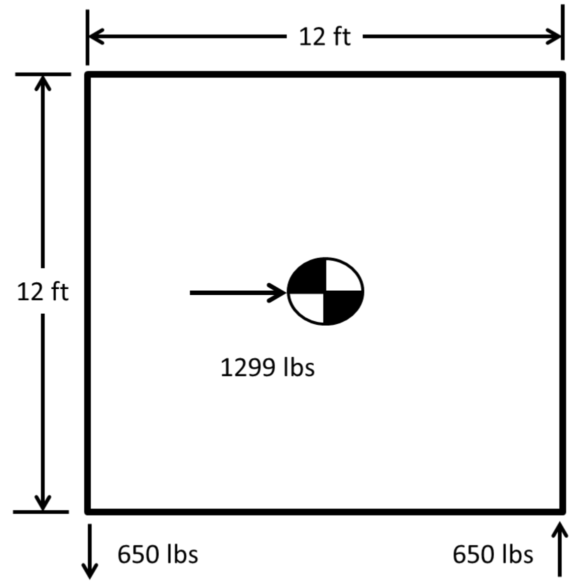

Figure 1. Hold-down Forces Due to Maximum ASD-factored Wind Load

Step 4: Determine velocity pressure exposure coefficient

Velocity pressure exposure coefficient was determined using Table 29.3-1 for a height above ground of 10 ft and Exposure C

K_z = 0.85 (Table 29.3-1)

Step 5: Calculate velocity pressure

$q_z = 0.00256\, K_z K_{zt} K_d V^2$

$= 0.00256(0.85)(1)(0.85)(180^2) = 59.93$ psf (Eqn 29.3-1)

Step 6: Determine force coefficients

The ratio of solid area to gross area is calculated in the appendix at the end of this paper, with the result being

$\varepsilon = 0.45$

The force coefficient for lattice frameworks is given by

$C_{f,\,deck}$ = 1.6 (Fig 29.5-2)

The force coefficient for deck posts is given by

$$C_{f,deck\ post} = 2.0\left(\text{for } \frac{h}{D} = \frac{10\,ft}{\frac{8.5\,in}{12\left(\frac{in}{ft}\right)}} = 34.29\right)\text{(Fig 29.5-1)}$$

Step 7: Calculate wind loads

Calculate area of deck framework (see Appendix for details)

$A_f = 23.35\ \text{ft}^2$

Wind load on deck

$F_{deck} = q_z G C_f A_f = 59.93(0.9)(1.6)(23.35) = 2{,}018$ lb (Eqn 29.5-1)

ASD factored deck load

$F_{ASD,d} = 0.6F_{deck} = 0.6(2052\text{lb}) = 1{,}211$ lb

Wind load on deck posts

$F_{post} = q_z G C_f A_f = 59.93(0.9)(2)(2.69) = 291$ lb

ASD factored deck post load

$F_{ASD,p} = 0.6F_{post} = 0.6(291\text{ lb}) = 175$ lb

Total factored load on deck

$F_D = F_{ad} + ½F_{ap} = 1211\text{ lb} + (0.5)(175\text{ lb}) = 1{,}299$ lb

To analyze the force at the reactions, the wind load F_D can be placed at the center of mass which is typically near the center of the deck (Figure 1). The effect of the posts resisting lateral loads was conservatively neglected. The reaction forces were assumed to occur at the hold-down tension devices that were assumed to be attached at the corners of the deck. To gain an understanding of decks with different length-to-width ratios, hold-down forces with different ratios using a deck area of 144 ft^2 are summarized in Table 2.

Table 1. Steps to Determine Wind Load on Residential Decks Using ASCE 7

Step 1: Determine risk category of structure (Table 1.5-1)

Step 2: Determine the basic wind speed, V, for the applicable risk category (Figure 26.5-1A)

Step 3: Determine wind load parameters:
Wind directionality factor, K_d (Table 26.6-1)
Exposure category B, C, or D (Section 26.7)
Topographic factor, K_{zt} (Figure 26.8-1)
Gust effect factor, G (Section 26.9)

Step 4: Determine velocity pressure exposure coefficient, K_z (Table 29.3-1)

Step 5: Calculate velocity pressure, q_z (Eq. 29.3-1)

Step 6: Determine force coefficient, C_f
Open signs, lattice frameworks (Figure 29.5-2)
Chimneys, tanks, rooftop equipment (Figure 29.5-1)

Step 7: Calculate wind load, F (Eq. 29.5-1)

dure in ASCE7-10 is identical to the analytical procedure in ASCE 7-05 except for the determination of the basic wind speed V.

Method for Determining Wind Load

The directional procedure or analytical procedure is one method permitted in ASCE 7 to determine wind loads and applies to residential decks. Most residential decks are in compliance with the conditions in ASCE 7-10 Section 29.1.2. Table 1 summarizes the steps to determine wind loads.

Example

All references to tables and figures in this example refer to ASCE 7-10.

Assumptions

- Worst case wind speed, V (southern tip of Florida)
- Exposure Category C
- Deck height of 10 ft
- Topographic Factor of 1.0
- Allowable stress design (ASD) format

Step 1: Determine risk category of structure

Risk Category II (Table 1.5-1)

Note: Residential decks do not fit the structures in categories I, III, and IV and therefore fall under risk category II

Step 2: Determine the basic wind speed for the applicable risk category

V = 180 mph (Fig 26.5-1A)

This was the worst-case wind speed on the southern tip of Florida. This wind speed has a mean recurrence interval of 700 years.

Step 3: Determine wind load parameters: wind directionality, exposure category, topographic and gust effect factors

Wind directionality factor for open signs and lattice framework

K_d = 0.85 (Table 26.6-1)

Assumed exposure category

Exposure Category C (Section 26.7)

Assumed topographic factor (this factor could be greater than one for sites with isolated hills, ridges or escarpments as determined in Section 26.8.1

K_{zt} = 1.0 (Fig 26.8-1)

The fundamental frequency for this deck is assumed to be greater than 1Hz and is therefore considered rigid according to Section 26.2. ($f_n = 1/T_n$ = 8.93 Hz) In this example the gust factor was determined using ASCE7-10 Eqn. 26.9-6, but if a deck is rigid then the gust factor is permitted to be taken as 0.85.

Gust Effect Factor, G, for rigid structure (Section 26.9)

$$h = 10\text{ ft}$$
$$z = 0.6h = (0.6)(10\text{ ft}) = 6\text{ ft}$$
$$z_{\min} = 15\text{ ft (Table 26.9-1)}$$
$$c = 0.2\text{ (Table 26.9-1)}$$
$$I_z = c\left(\frac{33}{z_{\min}}\right)^{\frac{1}{6}} = 0.2\left(\frac{33}{15}\right)^{\frac{1}{6}} = 0.23$$