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Utilizing ASCE/SEI 7 to Estimate Wind Speeds for Forensic Investigations

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Abstract

The American Society of Civil Engineers/Structural Engineering Institute (ASCE/SEI) 7 standard is utilized to determine design wind loading on buildings and other structures. However, it can also be utilized in a forensic capacity to approximate a wind speed that would cause specific conditions to occur, such as the overturning of a structure. This paper provides a brief overview of the ASCE/SEI 7 method for wind loading and discusses the use of various adjustment factors used to determine the wind on structures, including wind directionality factor, velocity pressure coefficient, topographic factor, and the ground elevation factor. A clear understanding of these factors — and how to apply them — is crucial to estimating a wind speed and resulting force to cause a particular event or condition to occur.

Keywords

ASCE 7, ASCE/SEI 7, wind, overturning, sliding, yielding, forensic investigation, forensic engineering

Introduction

Much work has been published through industry organizations related to wind and resulting damage to buildings and structures. Damage surveys following natural disasters such as hurricanes have correlated measured wind speeds to expected building performance based on current code provisions[1]. Dynamic finite element analysis has evaluated the effects of wind shedding on tall slender structures following collapses[2].

Investigations have been completed related to the design and construction practices for temporary structure installations after failures to identify shortcomings in the employed processes[3]. Many more publications documenting testing, research, or investigations may be cited to understand how known wind or other environmental conditions have affected structures. But what about when environmental conditions are unknown, and an event has occurred? Many times in forensic engineering, what is needed to assist the trier of fact understand a sequence of events is a straight-forward determination of complex engineering principles to demonstrate if a minimum standard of care was or was not met. One such example is determining minimum wind speeds necessary to cause a specific structural response.

The ASCE/SEI 7 standard[4] is frequently used to determine design loading, including wind on buildings and other structures. Determining the force required for a specific condition to occur, such as overturning a structure, moving an item, or yielding a component, is a simple calculation if you have basic information regarding the geometry, weight of the structure and any supported cladding or components, and, if necessary, material strength characteristics.

This paper is focused on estimating a wind speed required to cause an event or action to occur — not in evaluating weather station data to determine an applied load on a structure at a particular time. The design wind pressure (loading) for a given structure is based on various adjustment factors considering the structure type and geometry, height, site location, statistics, probabilities, and topography of the site. Appropriately estimating a wind speed resulting in specific forces acting on a structure requires an understanding of these factors and their appropriate application.

The ASCE/SEI 7 standard, which is intended for design of structures, is organized in a manner considering design engineers will be using the document. However, the application of all factors used in design may not be relevant. For this paper, ASCE/SEI 7-16[4] is referenced, which considers some differing factors (such as the ground elevation coefficient), and utilizes an importance factor of 1.0 for all wind. These factors differ from earlier versions of

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the standard; however, the same procedure may be modified and applied to those earlier code editions. Additionally, this method may be used directly with the provisions of ASCE/SEI 7-22, the most recent published edition of the standard, if adopted by the local building department. Utilization of an earlier version of the ASCE/SEI 7 standard is not recommended by the authors though, as additional testing and research has resulted in the refinement of wind force determination in ASCE/SEI 7.

Background

Estimating the wind speed required to induce forces large enough for a particular structural reaction to occur is most likely to be used in the jurisprudence process resulting from a claim of property loss, injury, and/or harm. Therefore, use of accepted standards and methods is crucial to the work being admissible in a legal setting.

The ASCE/SEI 7 standard was developed as a progression of the ANSI A58 standard following extensive testing, modeling, and statistical analysis. ASCE/SEI 7 is widely referenced by current and historical model building codes and actively utilized in industry as a method for calculating wind loading (and other environmental forces) for buildings and structures. Larger, global structural failures (or investigations of structures outside the scope of Chapters 27, 28, or 29 of ASCE/SEI 7) require additional consideration and would likely warrant a structure-specific evaluation such as a wind tunnel analysis.

The ASCE/SEI 7 equation 26.10-1 is used to determine the velocity pressure at some height "z" above the ground. The velocity pressure coefficient is then used to calculate a pressure on the structure based on the structure type[3].

$q_z = .00256\ K_z K_{zt} K_d K_e V^2$ (EQ 26.10-1)

Review of each of these factors is crucial to applying them appropriately to determine the wind speed to overturn a structure.

The 0.00256 factor accounts for the stagnation pressure at mean sea level and standard atmospheric pressure. This is a constant value, but is based on variables, which are accounted for in the latter coefficients.

K_z is the velocity pressure exposure coefficient evaluated at height "z" above the ground surface. The ASCE/SEI 7 standard is based on a normalized three-second gust at 33 feet (10 meters) above the ground for exposure category C. The standard measurement elevation and exposure is noted in the wind speed maps and is apparent with review of Table 26.10-1 of the standard. This factor is used to adjust the wind pressure on a structure based on exposure category and height of the structure (or part of that structure). Heights below 15 feet have a constant value[4].

To account for different wind slowdown or drag effects, three exposure categories are utilized in ASCE/SEI 7 based on obstructions in the area of consideration. The exposure categories are based on Surface Roughness Categories B, C, and D. The exact definitions are within the standard, but generally roughness B is an urban or suburban area with many close obstructions, roughness C is an open area with scattered obstructions, and roughness D is an unobstructed area like water[4].

K_{zt} is the topographic factor used to account for wind speed-up effects at terrain features such as hills or escarpments[4]. This factor requires specific placement of a structure on or adjacent to a terrain feature as well as specific geometry of the feature itself. The resulting increase in velocity pressure is the result of a speed-up effect that has been demonstrated in wind-tunnel testing.

K_d is the wind directionality factor. Commentary section C26.6 of ASCE/SEI 7 states that this factor 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."[4]

K_e is the ground elevation factor to adjust the calculated pressure for altitude (air density)[4]. As the air density decreases with altitude, so does the resulting velocity pressure caused by wind.

V is the wind speed used to calculate the pressure based on the wind speed maps[4]. In the authors' procedure, they are solving for this velocity; therefore, the wind speed maps are not required for use.

Application

The purpose of this procedure is to estimate the wind speed required to cause an event or action to occur — not estimating the forces acting upon the structure from weather data at local weather stations. This is an important distinction to make when the information is provided and/or explained to others (clients, attorneys, jurors, etc.). Three key points result from this distinction that affect the calculation of the wind pressure on a structure using the ASCE/SEI 7 methodology:

1. The exposure category of the surrounding area (used in determination of the velocity pressure exposure coefficient, K_z) is only considered to modify the wind pressure as it varies with height. Following the design load development provisions of ASCE/SEI 7 and altering pressures due to variances between exposure C (at a standardized measurement location) and the exposure of the subject structure is not applicable. This is because the methodology being considered is not comparing weather station data (reported within exposure category C) to the structure location. Instead, it is considering the effects of wind at different elevations. This change in pressure profile with height is affected by the wind interacting with the terrain and is most evident when the values for each exposure category are normalized about 15 feet in height (**Figure 1**).

Figure 1
Force required to overturn a short structure in the desert.

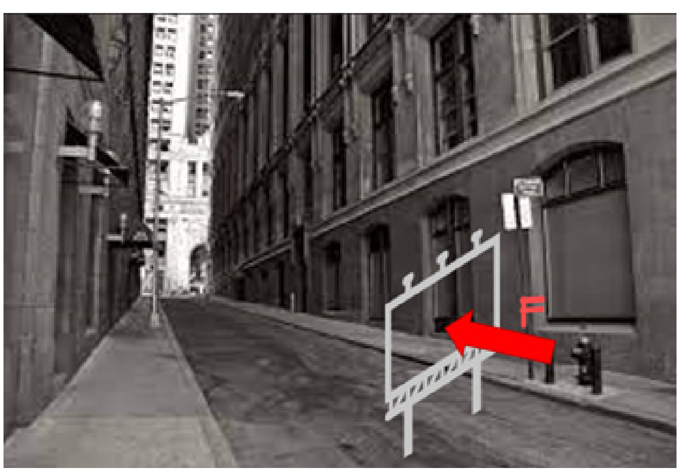

Figure 2
Force required to overturn a short structure in the city.

While this may seem counter intuitive to the ASCE/SEI 7 methodology, consider the following: A structure less than 15 feet in height located in an urban setting (exposure B) would be subjected to the same force for a given wind speed as an identical one at an airport (exposure C). This is because the pressure/force on a structure for a given wind speed is calculated based on the geometry/type of the structure. Any structures 15 feet or less in height have a constant velocity pressure coefficient, and they would develop the same pressure/force for a given wind speed (**Figure 1** and **Figure 2**). Therefore, the velocity pressure coefficient should be normalized about 15 feet in height to account for the above-described conditions as well as account for pressure changes with height (**Figure 3**).

2. Topographic features such as hills are relevant as they change the assumed wind speed/pressure profile with respect to the height of a structure. Reviewing the calculations for the topographic factor (K_{zt}), it can be noted that the coefficient varies by exposure category. Therefore, for the same reason as noted above, this value needs to be normalized. The height about which the values

Height	Exposure B	Exposure C	Exposure D
15	1.00	1.00	1.00
20	1.09	1.06	1.05
25	1.16	1.11	1.09
30	1.23	1.15	1.13
33	1.26	1.18	1.15
40	1.33	1.22	1.18
50	1.42	1.28	1.23
60	1.49	1.33	1.27
70	1.56	1.38	1.30
80	1.63	1.42	1.34
90	1.68	1.46	1.36
100	1.74	1.48	1.39
120	1.82	1.54	1.44
140	1.91	1.60	1.48
160	1.98	1.64	1.50
180	2.05	1.68	1.53
200	2.11	1.72	1.56
250	2.25	1.80	1.63
300	2.37	1.87	1.68
350	2.47	1.93	1.73
400	2.58	1.99	1.77
450	2.67	2.04	1.81
500	2.74	2.08	1.83

Figure 3
Velocity pressure coefficients (K_z) normalized about 15 feet for each exposure category.

are normalized should be the same height as the velocity pressure coefficient.

3. The wind directionality factor (K_d) is not applicable. This factor is used in a design application to account for the reduced probability that a maximum design wind speed and resulting pressure coefficient occur in a direction that is critical to the structure. Review of ASCE/SEI 7-16 Table 26.6-1 has values ranging from 0.85 to 1.0 for various structure types. It also notes that the factor should only be applied when wind tunnel testing is not being used to determine wind forces acting upon a structure. This is not the condition being considered when estimating a wind speed to cause a specific condition to occur like overturning. This process considers the wind pressure being applied to the structure in the critical direction to produce the most conservative results.

The ground elevation factor (K_e) is appropriate to apply, as the density of air changes with elevation. This air density is assumed to be that which is present at sea level — so at elevated sites, the decrease in air density will revise the 0.00256 stagnation pressure factor noted previously.

Additional factors, such as the gust effect (G), external pressure coefficients (C_p), and solidity ratio (ε), require consideration for application in each specific investigation. The applicability of each factor is beyond the depth of this paper. Further, the application of the Envelope Procedure, provided in Chapter 28 of ASCE/SEI 7, may be considered if the structure being considered is a low-rise structure (less than 60 foot mean roof height). The Envelope Method was developed for use with low-rise buildings only; therefore, it is not appropriate for taller or non-building structures.

Case Study

Consider a portal frame-type structure (**Figure 4**) that is constructed of aluminum pre-engineered box truss sections (commonly used for stages and supporting equipment) at an entrance to a public event with a sign attached to the horizontal beam member as well as decorative faux foliage attached to the truss members. People would pass under the structure to enter the event. The structure is 11 feet tall by 11 feet wide and weighs 350 pounds (with a calculable weight distribution with respect to height). In this specific case study, it is a temporary structure, and is not anchored to the ground, relying solely on structure weight to resist overturning.

Structures such as this can be subject to various codes and/or standards, depending on what has been adopted by the local authority having jurisdiction (AHJ). In the case of the subject structure, the local jurisdiction had adopted the International Building Code (IBC) and made it applicable to temporary structures of this construction type that references the ASCE/SEI 7 standard. However, in lieu of local requirements, standards (such as ANSI E1.21-2013 *Entertainment Technology - Temporary Structures Used for Technical Production of Outdoor Entertainment Events*) could be utilized to provide guidance that will ultimately reference the ASCE/SEI 7 and ASCE/SEI 37-02 (*Design Loads on Structures During Construction*) standards. Had the AHJ not adopted IBC for this structure, a minimum design wind speed of 40 mph with a factor of safety of 1.5 would be considered using the above ANSI standard[5,6].

Due to the actual mechanism of failure being overturning of the structure, sliding or uplift of a light structure such as this may also be appropriate to consider. However, for the purpose of this paper, these failure mechanisms were not evaluated.

The structure is less than 15 feet tall; therefore, the velocity pressure is constant for the full height of the structure. Since the structure was considered a trussed tower, the solidity ratio (solid area divided by gross area of the face) of the framework is used to calculate the force coefficient for the truss sections. A different force coefficient

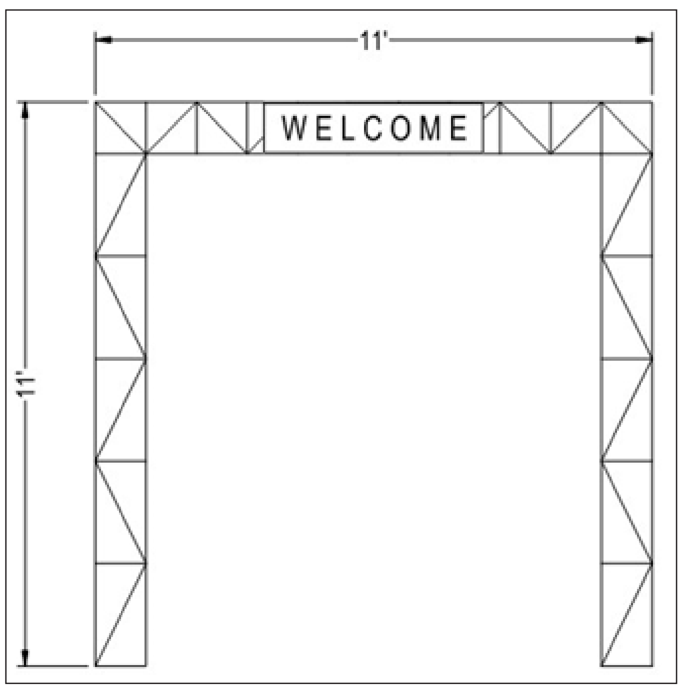

Figure 4
Diagram of structure for case study.

must be utilized for the sign versus the framework, as it is a solid surface.

Utilizing the appropriate force coefficients for the structure and the attached sign, one can calculate the resulting loading on each component for a given wind speed. Since the sign and truss sections use different force coefficients, it is necessary to set up equations for each component referencing the same wind speed variable. Using systems of equations for overturning forces for the various components, a resulting wind speed involved in overturning of the structure can be determined.

The decorative faux foliage added to the frame would increase the solidity ratio but is difficult to accurately quantify. As such, the authors determined that by considering the faux foliage to increase the solidity ratio of the structure, it resulted in a lower calculated wind speed required to cause overturning. This decrease in calculated windspeed is because there is more considered surface area for the wind to interact with, resulting in more force applied to the structure for a given wind speed.

In practice, this can be accounted for by varying the considered area and providing a range for the overturning wind speed. For the purposes of this paper, the area of faux foliage was held constant to make the comparison easier to understand.

The calculation to determine the overturning wind speed was performed in the three exposure categories with the unmodified factors and compared to the modified factors previously identified herein (indicated as the "NA" column of **Figure 5**). For this case study, the estimated overturning windspeed varied from 7% to 44% higher than the modified factor calculation, when (inappropriately) considering all the ASCE/SEI 7 prescribed design factors.

Exposure	B	C	D	NA
K_{zt}	1	1	1	1
K_z	0.57	0.85	1.03	1
K_d	0.85	0.85	0.85	1
K_e	1	1	1	1
$V_{overturning}$ (mph)	35.8	29.3	26.6	24.9
% Difference	44%	18%	7%	—

Figure 5
Comparison of overturning wind speeds for the case study in the three exposure categories with no modification to the factors (B-D) compared to modified factors.

Potential Next Steps

Though the purpose of this paper is to present the method to utilize ASCE/SEI 7 to estimate wind speeds that would cause a particular event or condition to occur, this may be taken further in a forensic application. There are a number of engineering and design codes, such as the International Building Code (IBC)[7], the International Residential Code (IRC)[8], and AASHTO Signs, Luminaires, and Traffic Signs[9] that refer to ASCE/SEI 7 for wind loads and calculations methods. Other codes could be reviewed for applicability for the methods shown here. In addition, engagement with a forensic meteorologist may be warranted if local weather stations are not within reasonable proximity to the site in question. Through the involvement of forensic meteorology, in conjunction with these calculations, it is possible to substantiate causation of a particular event or condition on a specific date.

Conclusion

The ASCE/SEI 7 method for calculating wind loading on structures can be utilized in a forensic capacity; however, it is critical that engineers performing the calculations understand what information they are presenting. This paper considered the ASCE/SEI 7 method for estimating the wind speed required to cause a particular event to occur, such as to overturn a structure. This is likely to be applicable to engineering standards and codes that reference ASCE/SEI 7 for wind-related design criteria.

Modification of the velocity pressure coefficient (K_z) and wind directionality factor (K_d) are necessary to accurately perform the calculation. If no modification of the factors is performed, it can lead to an inaccurate estimation. As illustrated in the case study, overestimation of the wind speed required to overturn the structure ranged from 7% to 44%, considering the simple structure presented. This will vary based on the size and type of structure being considered.

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