Extreme Wind Load Criteria

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Abstract

Determination of wind loads involve many parameters. These parameters can be divided into three categories; wind climate, localized wind characteristics and wind-structure interaction. Using the wind loading formulation of ASCE 7-98, the paper discusses each parameter for calculation of wind loads on transmission line structures.

Introduction

All buildings and structures around the world are affected by extreme winds. As a result, they are designed to resist wind loads induced by windstorms. Some structures, such as one-story reinforced concrete buildings, are not sensitive to wind loads, while other structures, such as transmission line structures, are very sensitive to wind effects. Hence, more attention is given to wind loads for transmission line structures.

Wind is a natural phenomenon that fluctuates continuously. Any wind speed and wind direction record would show that wind fluctuates continuously in space and time. These fluctuations are termed wind characteristics. Also, weather is a random phenomenon with windstorms occurring in an unpredictable manner during the life of a structure. Because of temporal unpredictability of windstorms, basic design wind speed is assessed in a probabilistic sense.

Thus, the design wind loads are assessed using wind climate of the geographical region and local wind characteristics. The fluctuating nature of

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wind is hidden in equivalent static loads used for design purposes. Standards and codes are developed to provide equivalent static loads for a specified probability of exceeding wind speed (wind climate).

This paper discusses the various parameters involved in developing a simple static loading criteria for transmission lines structures. Formulation of the national standard (ASCE 7-98, 2000) is used for discussion of parameters.

ASCE 7-98 Formulation of Wind Loads

The national consensus standard, *Minimum Design Loads for Buildings and Other Structures*, ASCE 7-98 (2000) specifics wind loads in Section 6. The formulation of the wind loads for structures is given by the following two equations

$$q_z = 0.00256\, K_z K_{zt} K_d V^2 I \qquad (1)$$
$$F = q_z G C_f A_f \qquad (2)$$

Where F- design wind force (lb, N)

- q_z- velocity pressure evaluated at height z (lb/ft^2, N/m^2)
- K_z- velocity pressure exposure coefficient evaluated at height z
- K_{zt}- topographic factor
- K_d- wind directionality factor
- V- basic wind speed corresponding to a 3-second gust speed at 33ft (10m) above ground in flat, open terrain (miles/hour, m/s)
- I- importance factor
- G- gust effect factor
- C_f- force coefficient (shape factor)
- A_f- area projected on a plane normal to the wind direction (sq ft, sq m)

Each of the terms of equations 1 and 2 have specific role in determining wind loads. The parameters basic wind speed V and importance factor I are related to wind climate. Other parameters in the equations are related to local wind characteristics and to wind-structure interaction.

Basic Wind Speed V

Basic wind speeds given in Figure 6-1 in ASCE 7-98 (2000) are used to determine wind loads. The map of Figure 6-1 is developed using statistical analysis of recorded maximum annual gust speeds at almost 450 stations in the contiguous United States; exceptions are hurricane-prone regions. Peterka and Shahid (1998) used the concept of superstation by combining recorded data at 8 to 10 stations in a region. The combined data was checked for independence and represented 300 to 400 years of data. The advantage of long length of record is that it significantly narrows (reduces) error-band. Fisher-Tippett Type I extreme value distribution is used to obtain wind speeds associated with different annual probability of exceeding. The map in Figure 6-1 of ASCE 7-98 is for 0.02 annual probability of exceeding wind speed (50-year mean recurrence interval (MRI)). The annual probability of exceeding and MRI are reciprocal of each other. The East coast and Gulf coast of the United States as well as the islands in the Caribbean and Pacific Oceans are affected by hurricane winds (in Guam, hurricane is called typhoon). The wind climate in hurricane-prone regions is distinctly different than the one in the contiguous United States. The wind speed contours in hurricane-prone regions are developed by Vickery and Twisdale (1995) using Monte-Carlo numerical simulation. Since the wind climate of hurricanes is different, it was necessary to calculate wind speeds in coastal regions using 500-year MRI. These wind speeds, then, are divided by $\sqrt{1.5}$ to obtain equivalent 50-year MRI wind speed contours (see Commentary Section C 6.5.4 of ASCE 7-98 (2000) for further explanation). Thus, the wind speeds in the map of Figure 6-1 of ASCE 7-98 (2000) are consistent with 50-year MRI.

The 50-year MRI is a probabilistic term. There are different probabilities of exceeding 50-year MRI wind speed depending on the life of a structure. Table 1 shows the probabilities of exceeding basic wind speed of map of ASCE 7-98 for various life span of a structure. For example, according to Table 1, if a transmission line structure's life is 50 year, there is a 64% chance of exceeding 50-year MRI wind speeds; if the life of the structure is 25 years, there is a 40% probability of exceeding 50-year MRI wind speed. These numbers suggest that there is a good chance of exceeding 50-year MRI wind speed during the life of a transmission line structure.

Table 1. Probability of Exceeding (ASCE 7-98, 2000)

Mean Recurrence Interval (years)	Annual Probability of Exceeding	Life of a Structure			
		1	10	25	50
25	0.04	0.04	0.34	0.64	0.87
50	0.02	0.02	0.18	0.40	0.64
100	0.01	0.01	0.10	0.22	0.40
200	0.005	0.005	0.05	0.10	0.22

Importance Factor I

Importance factor I is used to change basic wind speed from 50-year MRI (0.02 annual probability of exceeding basic wind speed) to 25-year MRI or 100-year MRI. As can be seen in Table 1, 100-year MRI basic wind speed will have 22% chance of exceeding during the structure's life of 25 years. For important structures, higher structural reliability is desired. Importance factor for structures to be designed for 100-year MRI wind speed is 1.15; thus the wind loads are increased by 15%.

Constant 0.00256

The constant 0.00256 in equation 1 reflects mass density of air and dimensions of wind speed. We like to use wind speed in miles per hour, but the resulting pressures are in pounds per square foot. Hence, it is necessary to convert wind speed from miles per hour to feet per second. This conversion is hidden in the constant 0.00256. For SI system where wind speed is in meter per second and pressure is in N/m^2, this constant is 0.613.

The density of air for temperature of 59° F and sea level barometric pressure of 29.9 inches of mercury is taken as 0.0765 pounds per cubic foot. The air density is strongly affected by elevation above sea level and to some extent by temperature and relative humidity. Table 2 gives air density for various altitude above sea level. The maximum and minimum values of air density reflect the range of density for extreme temperatures and relative humidity. It is advisable to use maximum value of air density at high altitude above sea level unless a meteorologist is consulted to ascertain extreme temperature and relative humidity values during probable windstorms. At 10,000 ft above sea level, the air density (maximum value) is smaller by 23 percent; thus, the wind load can be reduced by the same amount.

Velocity Pressure Exposure Coefficient K_z

The velocity pressure exposure coefficient (exposure coefficient) reflects change in wind speed due to terrain and height above ground. The winds are movement of air. The airflow is retarded due to the friction of ground. The winds are slower close to the ground and are reduced more if ground surface is rougher (e.g. suburban, wooded terrain). ASCE 7-98 (2000) defines four exposure categories; A. large city centers; B. urban, suburban and wooded areas; C. open terrain like airports; and D. area exposed to large body of water. The wind speed map (figure 6-1 of ASCE 7-98) is for Exposure C and

for wind 33ft (10 m) above ground. The exposure coefficient is designed to adjust wind speed for any height above ground and for one of the four terrains (the coefficient is applied to pressure).
For example, wind pressure at 120 ft above ground in open terrain is 31% higher (K_{120}=1.31 for Exposure C) than the one at 33 ft. However, if the structure is located in suburban or heavily wooded area, the pressure is only 4% higher (k_{120}=1.04 for Exposure B) than the basic pressure obtained with basic wind speed of the map (at 33 ft in open terrain). Correct assessment of surrounding terrain can provide more accurate wind loads.

Table 2. Air Density (ASCE 7-98, 2000)

Altitude		Ambient Air Density		
Feet	**Meters***	**Minimum (lb/ft^3)**	**Average** (lb/ft^3)**	**Maximum (lb/ft^3)**
0	0	0.0712	0.0765	0.0822
2,000	610	0.0675	0.0720	0.0768
4,000	1,219	0.0640	0.0678	0.0718
6,000	1,829	0.0608	0.0639	0.0672
8,000	2,438	0.0577	0.0602	0.0628
10,000	3,048	0.0547	0.0567	0.0588

***1 ft = 0.305 m**
****1 lb/ft^3 = 16.0 kg/m^3**

Topographic Factor K_{zt}

Wind flow over hilly terrain is a very complex phenomena. Wind speeds can increase or decrease depending on the shape of the hills and the complex terrain. Literature available for wind flow over complex terrain (Jackson and Hunt, 1975; Lemelin et al, 1988; Walmsley et al, 1986) permits some simplication of wind speed-up criteria over isolated hill and escarpment. Where the terrain is rolling hills or complex terrain, the engineer is guided to use good judgment, seek expert advice, or pursue wind tunnel testing.

ASCE 7-98 (2000) topographic effect criteria are for isolated hill or escarpment (no similar feature 2 miles upwind of the site) that is at least 15 ft high for Exposure C and 60ft high for Exposure B. The wind speed-up is maximum at the crest of a hill or an escarpment. This speed-up depends on the shape of the topographic feature. The wind speed-up reduces as the distance from the crest increases and as the height above ground increases. Thus, there is a speed-up bubble that depends on slope of hill or escarpment, distance from the crest, and height z from the ground. These items are included in the topographic factor K_{zt} of the ASCE 7-98 (2000). Currently, sufficient information is not available to permit any shielding (reduction of wind speed) due to topographic feature. Engineer would have to resort to wind tunnel testing for a specific site to take advantage of shielding.

Gust Effect Factor G

Gust effect factor is often called 'gust response factor.' It is a factor that accounts for the response of a structure due to turbulence in the wind. Two types of response of structure are considered in gust effect factor, (1) background turbulence response, and (2) resonance turbulence response.

The background turbulence response is related to a relatively rigid structure. The response depends on turbulence intensity in wind, size of gust and size of structure. It should be noted that turbulence intensity and size of gust vary with terrain and height above ground. Gust effect factor based only on background turbulence response has a value of less than one since the basic wind speed is a gust speed. Also, the gust size and structure size are related; the larger the structure, the smaller the value of gust effect factor.

The resonance turbulence response is related to frequency of turbulence matching the frequency of vibration of a structure. ASCE 7-98 (2000) specifies that resonance response has to be considered if a structure has fundamental frequency of vibration less that 1 Hz (1 cycle per second or period of a cycle is greater than 1 second); in this case the structure is considered flexible. The resonance turbulence response depends on several factors including turbulence intensity, gust size, fundamental frequency of the structure, structural and aerodynamic damping, structure size and gust correlation. In addition, for transmission line structure, matching of frequency of vibration of tower and conductor is an important parameter. Vann et al (1997) conducted a sensitivity study of transmission line structure for 'gust response factor' for parameters such as pole height, conductor span and pole damping factor. He points out that even though basic wind speed is 3-second gust, the structure will experience resonance response in addition to background turbulence response if it is flexible. The formulation of determination of gust effect factor, which includes resonance turbulence response, is complex. For brevity, the reader is referred to the literature (Davenport, 1962; ASCE 7-98, 2000; ASCE, 1991 under revision).

Force Coefficient C_f

Force coefficients for any structure depends on the size and shape of the structure. Only way to determine force coefficient value for a structure is through experimentation. Wind tunnel testing is used to obtain force coefficients. Wind tunnel simulates wind and its characteristics at model scale to perform tests on models. The geometric scale can vary from 1:25 to 1:500. Because of the geometric scaling of the model, wind tunnel has certain limitations. For example, it is not feasible to match Reynolds number between prototype and model scale. However, fluid dynamicists working in wind tunnel can account for this mis-match to obtain credible results. The projected area A_f is used in wind tunnel data analysis to obtain force coefficient. Thus, the force coefficient and area of the structure are interrelated; they have to be used in the same way as they were used to obtain force coefficients from wind tunnel.

Summary

Wind loads depend on many parameters. In general parameters can be divided into three categories; wind climate (basic wind speed and importance factor); local wind characteristics (height and terrain exposure, topographic factor, turbulence); and wind-structure interaction (gust effect factor and force coefficients). All these parameters are accounted for in formulation of wind loads in ASCE 7-98 (2000). In some cases, e.g., gust effect factor, the formulation is simplified for a complex phenomenon. As we improve our understanding of each of the parameter, the formulation of wind loads criteria may become more complex, but it will be more accurate. Availability of computer software will ease the burden of complex calculations, and will allow us to estimate more accurately the wind loads.

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The development of the map of extreme ice loads for ASCE Manual 74

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Abstract

In this paper we discuss the development of the map of extreme ice loads with concurrent wind speeds that is in the latest revision of ASCE Manual 74 and in ASCE Standard 7. This map is based on historical weather data from hundreds of weather stations run by the National Weather Service, Air Force, and Federal Aviation Administration. Equivalent uniform radial ice thicknesses on wires perpendicular to the wind direction in past freezing rain storms were determined from the data at each weather station using ice accretion models. Qualitative damage information was obtained for the storms that appeared to be severe enough to damage trees and power lines. This information was used both to check the modeling algorithms and to group the stations into superstations for the extreme value analysis. Ice thicknesses for long return periods were determined by fitting the generalized Pareto distribution to the sample of largest ice thicknesses for each superstation. Wind speeds concurrent with the extreme ice thicknesses were also calculated. In the West, from the Rocky Mountains to the Pacific, ice thickness zones were extrapolated using qualitative information because extreme ice thicknesses have not yet been calculated from the weather data in this region. For application to overhead electrical wires, the mapped ice thicknesses are adjusted for return period, height above ground, topography, and possibly wire orientation.

1. Introduction

Ice and wind-on-ice loads on electric power transmission lines and communication towers are the governing loads on these structures in much of the United States. For

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the 1998 revision of ASCE Standard 7 *Minimum Design Loads for Buildings and Other Structures* (ASCE 2000), the Ice Load Task Committee provided a map of ice thicknesses from freezing rain with concurrent gust speeds for a 50-year return period for the eastern half of the country. This Standard is referenced by other codes, guidelines and standards, including the *National Electrical Safety Code* (NESC), ASCE Manual 74 *Guidelines for Electrical Transmission Lines Structural Loading*, and EIA/TIA 222 *Structural Standards for Steel Antenna Towers and Antenna Supporting Structures*. A revised ice map is provided in the draft of the 2002 revision of ASCE Standard 7, and for the revision of ASCE Manual 74 that is also in progress. The 1998 map was revised based on work done by the Cold Regions Research and Engineering Laboratory (CRREL) for the American Lifelines Alliance (www.americanlifelinesalliance.org) to analyze weather data in the Plains states, discussions with the Oregon State Climatologist about the map for the Pacific Northwest, and qualitative damage information from *Storm Data* (NOAA 1959-1995) west of the Rockies, excluding the Pacific Northwest.

CRREL has developed software and algorithms for processing historical data from weather stations with hourly weather data and 6-hourly or daily precipitation data. The Air Force Combat Climatology Center (AFCCC) provides researchers at CRREL with archived weather and precipitation data. The period of record of the electronically archived data typically begins in the late 1940s for long-established National Weather Service and military stations and in 1973 for Federal Aviation Administration stations. The weather and precipitation data are first merged and the accumulated precipitation is prorated to each hour based on the type and severity of precipitation. Freezing rain storms are extracted from these merged data. The accretion of ice, expressed as an equivalent radial thickness, and wind-on-ice loads are modeled for each storm. Both the detailed CRREL ice accretion model (1996b), and the sometimes more conservative Simple model (Jones 1996a,b), are used. The CRREL model does a heat-balance analysis to determine how much of the freezing precipitation impinging on a horizontal cylinder freezes. The Simple model simulates the accretion of ice, assuming that it is cold enough that all the precipitation freezes.

Model results are checked for ice storms with large modeled ice thicknesses using qualitative damage information from *Climatological Data, National Summary* (NOAA 1950–1958) and *Storm Data* (NOAA 1959–present) supplemented by contemporaneous newspaper reports. The damage reports are also used to determine the footprint of damage to overhead lines, telecommunication towers, and trees for each ice storm.

To generate a long period of record for the extreme value analysis of ice and wind-on-ice loads, the weather stations are grouped into superstations. These groupings are based on the frequency of ice storms, the distribution of damaging ice storms, topography, proximity to large bodies of water, etc. Ice thicknesses and wind-on-ice loads for a 50-yr return period are determined using the peaks-over-threshold method with the generalized Pareto distribution (Hosking and Wallis 1987). This is a three-parameter distribution, which allows for a heavy tail if the data warrant. The