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Ahsan Kareem[a]

[a]*NatHaz Modeling Laboratory, University of Notre Dame, IN 46530, USA*

ABSTRACT: This paper focuses on three items for sharing with the APEC delegates concerning standards and codes in the US. First is a summary paper dealing with a recent study conducted by the author and his student Rachel Bashor involving a comparison of international codes focusing on high-rise buildings. The second section presents a summary paper addressing the need for potentially enhanced load factors for future implementation in standards related to high-rise buildings to account for uncertain dynamic characteristics. The third section deals with a Power Point presentation highlighting the revisions in ASCE 7 05 that will lead to ASCE 7 10.

KEYWORDS: standards and codes; high-rise buildings; load factor; uncertainties; damping; design winds

INTRODUCTION

This economy report is a compendium of three documents:

- Comparative Study of Major International Standards
- Load Factors for Dynamically Sensitive Structures
- Wind Loads Provisions: Current Directions and Developments

In the following a brief synopsis of each document is presented.

Comparative Study of Major International Standards

Globalization of the construction industry and the development of unified international codes and standards intensifies the need to better understand the underlying differences between the major international wind loading standards. A comprehensive comparison of the wind loads and their effects on tall buildings is conducted utilizing five major international codes and standards: ASCE 2005 (American), AS/NZ 2002 (Australian and New Zealand), NBCC 2005 (Canadian), AIJ 2004 (Japanese), and Eurocode 2004 (European). The key areas of comparison include the provisions for strength design in the alongwind, acrosswind, and torsional directions as well as the serviceability requirements in respective directions. As the standards utilize the same basic theoretical framework, the equations are re-written in a generic format in order to compare the individual parameters.

Load Factors for Dynamically Sensitive Structures

The current recommendations for load factors concerning wind are based on rigid buildings, which may not be adequate for dynamically sensitive structures. In light of the uncertainties associated with the dynamic characteristics of buildings (e.g., mass, stiffness and damping), the departure of response being proportional to the square of wind velocity, and the target limit states, the load factors for flexible buildings may likely deviate from those currently used in ASCE 7-05. This study investigates the efficacy of the current load factors for dynamically sensitive structures in the presence of uncertainties. A systematic analysis is performed in which uncertainties associated with each component of the wind load effects is incorporated. These components include the design wind speed distribution, aerodynamic loads, and building dynamic properties. The results of this analysis are discussed in light of previous studies and recent efforts, and finally recommendations are made.

Wind Loads Provisions: Current Directions and Developments

This document is a Power Point presentation only as the subject is a very recent development concerning the latest changes in ASCE 7 for it ASCE 7 10 version. The PP highlights the need for changes and details significant proposed changes, reorganization of wind provisions and a new addition related to a simplified method for buildings up to 160 feet in height. The PP is prepared by Prof. Ron Cook, Chair of the ASCE 7 Wind Task Committee.

CONCLUDING REMARKS

It is envisaged that these documents would help the APEC delegates during their deliberations concerning the harmonization of the building standards, emerging issues like the comparison of standards/codes; need to revisit load factors, especially for dynamically sensitive buildings and the use of higher mean recurrence interval winds and its implications on load factors in light of uncertainties and dependence of damping and frequency on the level of building response; upcoming changes in ASCE 7.

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Submitted by

Ahsan Kareem
Robert M Moran Professor
NatHaz Modeling Laboratory
University of Notre Dame,
Notre Dame, IN 46556
.nd.edu/~nathaz
@nd.edu

COMPARATIVE STUDY OF MAJOR INTERNATIONAL STANDARDS

Rachel Bashor[1] and Ahsan Kareem[2]
[1] *Ph.D. Candidate, NatHaz Modeling Laboratory, University of Notre Dame, Notre Dame, IN, USA, rstansel@nd.edu*
[2] *Professor, NatHaz Modeling Laboratory, University of Notre Dame, Notre Dame, IN, USA, kareem@nd.edu*

ABSTRACT

Globalization of the construction industry and the development of unified international codes and standards intensifies the need to better understand the underlying differences between the major international wind loading standards. A comprehensive comparison of the wind loads and their effects on tall buildings is conducted utilizing five major international codes and standards: ASCE 2005 (American), AS/NZ 2002 (Australian and New Zealand), NBCC 2005 (Canadian), AIJ 2004 (Japanese), and Eurocode 2004 (European). The key areas of comparison include the provisions for strength design in the alongwind, acrosswind, and torsional directions as well as the serviceability requirements in respective directions. As the standards utilize the same basic theoretical framework, the equations are re-written in a generic format in order to compare the individual parameters.

KEYWORDS: WIND CODES AND STANDARDS, TALL BUILDINGS, WIND LOADING

Introduction

Globalization of the construction industry and the development of unified international codes and standards, i.e. ISO Draft [ISO], intensifies the need to better understand the underlying differences between the major international wind loading standards. Previous studies have found that the varying definitions of wind field characteristics, including mean wind velocity profile, turbulence intensity profile, wind spectrum, turbulence length scale, and wind correlation structure, were the primary contributors to the scatter in predicted response quantities [Zhou *et al.* 2002; Tamura *et al.* 2005]. As nearly every major building code has been updated in the last few years, it is necessary to update previous code comparison work.

A comprehensive comparison of the wind loads and their effects on tall buildings is conducted utilizing five major international codes and standards. These codes - the American Society of Civil Engineers Recommendations [ASCE 2005], the Australian and New Zealand Standard [SAA 2002], the National Building Code of Canada [NRC 2005], the Architectural Institute of Japan Recommendations [AIJ 2004] and the European Standard [Eurocode 2004] - all utilize the traditional displacement-based gust loading factor for assessing the dynamic along-wind loads and their effects on tall structures but incorporate different provisions for acrosswind and torsional loads [Holmes *et al.* 2005; Tamura *et al.* 2005].

The key areas of comparison include provisions for strength design in the alongwind, acrosswind, and torsional directions as well as serviceability requirements in respective directions. As the standards utilize the same basic theory, the equations are re-written in a generic format in order to compare the individual parameters. Changes from previous versions are highlighted and several examples are presented. Finally, the deviations in the results are discussed and suggestions are made to improve agreement between the standards.

Wind Characteristics in Codes and Standards

Although these standards determine wind loading in the along-wind direction using a random-vibration-based gust factor approach, the parameters are defined differently. These parameters are re-written in a consistent format and compared with each other. Some of the difficulties in using international standards is the use of different terminology and the incorporation of factors within other terms, making it hard for designers to work in a global environment. Rewriting the basic equations in a generic format will help designers decipher the nuances of the different codes and understand the resulting differences in the response. Note that the scope of this analysis is limited to dynamically sensitive buildings of regular shape. All– standards recommend that extremely tall and irregular shaped structures –be designed using wind tunnel studies.

Alongwind Wind Loads

In all five standards, the alongwind loads are determined by multiplying the wind pressure by the surface area of the building. The general expression for pressures on a building for all the standards can be expressed as:

$$p = qGC_p \tag{1}$$

where $q =$ velocity pressure; $G =$ gust loading factor; and C_p = pressure coefficient. The following investigates both internal pressures and external pressures, acting in the windward and leeward directions. The loads are then determined by combining the pressures acting on a wall and the corresponding tributary area. Moments are determined by multiplying the load at a given height by the corresponding height. Base shear forces and moments are then determined by the sum of the loads and moments at each level.

The velocity pressure can be expressed as:

$$q = \tfrac{1}{2}\rho V_0^2 \cdot C_{\exp osure} \cdot C_{terrain} \cdot C_{direction} \cdot C_{importance} \cdot C_{other} \tag{2}$$

where $\rho =$ air density; V_0 = basic wind velocity; $C_{\exp osure}$ = velocity profile or exposure factor; $C_{terrain}$ = terrain and topography factor; $C_{direction}$ = directionality factor; $C_{importance}$ = building importance factor; and C_{other} = a factor accounting for other things such as hurricane zone, shielding, or mean recurrence interval. The effects of terrain directionality, building importance, and other factors are not considered in this study. However, the definitions of velocity profile are analyzed in detail and compared between the five standards.

Averaging times for wind velocity vary between the standards and within the standards. For example, in Eurocode, the velocity is adjusted from 10 minute to one hour for calculations of response. In addition, the reference height at which the gust factor and other parameters are calculated is different between the codes. These differences between averaging time and reference heights affect the intermediate parameters and resulting responses, making a simple comparison among the standards challenging. Throughout this analysis, the effect of differing averaging times has been minimized as much as possible.

The gust loading factor for the five standards may be written in terms of a general form as:

$$G = \frac{1 + gr\sqrt{B+R}}{G_v} \tag{3}$$

where g is the peak factor for response, r describes the turbulence intensity, G_v is the gust factor for the wind velocity pressure, B is the background factor and R is the resonant factor general expressed as:

$$R = \frac{\pi SE}{4\zeta} \tag{4}$$

with S as the size reduction factor, E as the energy factor, and ζ as the damping ratio. A major portion of this study compares the multiple parameters used to define the gust loading factor in the five standards. The parameters are all re-written in terms of a general form so as to accurately compare the various parameters. The comparison of the individual parameters reveals several areas of disagreement between the codes, leading to wind loads that may differ greatly.

Acrosswind and Torsional Loads

Although the standards are fairly consistent with respect to alongwind loading, the treatment of acrosswind and torsional loading differs amongst the codes. ASCE, Eurocode, and NBCC utilize partial loading to account for acrosswind and torsional loads, although ASCE provides an alternative method in the Commentary. The partial loading technique simply applies fractions of the alongwind pressures in different combinations. Torsion is introduced either by asymmetric loading, as in NBCC and Eurocode, or by an applied moment defined as a combination of the alongwind load times an eccentricity (ASCE). The procedures used to determine the alongwind and torsion loads are compared in this analysis; however, as these procedures typically rely on databases, the results vary to a higher degree than the alongwind comparisons.

Accelerations

In addition to strength requirements, the serviceability requirements, in terms of acceleration, are assessed. All the codes and standards provide equations for defining alongwind accelerations, however acrosswind and torsional accelerations are not included in every code. The alongwind acceleration can be generically defined as:

$$\hat{\ddot{x}}(z) = \frac{q_h G_R C_{fx} bhK}{m_1} \phi_1(z) \tag{5}$$

where q_h is the velocity pressure at the reference height, G_R is the resonant component of the gust effect factor, C_{fx} is the force coefficient, b is the building width, h is the building height, K is the mode shape correction factor, m_1 is the generalized mass in the first mode, and $\phi_1(z) = \left(\frac{z}{h}\right)^k$ is the first mode shape evaluated at height z.

Example Analyses of Tall Buildings

To compare the wind loading standards, several example buildings are analyzed with each code. The first example building is a square building with height of 200 m, width and depth of 33 m, natural frequency for alongwind and acrosswind of 0.2 Hz, damping of 1% in all directions, linear mode shapes, building density of 180 kg/m^3, air density of 1.22 kg/m^3, basic wind velocity for strength of 40 m/s (3 second) and basic wind velocity for serviceability (3 second) of 35 m/s. To convert the velocity to different averaging times, the relationship developed by Durst [ASCE 2005] is utilized. The building is analyzed using first an urban exposure then an open exposure. Factors accounting for wind direction, importance, etc. are assumed to be 1. Selected results from the analysis of Example 1 are presented in Table 1.

The analysis of Example 1 reveals the strong influence of averaging time, velocity profile, turbulence profile, and pressure coefficients on the resulting response. In an effort to minimize these effects, the second example ensures that these values are equivalent. Specifically, the velocity at the roof height, the turbulence intensity at the roof height, and the pressure coefficients are the same for each standard. The analysis of the two examples reveals that, except in the case of Aerodata's serviceability, ASCE, Aerodata, and AS/NZ yield consistent responses with the same basic wind velocity. Although intermediate parameters may vary, Eurocode yields consistent results if the velocity at reference height is modified. AIJ and NBCC yield higher results, partly due to differences in averaging time and partly due to the use of the Davenport spectrum in NBCC.

Table 1: Alongwind Results for Example 1 using Urban Exposure

	ASCE	Aerodata	AS/NZ	Eurocode B	Eurocode C	AIJ	NBCC
V_0 (m/s)	40.0	40.0	40.0	28.1	28.1	28.1	26.4
h_{ref} (m)	120	200	200	120	120	200	200
$\bar{V}_{h_{ref}}$ (m/s)	27.5	32.6	46.4	31.5	31.5	36.4	33.1
q_h (kN/m^2)	1.409	–	1.313	1.726	1.726	0.807	0.425
B	0.583	–	0.633	0.512	0.409	0.491	0.422
R	0.526	–	0.601	0.735	1.015	0.810	1.672
G_vG	2.693	–	2.487	2.497	2.613	2.179	2.841
V_{base} (MN)	9.95	8.10	9.65	11.27	11.93	11.39	15.11
M_{base} (MN-m)	1,084	1,112	1,049	1,398	1,477	1,294	1,667
$\sigma_{\ddot{x}}$ (milli-g)	3.44	3.98	3.38	5.37	6.39	3.96	–
$\hat{\ddot{x}}$ (milli-g)	13.03	15.06	10.44	17.21	20.49	12.72	–

NOTE: Aerodata refers to the Commentary section of ASCE. Eurocode has two methods (B & C) to determine gust loading parameters. V_0 is basic wind velocity; h_{ref} is reference height; $\bar{V}_{h_{ref}}$ is design velocity; q_h is velocity pressure; B is background factor; R is resonance factor, G and G_v are gust factors; V_{base} is base shear; M_{base} is base moment; $\sigma_{\ddot{x}}$ is rms accelerations; and $\hat{\ddot{x}}$ is peak acceleration.

Concluding Remarks

This paper looks into the differences and similarities in major international wind codes. Although many parameters were examined, the scope is limited to dynamically sensitive, regular-shaped buildings with flat roofs that are classified as enclosed. To accurately compare the parameters, the various equations are written in a generic format. While significant discrepancies are apparent in the comparison of the intermediate parameters, ASCE and AS/NZ yield equivalent results in the alongwind directions and similar responses in the acrosswind direction. Eurocode also yields consistent results with ASCE and AS/NZ if the basic wind velocity is adjusted to match the mean velocity at reference height of ASCE. The difference in averaging time affects the responses of AIJ and NBCC when compared with the other standards. Finally, the results using NBCC are shown to be especially large due, in part, to the large discrepancy of the normalized wind velocity spectrum.

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Load Factors for Dynamically Sensitive Structures

Rachel Bashor[1] and Ahsan Kareem[2]

[1]Graduate Student, University of Notre Dame, Notre Dame, IN, USA, rstansel@nd.edu
[2]Professor, University of Notre Dame, Notre Dame, IN, USA, kareem@nd.edu

ABSTRACT

The current recommendations for load factors concerning wind are based on rigid buildings, which may not be adequate for dynamically sensitive structures. In light of the uncertainties associated with the dynamic characteristics of buildings (e.g., mass, stiffness and damping), the departure of response being proportional to the square of wind velocity, and the target limit states, the load factors for flexible buildings may likely deviate from those currently used in ASCE 7-05. This study investigates the efficacy of the current load factors for dynamically sensitive structures in the presence of uncertainties. A systematic analysis is performed in which uncertainties associated with each component of the wind load effects is incorporated. These components include the design wind speed distribution, aerodynamic loads, and building dynamic properties. The results of this analysis are discussed in light of previous studies and recent efforts, and finally recommendations are made.

INTRODUCTION

The current recommendations in ASCE 7 for load factors concerning wind are based on rigid buildings, which may not be adequate for dynamically sensitive structures. Based on the uncertainties associated with dynamic features of buildings and the target limit state, more appropriate load factors for tall building design are required. These load factors would primarily account for deviations in the actual loads from the nominal loads and for uncertainties associated with the load effects. In light of the uncertainties associated with the dynamic characteristics of buildings (e.g., mass, stiffness and damping), the departure of response being proportional to the square of wind velocity, and the target limit states, the load factors for tall buildings may likely deviate from those currently used in ASCE 7-05.

The goal of this study is to investigate the efficacy of current load factors for dynamically sensitive structures in the presence of uncertainties. A systematic analysis is performed in which uncertainties associated with each component of the wind load effects is incorporated. These components include the design wind speed distribution, aerodynamic loads, and building dynamic properties. The results of this analysis are discussed in light of previous studies and recent efforts, including studies by Ellingwood and Tekie [1], Gabbai et al. [2], and Irwin [3]. Additionally, the use of a large return period (i.e. 700 years) wind speed is also investigated and compared with current and previous studies. Finally, recommendations are made for load factors for dynamically sensitive structures.

BACKGROUND

In terms of lateral system design, ASCE's fourth basic load combination generally governs [4]:

$$1.2D + 1.6W + L + 0.5(L_r \text{ or } S \text{ or } R) \qquad (1)$$

where D, W, L, L_r, S, R represent the dead load, wind load, live load, live roof load, snow load and rain load, respectively. In the original development of the load factor by Ellingwood, et al. [5] the load factor was defined using the First Order Reliability Method (FORM) for normal variables, given as:

$$\gamma_W = \left(\mu_W / W_n \right)(1 + \alpha\beta V_W) \tag{2}$$

where μ_W / W_n is the bias or ratio between the mean load and the nominal load (as determined by ASCE 7 for low-rise buildings); β is the reliability index; α is the sensitivity coefficient; and V_W is the coefficient of variation (CoV) in the wind pressure obtained from averaging across seven wind stations fitted with Type 1 distribution. Typical values for these parameters are: $\frac{\mu_W}{W_n} = 0.78$; $\beta = 2.5$; $\alpha = 0.75$; and $V_W = 0.37$. Substituting these values into Equation (2) yields:

$$\gamma_W = (0.78)(1 + 0.75 * 2.5 * 0.37) = 1.32 \tag{3}$$

The resulting load factor of Equation (3) is equivalent to the load factor used in ASCE 7-95 developed using the Simplified Procedure applicable to low-rise buildings [6].

In Ellingwood and Tekie [1], issues concerning the original load factor were revisited. The reliability index for wind load was found to be smaller than the reliability index for gravity loads. The choice of probability distribution for modeling the extreme wind speed was investigated and the difference between wind speed models in hurricane zones versus non-hurricane zones was examined. The authors concluded that the reliability index for wind loads should be 3.2 instead of the previous value of 2.5. The resulting load factors ranged from 1.2-1.7, leading to a proposed wind load factor of 1.5 for non-hurricane zones and 1.6-1.7 for buildings in hurricane zones and the basis for the value currently used in ASCE 7 of 1.6 [4].

Recently, concerns regarding the applicability of current load factors to flexible buildings due to the additional uncertainties involved have been raised as the original load factors were determined for rigid buildings [2]. These issues include the wind effects on dynamically sensitive buildings being proportional to wind speeds raised to powers higher than two and the dynamic response parameters, especially frequency and damping, contributing to additional uncertainty. To determine a more appropriate load factor for tall buildings, the Gabbai et al. [2] modeled an example building in the wind tunnel to determine the wind pressures and the following four cases were considered in a subsequent Monte Carlo simulation:

- *Case 1:* Rigid, no uncertainties
- *Case 2:* Flexible, no uncertainties
- *Case 3:* Flexible with *abc* uncertainties
- *Case 4:* Flexible with *abc* uncertainties plus uncertainties in frequency and damping.

The *abc* uncertainties were associated with experimental, sampling and wind speed conversions [2].

The load factors for Case 1 (rigid building) ranged from 1.9 – 2.3 which depart from Ellingwood et al's [5] value of 1.5 for rigid buildings. Given that there is no uncertainty and the building is assumed to be rigid for Case 1, the load factor in their study is not simply the square of the ratio between wind speeds of 500 MRI and 50 MRI (which would be 1.51). Thus, there is an unstated factor involved in the development of these load factors in Gabbai et al. [2] besides the building's flexibility and the additional uncertainties. In this study, the discrepancy between the proposed load factors of Gabbai et al. with the load factors currently used in ASCE is investigated by performing a suite of probabilistic analyses with a range of methods, uncertainties, and load factor definitions.

A COMMENT ON LOAD FACTORS AND RETURN PERIOD WINDS

Because the wind loads are proportional to the square of the wind speed for rigid buildings, the square root of the load factor can represent the intended design wind speed. The design wind speed can be expressed in terms of the MRI as:

$$x_R = \lambda + \delta \ln(R) \tag{4}$$

where x_R is the wind speed at an MRI of R and λ, δ are Gumbel parameters (Table C6-3 in ASCE 7-05 [4]). Substituting the values for λ, δ and rewriting Equation (4), the intended design period can be determined to be $R = e^{\left(\frac{f_R - 0.605}{0.101}\right)}$ where f_R is the factor between the design wind speed and the 50-yr wind speed. This factor is related to the load factor by $f_R = \sqrt{LF}$. Thus, if the load factor (LF) is 1.6, then the corresponding return period is 689 years as opposed to 462 years for a load factor of 1.5.

In the case of flexible buildings, $f_R = (LF)^{1/n}$, wind loads are proportional to the wind speed raised to a power n. The variable n is equal to 2 for rigid buildings since their response is due to mean and background turbulence effects and exceeds 2 for flexible buildings where the response is dominated by resonance on inertial effects. If, for example, n is equal to 2.5 and R is assumed to be 689, then the load factor for flexible buildings should be 1.8 to account for wind loads being proportional to the wind speed raised to 2.5. It is important to bear in mind this analysis assumes that both frequency and damping do not change with the level of response. It is plausible that concomitant increase in damping may very well counteract increase due to the dynamic effects. This may justify the use of the previous load factor for converting 50-year. loads to design level. A simple analysis based on the slopes of the aerodynamic load spectra [7] suggests values of damping to increase more than 50%-75% to allow this counteraction which may not be practically realized for all buildings. However, it is likely that any anticipated increase in damping may be counteracted by an increase in negative aerodynamic damping at these wind speeds, especially in the acrosswind direction.

METHODOLOGY

In order to determine an appropriate load factor for dynamically sensitive buildings, a Monte Carlo simulation is performed for over 130 separate cases. These cases investigate the effects of rigid versus flexible, alternate definitions of the wind speed, and varying uncertainties associated with frequency, damping, and other properties. To determine the load factors, the pressures, wind loads, base moments, and displacements are determined using both ASCE 7-05 [4] analysis procedures as well as a wind tunnel based technique utilizing the NatHaz Aerodynamics Database (http://aerodata.ce.nd.edu) [8]. Three separate definitions of the load factor are considered and two example buildings are analyzed. To complement the Monte Carlo simulation, a comprehensive FORM based analysis is utilized for selected cases [9].

The cases used in the analysis are as follows: (1) rigid or flexible; (2) uncertainties in wind speed; (3) uncertainties in frequency; (4) uncertainties in damping; and (5) all uncertainties. Additional combinations of these and other cases are also explored. **Error! Reference source not found.** describes the variables used to determine the pressures, loads and displacements using ASCE 7-05 along with their distributions and CoVs. Table 2 describes the variables used to determine the loads, moments and displacements using the Aerodynamics Database. The assumed distribution and CoVs are given.

For this analysis, three different load factor definitions are used. These are defined as:

- *Load Factor 1 (LF 1):* Developed from traditional reliability analysis, this assumes that the load effect is normally distributed and is the same definition used by Ellingwood, et al. [5]:

$$\gamma = \left(\frac{\mu_W}{W_n}\right)\left(1 + \alpha\beta\delta_W\right) \tag{5}$$

  where μ_W = mean value of the load effect, W_n = ASCE determined value of the load effect, $\alpha = 0.75$, $\beta = 3.2$, and δ_W = CoV of wind load effect.

- *Load Factor 2 (LF 2):* Often when a variable is a function of products of other variables, the resulting distribution is lognormal. Accordingly, a second load factor definition is introduced which assumes that the resulting variable is lognormally distributed:

$$\gamma = \left(\frac{\mu_W}{W_n}\right)\frac{\exp\left[\beta\varepsilon_\ell\sqrt{\ln\left(1+\delta_W^2\right)}\right]}{\sqrt{1+\delta_W^2}} \tag{6}$$

  where $\varepsilon_\ell = 0.72$ and the other variables are defined above.

- *Load Factor 3 (LF 3):* This definition is the same as for Load Factor 2 (LF 2) except that the CoVs and the resulting variables are derived from the propagation of uncertainties in other parameters based on FORM instead of the Monte Carlo simulation used in LF 1 and LF 2. The details are omitted here for the sake of brevity and can be found in Kareem [9].

Table 1: Variables used in ASCE 7-05 analysis

Variable	Description	pdf	CoV
ζ	Damping	Lognormal	0.4
f	Frequency	Lognormal	0.05
a	Experimental errors in wind tunnel measurements	Normal	0.05
b	Sampling errors in estimation of extreme wind speeds	Normal	0.075
c	Wind speed conversion	Normal	0.05
q	Observation errors in wind speed	Normal	0.025
ρ	Air density	Normal	0.05
K	Mode shape	Normal	0.05
C_{fx}	Drag coefficient	Lognormal	0.1
ρ_B	Building density	Normal	0.05
$\alpha, z_g, \hat{\alpha}, \hat{b}$ $\bar{\alpha}, \bar{b}, c, \ell, \bar{\varepsilon}$	Exposure parameters	Normal	0.05
GC_{pi}	Internal pressure coefficients	Normal	0.05
C_{pw}, C_{ps}, C_{pl}	External pressure coefficients	Normal	0.1

Table 2: Variables used in Aerodynamics Database analysis

Variable	Description	pdf	CoV
ζ	Damping	Lognormal	0.40
f	Frequency	Lognormal	0.05
a	Experimental errors in wind tunnel measurements	Normal	0.05
b	Sampling errors in estimation of extreme wind speeds	Normal	0.075
c	Wind speed conversion	Normal	0.05
q	Observation errors in wind speed	Normal	0.05
e_1	Uncertainty of b	Normal	0.05
e_2	Uncertainty of α	Normal	0.05
e_3	Uncertainty of C_M	Normal	0.25
e_4	Uncertainty of σ_m	Normal	0.15
ρ	Air density	Normal	0.05
K	Mode shape	Normal	0.05
C_D	Drag coefficient	Lognormal	0.10
ρ_B	Building density	Normal	0.05

DESCRIPTION OF METHODS

The first method in this analysis is the one described in ASCE 7-05 for flexible buildings [4]. This method determines the effects in the alongwind direction only. For the analysis here, this method is used to determine the pressures, loads, and displacements at the building top. For the LF 1 and LF 2 definitions, the nominal wind effect, W_n, is determined by ASCE 7 assuming no uncertainties. The second method uses the Aerodynamics Databases to determine the moments, loads, and displacements in both the alongwind and acrosswind directions, as defined in Reference [8]. The use of the Aerodynamics Database essentially represents wind tunnel practices with the High-Frequency Base Balance (HFBB) and will be referred to as "AeroData" in the following. Thus, this study compares the load factors for both a code-based procedure and a wind tunnel analysis, providing a comparison to both the work of Ellingwood and Tekie [1] and Gabbai et al. [2].

The nominal definition is the load obtained using the ASCE 7 procedure. For the AeroData method, two definitions of the nominal wind effect are used. The first is the same as the value obtained in ASCE 7 standard, referred to as Nom1. The second nominal definition

(Nom2) is the alternate procedure given in the commentary of ASCE 7-05 (Section C6.5.8, p. 295) [4]. All results for LF1, LF2, and LF3 have been normalized by the initial case with no uncertainties in order to eliminate the effect of the bias by ensuring the case with no uncertainties is equal to one and not less than one. Note that the effects of wind directionality were not included in this study in accordance to previous work [1].

DESCRIPTION OF EXAMPLE BUILDINGS

Two example buildings are used in the analysis. Building 1, utilized by Gabbai et al. [2], is 600 ft tall and has a cross-section of 100 ft x 150 ft. The building is assumed to be located in a suburban area within the continental US with a 3-second, 50-yr wind speed of 90 mph. The natural frequencies are 0.17 Hz and 0.177 Hz and the damping is assumed to be 1%. Only the case in which the wind is normal to the 150 ft face is considered herein. Building 2 is 656 ft tall with a cross-section of 130 ft x130 ft. This building is assumed to be located in an urban environment near the East Coast of the US with a 3-second, 50-yr wind speed of 141 mph. The natural frequency is 0.2 in each direction and the damping is assumed to be 2%.

RESULTS

ALONGWIND ANALYSIS

The results from the Monte Carlo simulations using the two example buildings are presented and discussed in the following. Table 3 shows the results of both example buildings using the ASCE method for all load factor definitions and each wind effect. For a given case, the load factor for each example is generally the same. As expected, for the cases in which no uncertainties are included, the load factors are equal to one. The pressure load factors are the same as the wind load factors as the wind loads are determined by multiplying the pressures by the tributary area. However, the displacement load factors are higher as frequency and damping are included multiple times in the evaluation of displacement.

Table 3: Alongwind load factors for Example Buildings 1 and 2 using ASCE method

Case	Example	Pressure		Load		Displacement		
	Building	LF1	LF2	LF1	LF2	LF1	LF2	LF3
Rigid	1	1.00	1.00	1.00	1.00	1.00	1.00	1.00
None	2	1.00	1.00	1.00	1.00	1.00	1.00	
Flexible	1	1.00	1.00	1.00	1.00	1.00	1.00	1.00
None	2	1.00	1.00	1.00	1.00	1.00	1.00	
Rigid	1	1.51	1.58	1.51	1.58	1.51	1.58	1.58
abc	2	1.51	1.58	1.51	1.58	1.51	1.58	
Flexible	1	1.63	1.75	1.63	1.75	1.63	1.75	1.75
abc	2	1.62	1.73	1.62	1.73	1.62	1.73	
Flexible	1	1.63	1.75	1.63	1.75	1.72	1.86	1.84
abc, f	2	1.62	1.73	1.62	1.73	1.71	1.85	
Flexible	1	1.75	1.89	1.75	1.89	1.93	2.15	2.17
abc, f, d	2	1.72	1.86	1.72	1.86	1.90	2.11	
Flexible	1	1.83	2.00	1.83	2.00	1.88	2.08	2.20
all	2	1.81	1.97	1.81	1.97	1.87	2.06	

NOTE: *None* refers to no uncertainties; *abc* refers to wind uncertainties; *f* refers to frequency uncertainties; *d* refers to damping uncertainties; and *all* refers to all uncertainties

With regard to rigid versus flexible, there is a significant increase in uncertainties for a flexible building. The uncertainties associated with frequency are considerably lower than the uncertainties associated with wind. However, the uncertainties associated with damping and the remaining variables do increase the load factors. Overall the LF 2 load factors are higher than the LF1 load factors when uncertainties are included, indicating that the earlier use of normal distribution in the definition (LF1) may not be an appropriate choice. As the resulting distribution of a variable that is a multiple of several variables is lognormal, the LF 2 definition is a more accurate representation.

In determining the displacement load factors for definition LF 3, the propagation of uncertainty associated with the frequency, damping, and all uncertainties were determined using a FORM analysis whereas for the wind, uncertainties propagated by Monte Carlo simulation for the definitions LF 1 and 2 were employed. As both definitions LF 2 and 3 are lognormal, the load factors for these cases are the same, except in the final case. The difference in this case can be attributed to the uncertainty associated with amplitude of load spectrum determined using the FORM analysis for the LF 3 definition differing from the Monte Carlo simulation.

The results of the Monte Carlo simulations using the AeroData method can be found in Table 4 and Table 5. For the AeroData load factors, the load values are slightly higher than those for the moments, with the displacement load factors still the highest. The effect of the nominal definition is negligible. Overall, the load factors for Example Building 2 are higher than those for Example Building 1. This can likely be attributed to the uncertainty associated with developing and evaluating the non-dimensionalized spectra. The results for the AeroData method follow the same trends as the results for the ASCE method. It is evident from the analysis that the uncertainties associated with a dynamically sensitive building are significant compared to those of a rigid building and are not accounted for in the current value of the load factor (1.6).

Table 4: Alongwind load factors for Example Building 1 using AeroData method

Case	Nominal Definition	Moment		Load		Displacement	
		LF1	LF2	LF1	LF2	LF1	LF2
Rigid	1	1.00	1.00	1.00	1.00	1.00	1.00
None	2	1.00	1.00	1.00	1.00	1.00	1.00
Flexible	1	1.00	1.00	1.00	1.00	1.00	1.00
None	2	1.00	1.00	1.00	1.00	1.00	1.00
Rigid	1	1.51	1.59	1.51	1.59	1.51	1.59
abc	2	1.51	1.58	1.51	1.58	1.51	1.58
Flexible	1	1.61	1.71	1.62	1.72	1.61	1.71
abc	2	1.61	1.71	1.62	1.72	1.61	1.71
Flexible	1	1.62	1.72	1.63	1.73	1.70	1.84
abc, f	2	1.61	1.71	1.62	1.72	1.70	1.83
Flexible	1	1.72	1.86	1.74	1.88	1.91	2.11
abc, f, d	2	1.73	1.87	1.75	1.89	1.92	2.14
Flexible	1	1.98	2.21	2.00	2.23	2.10	2.39
all	2	1.97	2.19	1.98	2.21	2.08	2.35

NOTE: *None* refers to no uncertainties; *abc* refers to wind uncertainties; *f* refers to frequency uncertainties; *d* refers to damping uncertainties; and *all* refers to all uncertainties.

Table 5: Alongwind load factors for Example Building 2 using AeroData method

Case	Nominal Definition	Moment LF1	Moment LF2	Load LF1	Load LF2	Displacement LF1	Displacement LF2
Rigid	1	1.00	1.00	1.00	1.00	1.00	1.00
None	2	1.00	1.00	1.00	1.00	1.00	1.00
Flexible	1	1.00	1.00	1.00	1.00	1.00	1.00
None	2	1.00	1.00	1.00	1.00	1.00	1.00
Rigid	1	1.51	1.58	1.51	1.58	1.51	1.58
abc	2	1.51	1.59	1.52	1.59	1.52	1.59
Flexible	1	1.65	1.77	1.66	1.78	1.65	1.76
abc	2	1.65	1.76	1.65	1.77	1.64	1.75
Flexible	1	1.65	1.76	1.66	1.77	1.73	1.87
abc, f	2	1.65	1.76	1.65	1.77	1.72	1.87
Flexible	1	1.80	1.96	1.82	1.98	1.99	2.23
abc, f, d	2	1.80	1.96	1.82	1.98	1.99	2.23
Flexible	1	2.00	2.25	2.02	2.27	2.14	2.45
all	2	2.00	2.25	2.02	2.27	2.14	2.45

NOTE: *None* refers to no uncertainties; *abc* refers to wind uncertainties; *f* refers to frequency uncertainties; *d* refers to damping uncertainties; and *all* refers to all uncertainties.

Acrosswind Analysis

The results for the Acrosswind analysis are given in Table 6. As shown, the rigid cases are in agreement for the two buildings. The load factors for moments and loads are similar in all cases, whereas displacement factors are somewhat smaller than the moment load factors. As expected, the load factors for acrosswind are larger than those for alongwind cases for flexible buildings. Thus, current load factors may not be adequate to account for the acrosswind load effects.

Table 6: Acrosswind load factors for Example Buildings 1 and 2 using AeroData method

Case	Example Building	Moment LF1	Moment LF2	Load LF1	Load LF2	Displacement LF1	Displacement LF2
Rigid	1	1.00	1.00	1.00	1.00	1.00	1.00
None	2	1.00	1.00	1.00	1.00	1.00	1.00
Flexible	1	1.00	1.00	1.00	1.00	1.00	1.00
None	2	1.00	1.00	1.00	1.00	1.00	1.00
Rigid	1	1.51	1.58	1.51	1.58	1.51	1.58
abc	2	1.51	1.59	1.51	1.59	1.51	1.59
Flexible	1	1.79	1.97	1.80	1.98	1.65	1.77
abc	2	1.79	1.97	1.79	1.98	1.67	1.80
Flexible	1	1.81	2.00	1.82	2.01	1.67	1.79
abc, f	2	1.80	1.99	1.80	2.00	1.68	1.82
Flexible	1	2.04	2.30	2.05	2.32	1.78	1.93
abc, f, d	2	2.03	2.31	2.04	2.32	1.80	1.98
Flexible	1	2.43	2.92	2.46	2.96	2.12	2.44
all	2	2.46	2.98	2.47	3.00	2.19	2.54

NOTE: *None* refers to no uncertainties; *abc* refers to wind uncertainties; *f* refers to frequency uncertainties; *d* refers to damping uncertainties; and *all* refers to all uncertainties.

Comparison with Others

To compare the current analysis with other research, the load factors using the definition defined by Gabbai et al. [2], referred to as LF4, are compared to those given by Gabbai et al. [2] in Table 7. The load factor definition LF 4 is derived from the assumption that the load factor is defined as the ratio between the point estimate of the 500-year wind speed and the point estimate of the 50-year wind speed, both based on the Extreme Value Type I distribution. This is the definition used by Gabbai et al. [2] and is defined as:

$$\gamma = \frac{W(N = 500, P = 0.9)}{W(N = 50, P = 0.5)} \tag{7}$$

where P is the percentage point associated with a desired quantile, e.g., $P = 0.9$ corresponds to the 90th percentile value, and N is the mean recurrence interval (MRI) of interest. The load factor definition LF 4 is used solely to compare with the results reported by Gabbai et al. [2].

Table 7: Comparison of current analysis with results in [2]

Analysis	Component or Method	Rigid *None*	Flexible *None*	Flexible *abc*	Flexible *abc, f, d*
Gabbai & Simiu	X^+	1.9	2.3	3.3	3.5
	X^-	2.2	2.7	3.2	3.4
	Y^+	1.9	2.3	2.8	2.8
	Y^-	2.3	2.9	3.4	3.5
Current Analysis	ASCE	1.51	1.66	1.97	2.38
	AeroData Nom1	1.51	1.68	1.97	2.37
	AeroData Nom2	1.51	1.68	1.96	2.38

In reviewing the table, as alluded to earlier, it is noted that the load factors for the rigid case with no uncertainties are significantly different. In the current analysis, this case yields values of 1.51 for all methods when using LF 4, whereas in Gabbai et al. [2] the value ranges from 1.9-2.3. The load factor in the current analysis, 1.51, corresponds to the ratio between the 500-yr wind and the 50-yr wind for a Type 1 distribution, raised to the power of 2. All load factors developed in Gabbai et al. [2] are significantly larger than those developed from this analysis. In addition, the load factors derived using definition LF4 are even higher than those derived using the other definitions.

To further investigate the observation made by Gabbai et al. [2] that the load factor should consider that the wind load for a dynamically sensitive building be proportional to the wind velocity raised to a power higher than 2.0, the load factors for both example buildings for the Rigid and Flexible cases in which there are no uncertainties are shown in Table 8. Additionally, the table shows the wind velocity ratio raised to the power n. As the table indicates, the Rigid case corresponds ideally to the wind velocity ratio squared. The Flexible case corresponds to the wind velocity raised to a power less than 2.5, but greater than 2.0. Thus, the load factor should consider that the wind load for a dynamically sensitive building is proportional to the wind velocity raised to a power higher than 2.0.

Table 8: Comparison of load factors to wind velocity ratio

Case	Building 1	Building 2	Wind Velocity Ratio n = 2	Wind Velocity Ratio n = 2.5
Rigid	1.51	1.51	1.51	1.68
Flexible	1.66	1.64		

To address the concern that the Gabbai et al. [2] factors are much larger than expected, it was assumed that the authors may have used a Type III model for the wind as opposed to the

Type I used in the current analysis. As Table 9 indicates, the use of a Type III model results in even lower load factors than when using a Type I distribution, which does not explain why the Gabbai et al. [2] load factors are high. If a Type III model was indeed used, the load factors should decrease, a trend also observed in Minciarelli, et al. [10].

Table 9: Comparison of wind distribution models

Case	LF 1	LF 2	LF 3	LF 4
Rigid, Type I	1.04	1.04	1.55	1.57
Rigid, Type III	1.01	1.01	1.19	1.19
Flexible, Type I	1.04	1.04	1.71	1.74
Flexible, Type III	1.01	1.01	1.24	1.24

Using a similar definition as in LF 2, in a memorandum Irwin [3] reported load factors for the wind effects when both wind load and dead load were considered (structural) and when only wind load was considered (cladding). The current analysis develops the load factor for cases when only wind load is considered. In Irwin's memorandum, the uncertainties due to frequency and damping were not explicitly included; rather these uncertainties were included in a factor named K_{dyn}. In addition, the load factors by Irwin for code-based loads did include wind directionality effects whereas the current analysis does not include this factor. Furthermore, the load factors developed using wind tunnel methods set the wind directionality factor to 1.0. To compare, the load factors reported by Irwin for non-hurricane zones are summarized in Table 10 along with results from the current analysis that corresponds to these cases.

Table 10: Comparison of load factors reported in [3] with current results

Load Factor	Reliability Index, β	Rigid		Flexible	
		Code Loads	Wind Tunnel	n = 2.5	n = 3.0
Wind + Dead[1]	3.0	1.41 (1.66)	1.39	1.43	1.55
Wind Only[2]	3.0	1.72 (2.02)	1.58	1.65	1.84
Wind Only[2]	2.5	1.51 (1.78)	1.45	–	–
Current Analysis	3.2	1.69*	–	1.85	

NOTE: Values in parentheses are adjusted by 0.85 for wind directionality; * This is for the case using code procedures for Rigid building with all uncertainties; [1] The load factor is defined using both wind and dead loads; [2] The load factor is also defined using just the wind load.

The table suggests that the load factors developed for wind only (cladding) using the code procedure are somewhat higher than those developed in the current analysis as well as those by Ellingwood and Tekie [1]. This difference may be attributed to slightly higher values of CoV used in the analysis in [3]. For the flexible building load factors, there is some variation between the load factors, which is likely due to the difference in the manner in which uncertainties associated with different techniques were defined and propagated. In summary, the analysis performed herein agrees with the analysis performed by both Irwin [3] and Gabbai et al. [2] in that current load factors based on rigid buildings are inadequate for dynamically sensitive buildings. However, the analysis performed by Gabbai et al. [2] suggests significantly larger load factors than either the analysis by Irwin or the analysis presented herein..

DISCUSSION

In Table 11, only the load factors using the definition LF 2 and the Nom1 definition for the AeroData method are displayed. This provides a simpler comparison and illustrates the conclusions of this research. The current load factor of 1.6 accounts for the uncertainties associated with wind in a rigid building, but fails to account for those associated with a dynamically sensitive building. While the effect of uncertainty in the frequency is not significant, the large uncertainty associated with damping increases the corresponding load factor. The recommended load factor for a dynamically sensitive building is around 1.9.

Table 11: Load factors for example buildings using wind load definition LF 2

	Building 1		Building 2	
Case	ASCE	AeroData	ASCE	AeroData
Rigid, *None*	1.00	1.00	1.00	1.00
Flexible, *None*	1.00	1.00	1.00	1.00
Rigid, *abc*	1.58	1.59	1.58	1.58
Flexible, *abc*	1.75	1.72	1.73	1.78
Flexible, *abc, f*	1.75	1.73	1.73	1.77
Flexible, *abc, f, d*	1.89	1.88	1.86	1.98
Flexible, *all*	2.00	2.23	1.97	2.27

NOTE: AeroData values correspond to the Nom1 definition.

It is appropriate to note that the current analysis which delineates the difference between rigid and flexible buildings (1.6 versus 1.9) relies on the building dynamic features remaining constant under the design loading condition. While recent full-scale studies reveal changes in both frequency and damping even at below-design wind speeds, damping in particular is bound to exceed nominal values used in design when buildings experience extreme excursions under design loads. Therefore, this difference between the rigid and flexible may become of academic interest and for all engineering purposes, as alluded to by others, may become unnecessary. In this context, reworking ASCE 7 to design a building for a specified return period (with a load factor of 1) would circumvent the need for load factors that differ based on the level of dynamic sensitivity of buildings to wind.

To that end, further analysis is conducted to the use of a mean recurrence interval (MRI) of 700 to be used in conjunction with a load factor of 1.0. This analysis focused solely on Example Building 1, as described above with the basic wind speed equal to 114 mph as given in [11]. **Error! Reference source not found.** summarizes the differences between using the two wind speeds when using ASCE 7-05, assuming that the importance factor and wind directionality factor are both one. These results correspond to W_n in Equation (6). The increased wind velocity not only increases the pressures, but also affects the gust effect factor for a flexible building, resulting in a significantly higher base shear and maximum displacement.

As a comparison, the load factors using an MRI of 700 were computed in the manner described above for the Example Building 1 and the ASCE Method. These results are shown in Table 13. In addition to the original cases, two additional cases are used: (1) frequency uncertainties and (2) frequency and damping uncertainties. In both these cases the uncertainties associated with the wind are assumed to be encompassed in the higher wind velocity. From this, an appropriate load factor to account for the uncertainty associated with frequency and damping for a flexible building using an MRI of 700 would be 1.4 for loads and 1.7 for displacement.

To further illustrate the effects of these load factors on the overall load and displacement of the Example Building 1, Table 14 compares the base values with the load factors and factored values for base shear and displacement. The current values (MRI = 50, LF = 1.6) are slightly less than those using an MRI of 700 and LF of 1.0, indicating that for rigid buildings, the use of the 700-yr wind velocity would be appropriate. However, neither of these cases includes the uncertainty associated with a dynamically sensitive structure. This study suggests a load factor of 1.9 for an MRI of 50 to account for the uncertainty associated with wind, flexibility, frequency, and damping, which results in a larger load than simply using a higher wind velocity. Thus, utilizing a higher MRI to account for uncertainties instead of the current factored load will increase the overall load but will not take into account the uncertainty associated with dynamically sensitive buildings.

Table 12: Results of Example Building 1 using ASCE 7-05 with MRI of 50 and 700

	MRI = 50	MRI = 700
V	90 mph	114 mph
$\overline{V}_{\bar{z}}$	108 ft/s	137 ft/s
Q	0.778	0.778
R	0.970	1.229
G	1.08	1.204
Base Shear	3750 kip	6680 kip
$\hat{V}_{\bar{z}}$	156 ft/s	198 ft/s
X_{max}	1.65 ft	2.94 ft

NOTE: V is basic wind velocity, $\overline{V}_{\bar{z}}$ is design wind velocity for strength, $\hat{V}_{\bar{z}}$ is design wind velocity for serviceability, Q is background factor, R is resonant factor, G is gust effect factor, and X_{max} is maximum displacement

Table 13: Load factors for Example Building 1 using ASCE method and MRI of 700

	Moment		Load		Displacement	
Case	LF1	LF2	LF1	LF2	LF1	LF2
Rigid, *None*	1.00	1.00	1.00	1.00	1.00	1.00
Flexible, *None*	1.00	1.00	1.00	1.00	1.00	1.00
Rigid, *abc*	1.52	1.59	1.52	1.59	1.52	1.59
Flexible, *abc*	1.65	1.77	1.65	1.77	1.65	1.77
Flexible, *abc, f*	1.65	1.77	1.65	1.77	1.74	1.90
Flexible, *abc, f, d*	1.80	1.96	1.80	1.96	1.99	2.24
Flexible, *f*	1.05	1.05	1.05	1.05	1.31	1.33
Flexible, *f, d*	1.34	1.37	1.34	1.37	1.64	1.73

NOTE: *None* refers to no uncertainties; *abc* refers to wind uncertainties; *f* refers to frequency uncertainties; and *d* refers to damping uncertainties.

Table 14: Comparison of factored loads and displacements using MRI of 50 and 700

	MRI	Description	Value	Load Factor	Factored Value
Base Shear	50	Current	3750 kips	1.6	6000 kips
	50	Suggested	3750 kips	1.9	7125 kips
	700	No uncertainty	6680 kips	1.0	6680 kips
	700	*f, d* uncertainty	6680 kips	1.4	9352 kips
Displacement	50	Current	1.65 ft	1.6	2.64 ft
	50	Suggested	1.65 ft	1.9	3.14 ft
	700	No uncertainty	2.94 ft	1.0	2.94 ft
	700	*f, d* uncertainty	2.94 ft	1.7	5.00 ft

NOTE: *f* refers to frequency uncertainties and *d* refers to damping uncertainties

CONCLUDING REMARKS

The analysis suggests that the current load factor in ASCE 7-05 may not be appropriate for flexible buildings. An appropriate load factor would be around 1.9 to account for the uncertainties associated with flexible buildings that have uncertainties in wind, frequency, and damping. Having made this observation, it is very appropriate to note that the current analysis which delineates this difference between rigid and flexible buildings (1.6 versus 1.9) relies on the building dynamic features remaining constant under the design loading condition. While recent full-scale studies reveal changes in frequency and damping even at below-design wind speeds, damping in particular is bound to exceed nominal values used in design when buildings experience extreme excursions under design loads. Although increasing the mean recurrence interval of the basic wind velocity would concomitantly increase the overall load, the influence of uncertainties associated with dynamically sensitive buildings would still not be addressed. Therefore, rather than evaluating loads for desired limit states by a load factor applied to nominal 50-yr MRI winds, it is more appropriate to estimate loads at higher MRI wind speeds with commensurate values of structural properties and account for uncertainties through an uncertainty factor.

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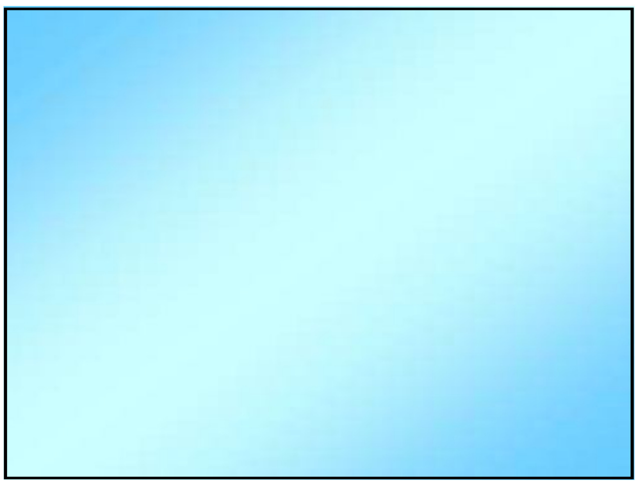


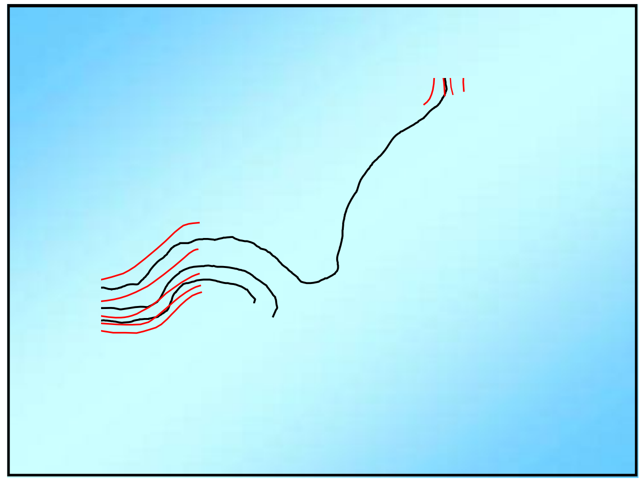

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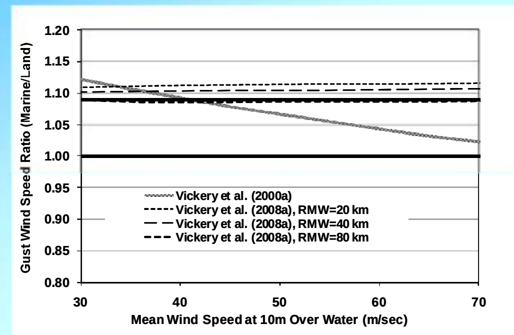

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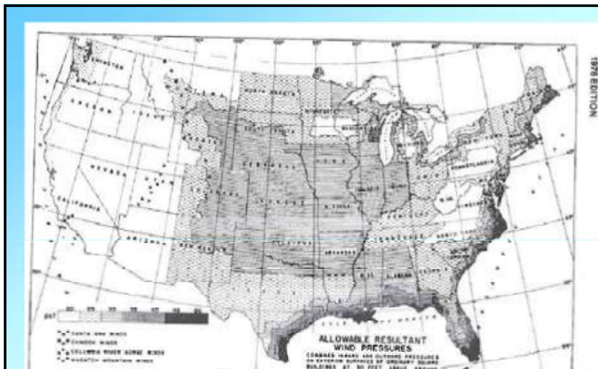

FIGURE NO. 4

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ASCE 7-05 Wind Pressure Equation

- *Involves 48 different variables*
- *Requires solution to 24 equations*

Wind Variable Categories (6 categories, 48 variables)

Building Geometry (5 variables)
$B, L, h, C_{pw}, C_{pw}, z$

Building Properties (3 variables)
I, T, β

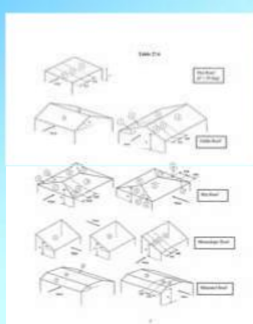
Wind Speed (4 variables)
$V, \bar{V}_{\bar{z}}, q_z, q_h$

Wind Climate (18 variables)
$K_z, G_f, I_{\bar{z}}, \bar{z}, g_Q, g_R, g_v, Q, R, L_{\bar{z}}, R_N, R_h, R_B, R_L, N_1, \eta_h, \eta_L, \eta_B$

Terrain Exposure (8 variables)
$\alpha, z_g, \bar{\alpha}, \bar{b}, c, l, \bar{\varepsilon}, z_{min}$

Site Topographic Features (9 variables)
$K_{zt}, K_1, K_2, K_3, H, L_B, x, \mu, \gamma$

Roof Pressures - MWFRS



Roof Pressure Zones

Roof Shapes:
- Flat
- Gable
- Hip
- Monoslope
- Mansard

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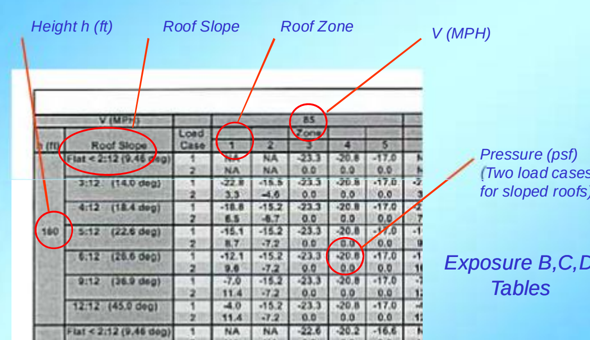
Roof Pressures - MWFRS

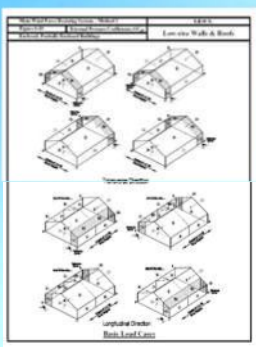


V (MPH)			85				
		Load			Zone		
h (ft)	Roof Slope	Case	1	2	3	4	5
160	Flat < 2:12 (9.46 deg)	1	NA	NA	-23.3	-20.8	-17.0
		2	NA	NA	0.0	0.0	0.0
	3:12 (14.0 deg)	1	-22.8	-15.5	-23.3	-20.8	-17.0
		2	3.3	-4.6	0.0	0.0	0.0
	4:12 (18.4 deg)	1	-18.8	-15.2	-23.3	-20.8	-17.0
		2	6.5	-6.7	0.0	0.0	0.0
	5:12 (22.6 deg)	1	-15.1	-15.2	-23.3	-20.8	-17.0
		2	8.7	-7.2	0.0	0.0	0.0
	6:12 (26.6 deg)	1	-12.1	-15.2	-23.3	-20.8	-17.0
		2	9.6	-7.2	0.0	0.0	0.0
	9:12 (36.9 deg)	1	-7.0	-15.2	-23.3	-20.8	-17.0
		2	11.4	-7.2	0.0	0.0	0.0
	12:12 (45.0 deg)	1	-4.0	-15.2	-23.3	-20.8	-17.0
		2	11.4	-7.2	0.0	0.0	0.0
	Flat < 2:12 (9.46 deg)	1	NA	NA	-22.6	-20.2	-16.6
		2	NA	NA	0.0	0.0	0.0

Exposure B,C,D Tables

Designing for Wind 68

Revisions to Low-Rise Envelope Method



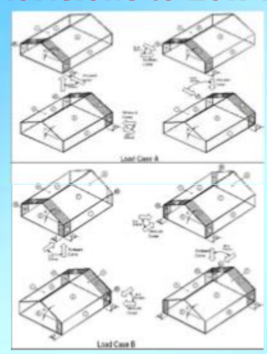
Current Fig. 6-10

Roof Angle θ (degrees)	Building Surface									
	1	2	3	4	5	6	1E	2E	3E	4E
0-5	0.40	-0.69	-0.37	-0.29	-0.45	-0.45	0.61	-1.07	-0.53	-0.43
20	0.53	-0.69	-0.48	-0.43	-0.45	-0.45	0.80	-1.07	-0.69	-0.64
30-45	0.56	0.21	-0.43	-0.37	-0.45	-0.45	0.69	0.27	-0.53	-0.48
90	0.56	0.56	-0.37	-0.37	-0.45	-0.45	0.69	0.69	-0.48	-0.48

Note 7: For the design of the MWFRS providing lateral resistance in a direction parallel to a ridge line or for flat roofs, use θ = 0° and locate the zone 2/3 boundary at the mid-length of the building.

Designing for Wind 79

Revisions to Low-Rise Envelope Method



Revised Fig. 6-10
A return to ASCE 7-98

Roof Angle θ (degrees)	LOAD CASE A — Building Surface							
	1	2	3	4	1E	2E	3E	4E
0-5	0.40	-0.69	-0.37	-0.29	0.61	-1.07	-0.53	-0.43
20	0.53	-0.69	-0.48	-0.43	0.80	-1.07	-0.69	-0.64
30-45	0.56	0.21	-0.43	-0.37	0.69	0.27	-0.53	-0.48
90	0.56	0.56	-0.37	-0.37	0.69	0.69	-0.48	-0.48

Roof Angle θ (degrees)	LOAD CASE B — Building Surface											
	1	2	3	4	5	6	1E	2E	3E	4E	5E	6E
0-90	-0.45	-0.69	-0.37	-0.45	0.40	-0.29	-0.48	-1.07	-0.53	-0.48	0.61	-0.43

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