Journal of Wind Engineering
and Industrial Aerodynamics 77&78 (1998) 673–684

On the formulation of ASCE7-95 gust effect factor

Giovanni Solari[a,*], Ahsan Kareem[b]

[a] *Department of Structural and Geotechnical Engineering, University of Genova, Via Montallegro, 1, 16145 Genova, Italy*

[b] *NatHaz Modeling Laboratory, University of Notre Dame, Notre Dame, IN 46556-0767, USA*

Abstract

Highlights of the formulation of the gust effect factor in recent revisions of the wind load provisions in ASCE7-95 are presented. The revised wind map is based on 50-year peak gust speeds in contrast with fastest mile speeds used in ANSI/ASCE7-93. The concepts of spatial and temporal averages are discussed, and the new gust effect factor (GEF) is introduced with its derivation detailed. Examples to illustrate the use of the new provisions in ASCE7-95 for flexible structures are provided. © 1998 Elsevier Science Ltd. All rights reserved.

Keywords: ASCE7-95 standard; Gust effect factor; Wind load provisions

1. Introduction

In the last routine revision cycle of ASCE7, the second author was invited to join the ASCE Task Committee for preparation of the 1995 provisions. The main task assigned to the author was to simplify the current procedure for evaluating the gust loading factor, as it involved several figures with each figure containing many plots that required interpolation. This task was further complicated by the change in the ASCE7 wind speed from fastest mile to a peak gust 3 s in duration. The second author invited the first author to join him in this task, as he was conducting similar exercises for the Eurocode [1–5]. This paper provides a summary of the development of the current ASCE7-95 [6] gust effect factor, with a summary of the wind speed averaging interval, formulation of the new version of gust loading factor, and examples which demonstrate the use of new procedures.

A new wind speed map based on 3 s gust speeds was introduced to replace the current map based on the fastest mile wind speed. For non-hurricane regions, the

* Corresponding author. E-mail: solari@diseg.unige.it.

PII: S0167-6105(98)00182-2

wind speeds in the new map include only two zones: 85 and 90 mph, thus eliminating the need to interpolate between two contours. In contrast with the database containing 129 stations in the old version, the present map is based on 485 weather stations. It is noteworthy that at some locations, the wind speeds have increased while for others they have decreased. The main reason for the switch is that the US National Weather Service no longer collects fastest mile wind speed data, with other reasons including: (1) 3 s gust speed data are collected at a large number of stations in the country, and (2) it provides a consistent measure of wind speed to be used and understood by design professionals, building code officials, meteorologists, the media, and the public.

2. Gust factor/gust loading factor

This section provides some background discussion of gust factors and gust loading factors [7] to familiarize the reader with these concepts and to develop a better understanding of the gust effect factor introduced in ASCE7-95.

Gustiness in wind introduces dynamic loading effects on the system, which can be examined in terms of a gust loading factor. In order to evaluate the peak response of the system, the peak wind load must be considered. Maximum load effects are due to correlated high pressures over the entire structure in the form of eddies at least of the size of the structure. Eddies of small size compared to the structure impinge successively rather than instantaneously and hence are unable to correlate significant pressures over the whole structure. Eddies which are larger envelop the entire structure and hence are able to cause well-correlated pressures.

Current design codes include the effect of gustiness by factoring up the maximum expected mean-wind effects of a given probability. For very small size structures, a short-duration gust, like 3 s gust, may be used to include the effects of gustiness. This idea may be extended to large systems by evaluating the maximum gust loading on individual components and correlating their occurrence over the structure to find the most probable overall maximum loading.

A prediction of the maximum load effects including amplification due to dynamic oscillation is needed in the design process [8]. The gust loading factor approach relies on gust factors that are based on random vibration theory to translate the dynamic amplification of loading caused by atmospheric turbulence and dynamic sensitivity of the structure into an equivalent static loading. This factor may be used to estimate the expected maximum deviation from mean response.

In ASCE7-93, the preceding concepts were utilized to include the contributions due to wind gustiness and dynamics of structures to ascertain design wind loads [9]. The averaging interval of the design wind (1 min for 60 mph fastest mile) is larger than typical short time gusts; therefore, gust factor/gust loading factor was greater than unity. The departure from unity was determined by the terrain, structural size and its dynamic characteristics. As the averaging interval is increased, the fluctuations in the averaged process are reduced. Similarly, as the structural size increases, the effect of impinging gusts is lessened by spatial averaging. Both time and space averaging play an important role in the development of gust factors. In ASCE7-95, the use of 3 s gusts introduces a new twist, as the design wind already includes the effect of gustiness. Accordingly, for a very small size structure, the new gust factor reduces to nearly unity and further decreases due to spatial averaging resulting from a lack of contemporaneous gust action. In the light of these changes the gust factor/loading factor is renamed “gust effect factor”. In the following section details are provided.

3. Gust effect factors

For the main wind-force resisting systems of buildings and other structures and for components and cladding of open buildings and other structures, ASCE7-95 requires the gust effect factor G to be 0.8 for exposure A and B and 0.85 for exposure C and D. These values were obtained by reducing the actual GEF by a factor of 0.9 to adjust the loads closer to those of ASCE7-93. In the case of flexible buildings and other structures, gust effect factors G_{f} for their main wind-force resisting systems shall be calculated by a rational analysis that incorporates the dynamic properties of the main wind-force resisting system. The commentary to ASCE7-95 provides one such rational method. The GEF is presented for three major categories namely: (1) rigid structures – simplified method; (2) rigid structures – complete analysis; and (3) flexible or dynamically sensitive structures. The following section provides the background used for the formulation of gust effect factors for ASCE7-97.

4. Basic formulation

Consider a rectangular plan building with height h, width b and depth d. The equivalent static wind pressure, i.e. the pressure when statically applied over the building gives rise to the maximum alongwind response, is given by the relationship

$$p = \bar{q}_z \bar{G} C_{\mathrm{p}} \tag{1}$$

where $\bar{q}_z$ is the mean dynamic pressure at height z above the ground surface, $\bar{G}$ is the gust response factor, and C_{p} is the mean pressure coefficient.

The mean dynamic pressure $\bar{q}_z$ assumes the form

$$\bar{q}_z = \frac{1}{2}\rho \bar{V}_z^2, \tag{2}$$

where $\rho = 1.25\ \mathrm{kg/m^3}$ is the average air density and $\bar{V}_z$ is the mean wind velocity at height z.

Using the closed-form solution developed in Ref. [5], the gust response factor $\bar{G}$ is given by

$$\bar{G} = 1 + 2gI_{\bar{z}}\sqrt{Q_0 + D}, \tag{3}$$

$$g = \left\{1.175 + 2\ln\left[\tilde{T}\sqrt{\frac{Q_1 + \tilde{n}_1^2 D}{Q_0 + D}}\right]\right\}^{1/2}, \tag{4}$$

$$Q_0 = \frac{1}{1 + 0.56\tilde{\tau}^{0.74} + 0.29\tilde{L}_0^{0.63}}, \tag{5}$$

$$\frac{Q_1}{Q_0} = \frac{1}{31.25\tilde{\tau}^{1.44} + 1.23\tilde{L}_1^{1.23}}, \tag{6}$$

$$D = \frac{1}{\beta}\frac{5.394N_1}{(1 + 10.302N_1)^{5/3}} C\{0.4N_1\tilde{H}\}C\{0.4N_1\tilde{B}\}[1 + \gamma C\{N_1\tilde{D}\} - \gamma], \tag{7}$$

$$\tilde{L}_0 = 0.5(\tilde{H} + \tilde{B}), \quad \tilde{L}_1 = 0.04(\tilde{H} + \tilde{B}) + 0.92\sqrt{\tilde{H}\tilde{B}}, \tag{8}$$

$$\tilde{H} = \frac{C_z h}{L_{\bar{z}}}, \quad \tilde{B} = \frac{C_x b}{L_{\bar{z}}}, \quad \tilde{D} = \frac{C_y d}{L_{\bar{z}}}, \quad \gamma = \frac{2C_w C_1}{(C_w + C_1)^2}, \tag{9}$$

$$\tilde{\tau} = \frac{\tau\bar{V}_{\bar{z}}}{L_{\bar{z}}}, \quad \tilde{T} = \frac{T\bar{V}_{\bar{z}}}{L_{\bar{z}}}, \quad N_1 = \frac{n_1 L_{\bar{z}}}{\bar{V}_{\bar{z}}}, \tag{10}$$

$$C\{\eta\} = \frac{1}{\eta} - \frac{1}{2\eta^2}(1 - e^{-2\eta}), \quad C\{0\} = 1, \tag{11}$$

where g is the peak response factor, I is the turbulence intensity, L is the integral length scale, $\bar{z} = 0.6h$ is the reference height, C_w and C_1 are the absolute values of the windward and leeward pressure coefficients, respectively, C_x and C_z are the horizontal and vertical exponential decay coefficients in the coherence function, respectively, C_y is the cross-correlation coefficient of pressures acting on the windward and leeward sides of building, τ is the duration of the peak gust, T is the time period over which the wind velocity is averaged, and n_1 and β are the fundamental frequency and the damping ratio, respectively, in the along-wind direction.

Let $\hat{q}_z$ be the peak dynamic pressure described by

$$\hat{q}_z = \tfrac{1}{2}\rho\hat{V}_z^2, \tag{12}$$

$$\hat{V}_z = \bar{V}_z\bar{G}_{vz}, \tag{13}$$

where $\hat{V}_z$ is the peak wind velocity at height z and $\bar{G}_{vz}$ is the gust velocity factor. Following the development in Ref. [4]:

$$\bar{G}_{vz} = 1 + g_v I_v\sqrt{P_0}, \tag{14}$$

$$g_v = \left\{1.175 + 2\ln\left[\tilde{T}\sqrt{\frac{P_1}{P_0}}\right]\right\}^{1/2}, \tag{15}$$

$$P_0 = \frac{1}{1 + 0.56\tilde{\tau}^{0.74}}, \tag{16}$$

$$\frac{P_1}{P_0} = \frac{1}{31.25\tilde{\tau}^{1.44}}, \tag{17}$$

where g_v is the peak velocity factor and I_z is the turbulence intensity. Discussion concerning the derivation of $\bar{G}_{vz}$ as a limiting case of $\bar{G}$ is presented in Refs. [4,5].

Substituting Eqs. (2), (12) and (13) in Eq. (1) and assuming that the turbulence intensity is small, the equivalent static wind pressure may be rewritten as

$$p = \hat{q}_z G C_\mathrm{p}\,, \tag{18}$$

$$G = \frac{\bar{G}}{\bar{G}_{v\bar{z}}}\,, \tag{19}$$

where G is referred to as the gust effect factor. By substituting $\bar{G}_{v\bar{z}}$ for $\bar{G}_{vz}$ in the denominator of Eq. (19) makes G independent of z. Furthermore, this simplification has been shown not to affect the results and has been employed in the formulation given in the Eurocode No. 1.

Following some mathematical manipulation, Eq. (19) reduces to

$$G = \frac{1 + 2gI_{\bar{z}}\sqrt{P_0}\sqrt{Q^2 + R^2}}{1 + 2g_v I_{\bar{z}}\sqrt{P_0}}\,, \tag{20}$$

$$Q^2 = \frac{Q_0}{P_0} = \frac{1 + 0.56\tilde{\tau}^{0.74}}{1 + 0.56\tilde{\tau}^{0.74} + 0.29\tilde{L}_0^{0.63}}\,, \tag{21}$$

$$R^2 = \frac{D}{P_0} = \frac{1 + 0.56\tilde{\tau}^{0.74}}{\beta}\,\frac{5.394 N_1}{(1 + 10.302 N_1)^{5/3}} \times C\{0.4 N_1 \tilde{H}\} C\{0.4 N_1 \tilde{B}\}[1 + \gamma C\{N_1 \tilde{D}\} - \gamma], \tag{22}$$

where Q^2 and R^2 are non-dimensional quantities representing the normalized mean square background and resonant responses, respectively, and P_0 is a coefficient that depends on the duration, τ, of the peak gust.

If a rigid structure is defined as a structure whose resonant response is negligible in comparison with the background response, the assumption of $D \ll Q_0$, $R^2 \ll Q^2$, $\tilde{n}_1 D \ll Q_1$, reduces Eq. (20) to the following

$$G = \frac{1 + 2g_Q I_{\bar{z}}\sqrt{P_0}Q}{1 + 2g_v I_{\bar{z}}\sqrt{P_0}}\,, \tag{23}$$

$$g_\mathrm{Q} = \left\{1.175 + 2\ln\left[\tilde{T}\sqrt{\frac{Q_1}{Q_0}}\right]\right\}^{1/2}, \tag{24}$$

where g_Q is referred to as the quasi-static peak response factor. Moreover, assuming $\tilde{L}_1 = 0$ for a conservative analysis, $Q_1/Q_0 = P_1/P_0$ (Eqs. (6) and (17)), $g_\mathrm{Q} = g_v$ (Eqs. (15) and (24)), Eq. (23) reduces to the following

$$G = \frac{1 + 2g_v I_{\bar{z}}\sqrt{P_0}Q}{1 + 2g_v I_{\bar{z}}\sqrt{P_0}}. \tag{25}$$

Finally, if it is assumed that surface exposed to wind is very small for a rigid point structure, h and b approach zero and $\tilde{L}_0 = 0$ (Eq. (8)) and $Q = 1$ (Eq. (21)). Therefore

$$G = 1. \tag{26}$$

The comparison of Eq. (20) (flexible structures), Eq. (25) (rigid structures), and Eq. (26) (point rigid structures) highlights the physical and mathematical interpretation of the gust effect factor G. If a structure is infinitely rigid and small, the non-contemporaneous action of wind and resonant effects are negligible and $G = 1$ (Eq. (26)), implying that the equivalent static pressure p is simply the product of the peak dynamic pressure and the pressure coefficient (Eq. (18)).

In case of infinitely rigid structures with a finite surface exposed to wind, the non-contemporaneous effects of the maximum pressure field reduce the net load effects. Eq. (25) reproduces this effect through a background response factor $Q < 1$ giving rise to $G < 1$. As a consequence, p diminishes (Eq. (18)) concomitantly with an increase in the structure size. If a structure is flexible and dynamically sensitive, pressure fluctuations excite its fundamental frequency, thus increasing the response. This is taken into account by Eq. (20), where the resonant response factor $R > 0$ increases G for increasing structural flexibility and decreasing damping properties. It is also interesting to point out that there exists a combination of Q and R values which may result in $G = 1$. In this case, the reduction due to non-contemporaneous wind action and the resonant amplification effects balance each other. In the case when the former prevails over the latter, $G < 1$, otherwise, $G > 1$.

5. ASCE7-95 standard

The ASCE7-95 standard provides design wind loads consistent with Eq. (18). The gust effect factors for flexible and rigid structures are derived from Eqs. (20) and (25) based on several scenarios. First of all, $\bar{V}_z$ and $\hat{V}_z$ are considered as mean hourly wind velocities and 3 s peak wind velocities, respectively; therefore, $T = 3600$ s and $\tau = 3$ s. Second, an extensive parametric analysis showed that the ratio $\bar{V}_z/L_z$ falls in the range 0.1–0.3 s^{-1} suggesting that G depends marginally on $\bar{V}_z/L_z$, thus, an average value of $\bar{V}_z/L_z = 0.2\ \mathrm{s}^{-1}$ was used. As a consequence, other parameters take the following values: $\tilde{\tau} = 0.6$, $\tilde{T} = 720$, $P_0 = 0.723$ (Eq. (16)), $P_1/P_0 = 0.0668$ (Eq. (17)).

It follows that the gust effect factor of flexible structures (Eq. (20)) may be rewritten as

$$G = \frac{1 + 1.7 g I_{\bar{z}} \sqrt{Q^2 + R^2}}{1 + 1.7 g_v I_{\bar{z}}} \tag{27}$$

while the gust effect factor of rigid structures (Eq. (25)) reduces to

$$G = \frac{1 + 1.7 g_v I_{\bar{z}} Q}{1 + 1.7 g_v I_{\bar{z}}}, \tag{28}$$

$$I_{\bar{z}} = c(33/\bar{z})^{1/6},$$

where $g_v = 3.41$ (Eq. (15)), $I_{\bar{z}}$ is the turbulence intensity at height $\bar{z}$, where $\bar{z}$ is the equivalent height of the structure ($0.6h$, but not less than $z_{\min}$ listed for each exposure in Table 1), and c is also given in Table 1. The following values of other parameters were used based on values reported in the literature: $C_x = C_z = 11.5$; $C_y = 15.4$; $c_w = 0.8$; and $c_1 = 0.5$ [3,9,10]. Accordingly,

$$Q^2 = \frac{1}{1 + 0.63[(b+h)/L_{\bar{z}}]^{0.63}}, \tag{29}$$

$$R^2 = \frac{1}{\beta} R_n R_h R_b (0.53 + 0.47 R_d), \tag{30}$$

$$R_n = \frac{7.465 N_1}{(1 + 10.302 N_1)^{5/3}}, \tag{31}$$

$$R_l = C\{\eta_l\} \quad (l = h, b, d), \tag{32}$$

$$\eta_h = 4.6 \frac{n_1 h}{\bar{V}_{\bar{z}}}, \quad \eta_b = 4.6 \frac{n_1 b}{\bar{V}_{\bar{z}}}, \quad \eta_d = 15.4 \frac{n_1 d}{\bar{V}_{\bar{z}}}, \tag{33}$$

$$L_{\bar{z}} = l(z/33)^{\varepsilon},$$

for which l and ε are listed in Table 1.

The mean hourly wind speed at height $\bar{z}$, in ft/s is given by

$$\bar{V}_{\bar{z}} = \bar{b}\left(\frac{z}{33}\right)^{\bar{\alpha}} \hat{V}_{\text{ref}},$$

where $\bar{b}$ and $\bar{\alpha}$ are listed in Table 1.

Based on the above expressions, a parametric study suggested that the peak response factor g falls in the range 3.8–4.1. Assuming $g = 4.1$, in order to be conservative, Eqs. (27) and (28) reduce to

$$G = \frac{1 + 7 I_{\bar{z}} \sqrt{Q^2 + R^2}}{1 + 5.8 I_{\bar{z}}}, \tag{34}$$

$$G = \frac{1 + 5.8 I_{\bar{z}} Q}{1 + 5.8 I_{\bar{z}}}. \tag{35}$$

Table 1

Exp	$\hat{\alpha}$	$\hat{b}$	$\bar{\alpha}$	$\bar{b}$	c	l (ft)	ε	$z_{\min}$(ft)[a]
A	1/5	0.64	1/3.0	0.30	0.45	180	1/2.0	60
B	1/7	0.84	1/4.0	0.45	0.30	320	1/3.0	30
C	1/9.5	1.00	1/6.5	0.65	0.20	500	1/5.0	15
D	1/11.5	1.07	1/9.0	0.80	0.15	650	1/8.0	7

[a] $z_{\min}$ is the minimum height used to ensure that the equivalent height $\bar{z}$ is greater of $0.6h$ or $z_{\min}$.

The comparison between sets of equations describing the flexible and rigid cases, i.e., Eqs. (20) and (25); Eqs. (27) and (28); and Eqs. (34) and (35), points to a problem resulting from the transition between flexible and rigid structures. On the one hand, the term $Q^2 + R^2$ smoothly collapses to Q^2 for rigid structures as R tends to zero, but the associated transition from g to g_v introduces a sudden change.

It is noted that the response of an infinitely rigid structure, i.e. a structure with $R = 0$, is characterized by an expected, i.e. effective or average, frequency in the low-frequency range of turbulence. A very small resonant harmonic content of the response is sufficient to raise the expected frequency close to the resonant frequency. In other words, since absolutely rigid structures do not exist in practice, the use of a peak velocity factor $g_v = 3.41$ may not be appropriate. Replacing this estimate by $g_v = 4.1$ is more conservative, which changes Eqs. (34) and (35) to

$$G = \frac{1 + 7I_{\bar{z}}\sqrt{Q^2 + R^2}}{1 + 7I_{\bar{z}}}, \tag{36}$$

$$G = \frac{1 + 7I_{\bar{z}}Q}{1 + 7I_{\bar{z}}}. \tag{37}$$

In ASCE7-95, Eq. (C6-9), Eq. (36) is presented in a slightly different way as given below

$$G = \frac{1 + 2gI_{\bar{z}}\sqrt{Q^2 + R^2}}{1 + 7I_{\bar{z}}}. \tag{38}$$

The recommended value for g is 3.5, which makes Eq. (38) equivalent to Eq. (36).

The gust effect factor values reported in ASCE7-95 are given by reducing actual GEF by a factor of 0.9 to adjust the loads closer to ASCE7-93 values.

The preceding equations contain several parameters related to wind field characteristics, which were quantified through an extensive literature search, the development of the practice in the US of converting the logarithmic law to the power law, and the calibration of the gust velocity profile in codes in order to be consistent with the existing standard ASCE7-93. This exercise took well over a year in order to arrive at the values that were consistent with full-scale data and other parts of the standard.

6. Maximum along-wind displacement

Utilizing the gust effect factor the maximum along-wind displacement $X_{\max}(z)$ as a function of height above the ground surface is given by

$$X_{\max}(z) = \frac{\phi(z)\rho bhC_{f_x}\hat{V}_{\bar{z}}^2}{2m_1(2\pi n_1)^2}KG, \tag{39}$$

where $\phi(z)$ is the fundamental mode shape equal to $(z/h)^{\xi}$, ξ is the mode exponent, ρ is the air density, C_{f_x} is the mean along-wind force coefficient, m_1 is the modal mass defined as: $\int \mu(z)\phi^2(z)\,\mathrm{d}z$, $\mu(z)$, is the mass per unit height, K is given by $(1.65)\hat{\alpha}/(\hat{\alpha}+\xi+1)$; and $\hat{V}_{\bar{z}}$ is the 3 s gust at $\bar{z}$. This can be evaluated by $\hat{V}_{\bar{z}} = \hat{b}(z/33)^{\hat{\alpha}}\hat{V}_{\mathrm{ref}}$ where $\hat{V}_{\mathrm{ref}}$ is the 3 s gust in exposure C at reference height (obtained from the Standard), and $\hat{b}$ and $\hat{a}$ are given in Table 1.

7. RMS along-wind acceleration

The RMS alongwind acceleration $\sigma_{\ddot{X}}(z)$ as a function of height above the ground surface is given by

$$\sigma_{\ddot{X}}(z) = \frac{0.85\phi(z)\rho b h C_{f_x}\bar{V}_{\bar{z}}^2}{m_1} I_{\bar{z}} K R. \tag{40}$$

8. Maximum along-wind acceleration

The maximum along-wind acceleration as a function of height above the ground surface is given by

$$\ddot{X}_{\max}(z) = g_{\ddot{X}}\sigma_{\ddot{X}}(z), \tag{41}$$

$$g_{\ddot{X}} = \sqrt{2\ln(n_1 T)} + \frac{0.5772}{\sqrt{2\ln(n_1 T)}},$$

where T is the length of time over which the minimum acceleration is computed, usually taken to be 3600 s to represent 1 h.

9. Examples

The following examples are presented to illustrate the calculation of the gust effect factor. Table 2 uses the given information to obtain values from Table 1. Table 3

Table 2
Values obtained from Table 1

$z_{\min}$	ε	c	$\bar{b}$	$\bar{\alpha}$	$\hat{b}$	$\hat{\alpha}$	l	C_{f_x}	ξ	Height (h)	Base (b)	Depth (d)
60 ft	0.5	0.45	0.3	0.33	0.64	0.2	180	1.3	1	600 ft	100 ft	100 ft

Table 3
Calculated values

$\hat{V}_{\mathrm{ref}}$	$\bar{z}$	$I_{\bar{z}}$	$L_{\bar{z}}$	Q^2	$\bar{V}_z$	$\hat{V}_{\bar{z}}$
132 ft/s	360 ft	0.302	594.52 ft	0.589	87.83 ft/s	136.24 ft/s
N_1	R_n	η, R_b	η, R_h	η, R_d	R^2	G
1.354	0.111	1.047, 0.555	6.285, 0.146	3.507, 0.245	0.580	1.055
K	m_1	$g_{\ddot{x}}$				
0.502	745400 slugs	3.787				

Table 4
Response estimate

z (ft)	ϕ (z)	$X_{\max}(z)$	RMS Acc. (ft/s^2)	RMS Acc. (milli-g)	Max. Acc. (ft/s^2)	Max. Acc. (milli-g)
0.0	0.00	0.00	0.00	0.00	0.00	0.00
60.0	0.10	0.08	0.02	0.6	0.07	2.2
120.0	0.20	0.16	0.04	1.2	0.14	4.5
180.0	0.30	0.23	0.06	1.8	0.22	6.7
240.0	0.40	0.31	0.08	2.4	0.29	8.9
300.0	0.50	0.39	0.10	3.0	0.36	11.2
360.0	0.60	0.47	0.11	3.5	0.43	13.4
420.0	0.70	0.55	0.13	4.1	0.50	15.7
480.0	0.80	0.63	0.15	4.7	0.58	17.9
540.0	0.90	0.70	0.17	5.3	0.65	20.1
600.0	1.00	0.78	0.19	5.9	0.72	22.4

presents the calculated values, while Table 4 summarizes the calculated displacements and accelerations as a function of the height, z.

Given values:
basic wind speed at reference height in exposure $C = 90$ mph (from the Standard)
type of exposure $= A$ (Location of the building)
building height $h = 600$ ft
building width $b = 100$ ft
building depth $d = 100$ ft
building natural frequency $n_1 = 0.2$ Hz
damping ratio $\beta = 0.01$ (critical damping ratio)
alongwind force coefficient $C_{f_x} = 1.3$
mode exponent $\xi = 1.0$ (linear mode shape)
building density $= 12$ lb/cu ft $= 0.3727$ slugs/cu ft
air density $\rho = 0.0024$ slugs/cu ft

A second example concerns a 598 ft tall reinforced concrete chimney whose fundamental frequency and damping ratio are equal to 0.48 Hz and 1%, respectively. The chimney diameter varies between 37.64 ft at the top to 53.83 ft at the base. It is located in exposure C in 90 mph wind speed region. The calculated GEF and maximum top displacement is equal to 0.978 and 0.29 ft, respectively. When the same chimney is moved to a coastal hurricane region with design wind of 140 mph the gust effect factor is increased to 1.067 as the higher wind speed adds to gustiness in the wind and the associated top displacement increases accordingly to 0.76 ft.

A comparison of ASCE7 predictions with other international codes and wind tunnel data can be found in Ref. [11].

10. Conclusions

ASCE7-95 presents a state-of-the art procedure for calculating gust effect factors which is based on a consistent formulation and quantified using an extensive literature search and calibration parameters related to the wind field characteristics. The current procedure is free from cumbersome charts needed to compute and/or interpolate values of parameters associated with the gust factor, as was the case with in ASCE7-93 and its predecessor versions. The gust effect factor is extended to include a procedure for evaluating maximum structural displacement and acceleration. This provision has been explicitly included for the first time in ASCE standard. For the next revision of ASCE-7, further modifications to the gust effect factor expression have been proposed, e.g. the introduction of separate peak factors for wind velocity and background and resonant responses. Complete details will be presented in a future publication.

Acknowledgements

During the preparation of this manuscript the author was supported in part by NSF grants CMS-9402196 and CMS 95-03779. T. Kijewski's assistance in the preparation of this manuscript is greatly appreciated.

References

[1] Basis of design and actions on structures, Eurocode No. 1, Commission of the European Communities, Brussels, Belgium, 1994.
[2] G. Solari, Alongwind response estimation: closed form solution, J. Struct. Div. ASCE 108 (1) (1982) 225–244.
[3] G. Solari, Turbulence modeling for gust loading, J. Struct. Eng. ASCE 113 (7) (1987) 1550–1569.
[4] G. Solari, Gust buffeting. I: peak wind velocity and equivalent pressure, J. Struct. Eng. ASCE 119 (2) (1993) 365–382.
[5] G. Solari, Gust buffeting II: dynamic alongwind response, J. Struct. Eng. ASCE 119 (2) (1993) 383–398.
[6] ASCE 7-95, American society of civil engineers minimum design loads for buildings and other structures, ASCE, NY, 1995.

[7] K. Gurley, A. Kareem, Gust Loading Factors for Tension Leg Platforms, Appl. Ocean Res. 15 (3) (1993).

[8] A. Kareem, Dynamic Response of High-rise Buildings to Stochastic Wind Loads, J. Wind Eng. Ind. Aerodyn. 41–44 (1992) 1101–1112.

[9] J. Vellozzi, H. Cohen, Gust response factors, J. Struct. Div. ASCE 97 (6) (1968) 1295–1313.

[10] E. Simiu, Equivalent static wind loads for tall building design, J. Struct. Div. ASCE 102 (4) (1976) 719–737.

[11] T. Kijewski, A. Kareem, Dynamic wind effects provisions in codes and standards and wind tunnel data: a comparative study, 8th US Conf. on Wind Engineering CD ROM, Baltimore, MD, 1997.