# Gust loading factors for design applications

Yin Zhou
*NatHaz Modeling Laboratory, Department of Civil Engineering and Geological Sciences, University of Notre Dame, Notre Dame, IN 46556-0767, USA. Email: Yzhou@nd.edu*

Ahsan Kareem
*NatHaz Modeling Laboratory, Department of Civil Engineering and Geological Sciences, University of Notre Dame, Notre Dame, IN 46556-0767, USA*

Ming Gu
*Department of Bridge Engineering, Tongji University, Shanghai, 200092, P. R. China*

ABSTRACT: Wind loads on structures under the buffeting action of wind gusts have been treated traditionally by the "gust loading factor" (GLF) method in most major codes and standards around the world. The equivalent static wind loading used for design is equal to the mean wind force multiplied by the GLF. Although the traditional GLF method can ensure an accurate estimation of the displacement response, it fails to provide a reliable estimate of some other response components. In order to overcome this shortcoming, a more realistic procedure for design loads is proposed in this paper. The procedure developed herein employs a base moment GLF rather than the traditional displacement based GLF. The expected extreme base moment is computed by multiplying the mean base moment by the proposed GLF. The extreme base moment is then distributed to each floor in terms of the floor load in a format very similar to the one used to distribute the base shear in the current design practice for earthquakes. Numerical examples show the convenience in use and the accuracy of the proposed procedure over the traditional approach.

## 1 INTRODUCTION

The diversity of structures that are sensitive to the effects of wind coupled with the increasing need to improve the performance of constructed facilities has placed a growing importance on the problem of wind effects on structures. Most structures are designed based on the recommended loads given in codes and standards. Therefore, in order to enhance the performance of structures under extreme wind conditions, it is important to visit the wind load recommendations in codes and standards. Generally, the wind codes and standards recommend an equivalent static wind loading for design. With the equivalent wind loading, the design engineers can obtain an accurate estimate of wind-induced effects through a simple static analysis. The equivalent static wind loading ensures the consistency of the results obtained from the static analysis with the actual wind-induced responses, which involve complicated wind-structure-interactions requiring wind tunnel tests or other alternative means familiar only to specialists.

Traditionally, the wind loading on structures has been estimated by using the GLF approach (Davenport 1967). According to the GLF method, the equivalent wind loading is equal to the mean wind force multiplying by a GLF. The GLF accounts for the dynamics of wind fluctuations and the load amplification introduced by the building dynamics. In this regard, the overall concept of GLF has provided design engineers a convenient vehicle to implement recent research findings in design and practice. Owing to its simplicity, the GLF method has received widespread acceptance around the world and is employed in wind loading codes and standards of almost all the major countries. The codes and standards include provisions for the design of low-rise to high-rise buildings, bridges, towers and other structures under the buffeting action of wind. Some of the major codes and standards are the NBC-1995 (NRCC 1996), AS1170.2-89 (1989), ASCE7-95 (1995), RLB-AIJ-1993 (1996), Eurocode (ENV 1994).

Notwithstanding its advantages, the GLF method has some shortcomings in the following two situations. The first is in the use of this method for structures that are relatively long, tall and flexible. Although the gust factor is originally defined for any load effect, in reality, it is based on the displacement response, i.e. the gust factor is essentially the ratio between the peak and the mean displacement response and the factor is indiscriminately used for any other response. This tacitly implies that the gust factor for any structural response is the same as the displacement response factor. Because only the dynamic and mean displacement responses in the first mode are included in the derivation, the gust factor is constant for a given structure. When the constant gust factor is used to the peak equivalent wind load, an equivalent wind load whose distribution is the same as that of the mean wind load is obtained. Obviously, this is in disagreement with the common understanding of the equivalent wind load on tall, long and flexible structures. For this kind of structures, the resonant response is dominant and the distribution of the equivalent wind load is, therefore, a function of the mass distribution and the mode shape. In this light, it is quite reasonable to examine the equivalent wind load by the traditional GLF method to ensure that the maximum load effects established are truly representative of the actual values. Secondly, as others have noted that the GLF method is not valid if either the mean wind force or the mean response is zero. An example of this kind is a suspended bridge or a cantilever bridge with asymmetrical first mode shape. Therefore, the mean displacement response in the first mode is equal to zero whether or not the mean wind load is zero.

Zhou et al. (1998b) examined the along-wind loading on tall buildings utilizing the GLF in the light of various wind-induced response components. They have reported that the GLF method provides an accurate assessment of the structural displacement, but results in less accurate estimation of other response quantities, for example, the base shear force. This observation is based on the fact the GLF is formulated using the displacement response; therefore, it fails to provide accurate prediction of other response components.

In light of the above, this paper aims at developing a more realistic procedure for design. The proposed procedure employs a base moment gust-loading factor, referred to as MGLF in the remaining discussion. The MGLF is formulated for tall structures. The expected extreme base moment is computed from the mean base moment multiplied by the MGLF. The extreme base moment is then distributed to other floors in a manner very similar to the one used in the current design practice for earthquake action. Furthermore, simple relationship between the proposed MGLF and traditional displacement GLF (DGLF) is determined, which makes it possible to use the proposed approach while still utilizing the existing database. A numerical example is given to demonstrate the convenience and the accuracy of the proposed procedure in comparison with the traditional approach.

## 2 TRADITIONAL DISPLACEMENT GUST FACTOR METHOD

The DGLF is defined based on the displacement response (Davenport 1967)

$$G_Y = \hat{Y}(z)/\bar{Y}(z) \tag{1}$$

where $G_Y$ = the displacement GLF or DGLF; $\hat{Y}(z)$= peak displacement response, when assuming a stationary Gaussian process

$$\hat{Y}(z) = \bar{Y}(z) + g_Y \sigma_Y \tag{2}$$

in which $g_Y$ = displacement peak factor; $\sigma_Y$ = RMS displacement; $\bar{Y}(z)$ = mean displacement response.

Accordingly, the DGLF is

$$G_Y = 1 + g_Y \sigma_Y(z)/\bar{Y}(z) \tag{3}$$

which is dependent on $g_Y, \sigma_Y, \bar{Y}$. These quantities are separately derived in the following.

By invoking the quasi-steady and strip theories, the wind force is given by

$$P(z,t) = 1/2\,\rho C_D W(\bar{U}(z) + u(z,t))^2 \tag{4}$$

where $W$ = the width of the building normal to the oncoming wind; $C_D$ = drag coefficient. By neglecting the contribution of the quadratic term (this effect has been considered elsewhere, e.g., Kareem et al. 1998, Zhou et al. 1999), one can obtain the mean wind load and the fluctuating wind load on the structure, respectively, as

$$\bar{P}(z) = 1/2\,\rho C_D W \bar{U}_H^2 (z/H)^{2\alpha} = \bar{P}_H (z/H)^{2\alpha} \tag{5}$$

$$p(z,t) = \rho C_D W \bar{U}_H u(z,t)(z/H)^{\alpha} \tag{6}$$

in which $\alpha$ = the exponent of mean wind velocity profile.

The mean structural displacement can be well approximated by the first mode mean displacement response

$$\bar{Y}(z) = \frac{\bar{P}^*}{k^*}\varphi(z) \tag{7}$$

where $\bar{P}^* = \int_0^H \bar{P}(z)\varphi(z)dz$ = the mean generalized wind load; $k^* = (2\pi f_1)^2 m^*$ = generalized stiffness; $m^* = \int_0^H m(z)\varphi^2(z)dz$ = generalized mass in the first mode; $\varphi(z) = (z/H)^{\beta}$ = the mode shape; $f_1$ = natural frequency of the first mode; $H$ = the height of the structure.

Using fundamentals of random vibration analysis, one can derive the expected values of the extreme displacement. Since Eq. 6 shows a linear relationship between the fluctuating wind velocity and the resulting wind load. Therefore, the wind loading process is also treated as Gaussian. Considering the fundamental mode of vibration of a structure, the governing equation of motion is

$$m^* \ddot{x}(t) + c^* \dot{x}(t) + k^* x(t) = p^*(t) \quad (8)$$

where $c^* = 2z\sqrt{k^* m^*}$ ; $p^*(t) = \int_0^H p(z,t)j(z)dz$ = the generalized fluctuating wind load; $z$ = the critical damping ratio. Under random loading, the response power spectral density is given by

$$S_x(f) = \frac{S_{p^*}(f)}{k^{*2}}\left|H(f)\right|^2 \quad (9)$$

where $S_x(f)$ and $S_{p^*}(f)$ = the PSD of the generalized displacement response and the generalized fluctuating wind load, respectively; and $\left|H(f)\right|^2$ = the transfer function of the structure

$$\left|H(f)\right|^2 = \frac{1}{[1-(f/f_1)^2]^2 + (2zf/f_1)^2} \quad (10)$$

The RMS displacement at any height is given by

$$s_Y(z) = s_x \cdot j(z) \quad (11)$$

or in a non-dimensional form

$$\frac{s_Y}{\overline{Y}} = \frac{\left(\int_0^\infty S_{p^*}(f)\left|H(f)\right|^2 df\right)^{1/2}}{\overline{P}^*} \quad (12)$$

All traditional formulations of GLF are based on the above expressions, each entailing different simplification. Formulations for large structures involve transformation of the wind fluctuating to pressure fluctuations in which the lack of correlation of turbulent wind over the projected area of the structure is included. Also, the correlation between the windward and leeward faces is included in some codes and ignored in others (Davenport 1967; Kareem 1986; Simiu & Scanlan 1996). The variation of turbulence intensity is either based on a wind spectrum that is independent of or dependent on height (Davenport 1967; Kareem 1985; Simiu & Scanlan 1996). These details lead to differences in the prediction of gust factors derived from different GLF formulations. Typically, Eq. 3 is recast in the following form

$$G_Y = 1 + 2I_h g_Y \sqrt{B+R} = 1 + 2I_h g_Y \sqrt{B + SE/z} \quad (13)$$

where $B, R$ = resonant and background response components, respectively; $S$ = size reduction factor; $E$ = gust energy factor; $I_h$ = turbulence intensity at the reference height $h$.

However, there has been some inconsistency regarding the evaluation of the peak response or the displacement peak factor. Utilizing the statistics ( Cartwright et al. 1956; Davenport 1964) one can get accurate estimation of the peak factor that usually involves computation of the higher-order moments. But this operation is not convenient enough to be included in a design guideline. One convenient format is

$$G_Y = 1 + 2I_h \sqrt{g_B^2 B + g_R^2 R} \quad (14)$$

in which $g_B, g_R$ = background and resonant peak factor, respectively. Usually, $g_B$ can be set equal to $g_u$, wind velocity peak factor; and

$$g_R = \sqrt{2\ln(f_1 T)} + \frac{0.5772}{\sqrt{2\ln(f_1 T)}} \quad (15)$$

where $T$ = observation time.

The form of DGLF in Eq. 14 is being included in the revised ASCE7. $B, E, S$ have been given in closed form or presented in a graphical form in current codes and standards (Solari & Kareem 1998). Rewriting Eq. 19 as

$$G_Y = 1 + \sqrt{G_{YB}^2 + G_{YR}^2} \quad (16)$$

$$G_{YB} = 2I_h g_u \sqrt{B} \quad (17)$$

$$G_{YR} = 2I_h g_R \sqrt{R} \quad (18)$$

where $G_{YB}, G_{YR}$ = background and resonant components of DGLF, respectively.

Based on the assumption of a linear-elastic structure, the traditional DGLF method defines the equivalent wind loading in the following way

$$\hat{P}(z) = G_Y \overline{P}(z) \quad (19)$$

where $\hat{P}(z)$ = the expected extreme equivalent wind loading. Correspondingly, the background and resonant equivalent static wind loading components defined in the DGLF method are given by

$$\hat{P}_{B-2a}(z) = G_{YB}\overline{P}(z) = G_{YB}\overline{P}_H (z/H)^{2a} \quad (20)$$

$$\hat{P}_{R-2a}(z) = G_{YR}\overline{P}(z) = G_{YR}\overline{P}_H (z/H)^{2a} \quad (21)$$

Except for the mean wind force, the peak wind loading components given by Eqs. 20 & 21 depart from the actual values. Therefore, the associated wind-induced response estimates may deviate from the accurate values. Detailed discussion on this topic can be found in Zhou et al. (1998a, b). The next section will provide a brief review of the resonant component.

## 3 CRITICAL REVIEW OF TRADITIONAL GLF METHOD

The resonant equivalent wind loading can be represented by the inertial force. When assuming a uniform mass distribution, $m(z) = m_0$, the actual peak resonant equivalent wind loading is

$$P_{R-b}(z) = g_R m_0 (2\pi f_1)^2 \sigma_R(z)$$

$$= G_{YR} m_0 (2\pi f_1)^2 \overline{P}^* / k^* \varphi(z) = G_{YR} \overline{P}_H \frac{1+2\beta}{1+2\alpha+\beta} (\frac{z}{H})^{\beta} \quad (22)$$

Note the difference between the distributions of the resonant equivalent wind loading given by the DGLF method (Eq. 21), and of the actual value given in Eq. 22. Clearly, the DGLF approach will result in an unrealistic prediction of the distribution of the resonant load effects. Assuming that the influence function of a response can be expressed as

$$i(z) = i_c (z/H)^{\beta_0} \quad (23)$$

where $i_c, \beta_0$ are constants. For the base shear force and the base moment, the preceding coefficients are $i_c = 1, \beta_0 = 0$ and $i_c = H, \beta_0 = 1$, respectively. Accordingly, the structural response based on this influence function is given by

$$\hat{r}_{R-2a} = \int_0^H \hat{P}_{R-2a}(z) i(z) dz = \frac{G_{YR} \overline{P}_H H i_c}{1+2\alpha+\beta_0} \quad (24)$$

while the actual value is

$$\hat{r}_{R-b} = \int_0^H \hat{P}_{R-b}(z) i(z) dz = \frac{G_{YR} \overline{P}_H H i_c}{1+2\alpha+\beta} \cdot \frac{1+2\beta}{1+\beta+\beta_0} \quad (25)$$

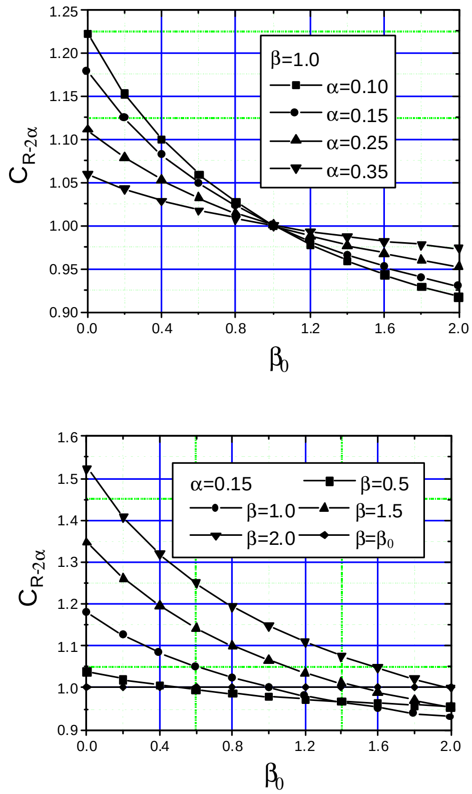
Now, the ratio between the response given by the DGLF method and the actual value is

$$C_{R-2a} = \hat{r}_{R-2a} / \hat{r}_{R-b} = \frac{(1+2\alpha+\beta)(1+\beta+\beta_0)}{(1+2\alpha+\beta_0)(1+2\beta)} \quad (26)$$

The sensitivity of the above factor to other major parameters is illustrated in Fig. 1. In Fig. 1(a), $\beta$ is set equal to unity, which implies a linear structural mode shape. The variation in the factor in Eq. 26 is shown for different value of $\beta_0$ (Eq. 23) and $\alpha$, the wind velocity exponent. The upper and lower values of the factor, $C_{R-2a}$, are 1.23 and 0.92, respectively, suggesting that indeed the prediction based on DGLF do depart from actual values. This is particular true for the base shear force case ($\beta_0 = 0$) when $\alpha = 0.1$. Buildings on the oceanfront lots could be influenced significantly by this discrepancy in the predicted base shear. In Fig. 1b, $\alpha$ is set equal to 0.15 and both $\beta$ and $\beta_0$ are varied. It is noted that $C_{R-2a}$ is more sensitive to the mode shape exponent than it is to $\alpha$. For $\beta$ varying between 0.5~2.0, this factor varies between 0.93~1.52.

## 4 LLUSTRATIVE EXAMPLE I

An example tall building is used for illustration, H × W × D = 200 × 50 × 40m; $m_0 = 234{,}275$ kg/m; $f_1 =$




a)

b)

Figure 1. Resonant response deviation factor

0.2 Hz; and $\zeta = 0.01$. The wind conditions are: $\alpha = 0.15$; $\overline{U}_{10} = 30 m/s$; $\sigma_u / \overline{U}_{10} = 0.2$; and the spectrum given by Davenport (1967).

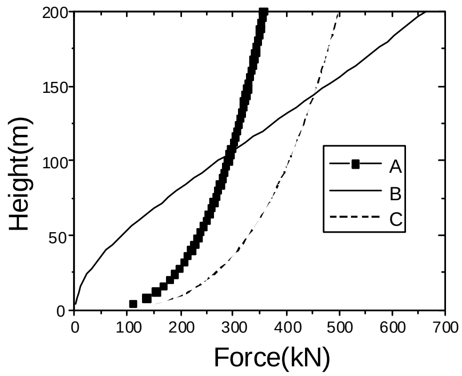
The equivalent wind loading and its load effects are illustrated in Fig. 2. It is noted that the shear force distribution predicted by the DGLF clearly deviates from the actual distribution. As on can expect, the displacement response is predicted accurately.

For this example case, the gust effect factors concerning the base shear force, base moment, as well as the first mode displacement responses are listed in the Table 1. The actual gust effect factor is different depending on the response component concerned. However, the gust effect factor obtained from the DGLF method for all responses is the same. For the base shear force in this example, the gust effect factor by the DGLF method is 12% more than the actual value.

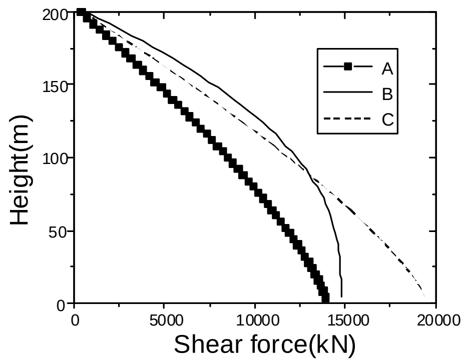
Similarly, an examination of the background response component can be performed as given in Zhou et al. (1998b), but it is not discussed here for brevity.

Table 1. Gust effect factors

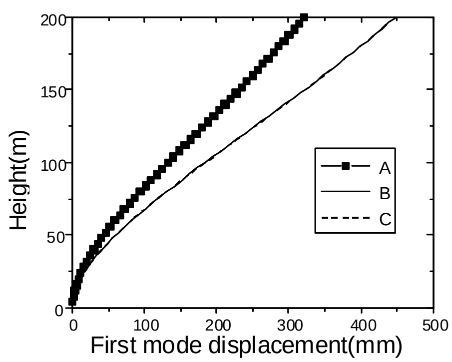
| | Base shear | Base moment | displacement |
|---|---|---|---|
| Actual | 2.29 | 2.51 | 2.57 |
| DGLF | 2.57 | 2.57 | 2.57 |




(a)




(b)




(c)

Figure 2. Resonant equivalent wind loads, shear and displacement response
A: The mean wind force; B: The resonant equivalent wind load; C: The resonant equivalent wind load obtained by the DGLF method

## 5 BASE MOMENT GUST LOADING FACTOR

For the base moment, considering a stationary Gaussian process, we have (Zhou et al. 1999)

$$G_{\boldsymbol{M}} = \hat{\boldsymbol{M}} / \overline{M} \tag{27}$$

$$\hat{\boldsymbol{M}} = \overline{M} + g_{\boldsymbol{M}} s_{\boldsymbol{M}} \tag{28}$$

$$G_{\boldsymbol{M}} = 1 + g_{\boldsymbol{M}} s_{\boldsymbol{M}} / \overline{M} \tag{29}$$

$$s_{\boldsymbol{M}}^2 = \int_0^\infty S_{\boldsymbol{M}}(f) df \tag{30}$$

Where $G_{\boldsymbol{M}}$ = the gust loading factor for base moment; $\overline{M}$ = mean base moment; $\hat{\boldsymbol{M}}$ = expected extreme base moment; and $s_{\boldsymbol{M}}$ = RMS base moment.

To evaluate the RMS value of the equivalent base moment, let us return to Eq. 8. With the PSD of the displacement response, Eq. 9, the PSD of the generalized equivalent, or alternatively response, wind loading can be computed as

$$S_{\boldsymbol{p}^*}(f) = k^{*2} S_x(f) = S_{p^*}(f) \left| H(f) \right|^2 \tag{31}$$

in which the generalized equivalent wind loading is

$$\boldsymbol{p}^* = \int_0^H \boldsymbol{p}(z,t) \boldsymbol{j}(z) dz \tag{32}$$

Note that we use the same form but in boldface to differentiate the response loads from the applied.

The distribution of the response loading along the height, $\boldsymbol{p}(z,t)$, is not the same as that of the mean wind load. Zhou et al. (1998b) have addressed this subject. Anyway, when assuming a linear mode shape, as generally used in most of the current literature, the following relationships are valid for both the applied wind load and the response wind loading

$$p^* = M / H \tag{33}$$

$$\boldsymbol{p}^* = \boldsymbol{M} / H \tag{34}$$

where $M, \boldsymbol{M}$ = respectively, the base moment of externally applied wind force and the equivalent base moment. Substituting these into Eq. 31, one can get

$$S_{\boldsymbol{M}}(f) = S_M(f) \left| H(f) \right|^2 \tag{35}$$

This very helpful relationship has been well documented by Boggs & Peterka (1989) and others and is actually the theoretical basis for the high frequency base balance technique. Obviously, it is exact when the structure is very rigid or for the background response, in which case the mechanical admittance is equal to unity, the two items are the same. The above relationship is also exact for structures with a linear mode shape. However, these conclusions can not be simply extended to actual buildings with non-linear mode shapes. The effects of non-linear mode shapes have been discussed by Boggs & Peterka (1989) and Zhou et al. (1998c, d; 1999), respectively. Although the effect of the non-linear mode shapes cannot be simply neglected, fortunately, in the case of base moment, it has an insignificant effect.

Similarly, the RMS equivalent base moment is given by

$$s_{\boldsymbol{M}} / \overline{M} = \left( \int_0^\infty S_M(f) \left| H(f) \right|^2 df \right)^{1/2} / \overline{M} \tag{36}$$

and the MGLF can be written as (Zhou et al. 1999)

$$G_{\boldsymbol{M}} = 1 + 2 I_h g_{\boldsymbol{M}} \sqrt{\boldsymbol{B} + \boldsymbol{R}} = 1 + 2 I_h \sqrt{g_u^2 \boldsymbol{B} + g_R^2 \boldsymbol{R}} \tag{37}$$

A very simple relationship between the MGLF and the DGLF can be pursued by introducing the following relationships when considering a structure with a linear mode shape, which is usually the subject addressed in most of the literature

$$\frac{s_Y}{\overline{Y}} = \frac{s_{\boldsymbol{P}^*} / k^*}{\overline{P}^* / k^*} = \frac{s_{\boldsymbol{P}^*}}{\overline{P}^*} = \frac{s_{\boldsymbol{M}}}{\overline{M}} \tag{38}$$

The preceding equation suggests that the MGLF is exactly the same as the DGLF used in the current codes and standards.

## 6 PROCEDURE FOR EQUIVALENT WIND LOADING

Based on the preceding discussions, the following procedure is suggested for design applications:

(1). Mean wind force

$$\bar{P}_i = \left(\tfrac{1}{2}\rho\bar{U}_H^2 (Z_i/H)^{2\alpha}\right)C_D\left(B\Delta H_i\right) \tag{39}$$

where $Z_i$ = the elevation of the $i$th floor above the ground; $\Delta H_i = Z_i - Z_{i-1}$.

(2). Mean base moment

$$\bar{M} = \sum_{i=1}^{N}\bar{P}_i Z_i \tag{40}$$

where $N$ = the number of floors of the structure.

(3). From current codes and standards, one can obtain the $B, S, E$, and compute the GLF

$$G_{MB} = G_{YB} = 2g_u I_h\sqrt{B} \tag{41}$$

$$G_{MR} = G_{YR} = 2g_R I_h\sqrt{SE/\zeta} \tag{42}$$

$$G_M = 1+\sqrt{G_{MB}^2 + G_{MR}^2} \tag{43}$$

(4). Compute the resonant peak base moment

$$\hat{M}_R = G_{MR}\bar{M} \tag{44}$$

(5). Compute the peak equivalent wind loading. For the resonant component

$$\hat{P}_{Ri} = \frac{m_i\phi_i}{\sum m_i\phi_i Z_i}\hat{M}_R \tag{45}$$

Background component

$$\hat{P}_{Bi} = G_{MB}\bar{P}_i \tag{46}$$

Equation 45 provides the actual resonant equivalent static wind loading for situations considered in codes and standards, and slightly conservative results for the situations departing from those in the codes; while Eq. 46 provides a good approximation of the background equivalent wind loading, resulting in error of response generally less than 5% (Zhou et al. 1998b).

(6). Compute the background and resonant responses using simple static analysis by applying the above equivalent wind loading. These response components are then combined to obtain the resultant response using an SRSS combination rule, and superimposed on the mean wind-induced response to obtain the expected extreme response (Zhou et al. 1999).

It is important to note that the MGLF has several advantages over DGLF, for example, (i) It provides the equivalent wind loading in a realistic manner. This is the most important feature of the proposed procedure; (ii) It uses the existing database, which permits a smooth transition from DGLF to MDGLF; (iii) It is formulated in a form that is familiar to most design engineers; (iv) The application range has been extended to accommodate the non-linear mode shape and non-uniform mass distribution; (v) It provides the opportunity for a generalized formulation and a consistent transition of response predictions for structures from relatively rigid to flexible; (vi) It makes possible to use unified expressions for both theoretical analysis and experimental procedures Zhou et al. (1999).

## 7 NUMERICAL EXAMPLE II

An illustrative example is used to highlight the presentation in the last section. The example building is similar to example I, except $f_1$ = 0.22 Hz, $m(z) = m_0(1-\lambda(z/H))$, $m_0$ = 5.5 × $10^5$ kg/m, $\phi_1(z) = (z/H)^{\beta}$. Four cases are considered: (1) $\beta = 1.0$, $\lambda = 0.0$; (2) $\beta = 1.6$, $\lambda = 0.0$; (3) $\beta = 1.0$, $\lambda = 0.2$; (4) $\beta = 1.6$, $\lambda = 0.2$. The wind condition remains the same as in example I.

The wind-loading components are plotted in Fig. 3. Since the traditional DGLF method does not differentiate among these cases, it gives the same value in each case. The mean and background wind loading components by the MGLF method are the same as those given by the DGLF method, but the resonant component is different. Even for case 1, the wind loading given by the MGLF method, a linear distribution, is clearly different from that given by the traditional method, which follows a $2\alpha$ exponent law.

Due to different distributions of wind loading, different responses are expected. Comparison of GLFs for different responses by the two procedures are listed in Table 2. The items in brackets are the ratio between the MGLF and the corresponding DGLF.

Adopting a simple relationship between the extreme equivalent wind loading and the mean wind force, the DGLF method gets a uniform GLF for all non-zero responses and for all four cases.

For case 1, the MGLF is, as expected, equal to DGLF. A non-linear mode shape (case 2), or non-uniform mass (case 3) or both (case 4) does influence the MGLF. But the effect of non-uniform mass is very small and the effect of non-linear mode shape on the resonant MGLF is 2.2% and the resultant MGLF 0.8%, which is almost negligible. For case 4, a small error resulted in comparison with case 2.

Nevertheless, since the MGLF procedure determines the equivalent wind loading in a more realistic manner than the DGLF method, obviously, the wind loads obtained by the DGLF method may differ from those by MGLF approach. Accordingly, the resulting response estimates will be impacted. Taking the base shear force as an example, the resonant base shear force by the MGLF procedure is 15% less than that obtained by the DGLF method for case 1, whereas, the overall extreme base shear is 5.4% less than the value obtained from DGLF analysis. For case 2, these respective errors increase to 23.2% and 8.3%. Although for the base shear force, the effect is on the safe side, this conclusion cannot simply be applied to other responses. Due to different distributions of wind loading, the deviation of responses by the DGLF method will depend on the response and the structure being concerned. For example, the resonant equivalent wind loading on the top floor by the DGLF method is 33% (350 / 520 *kN*) less than the actual value, or the value given by the MGLF procedure for case 2.

## 8 CONCLUDING REMARKS

The equivalent static wind loading on structures utilizing the traditional “gust loading factor” method usually differs from the actual loads, and consequently leads to unfavorable estimates of the associated wind-induced response. In this paper, a new procedure for determining the equivalent wind loading, which employs a base moment gust-loading factor, is proposed. The expected extreme base moment is obtained by multiplying the mean base moment by the proposed base moment gust-loading factor. The expected extreme base moment is used to establish loads at each floors in a manner similar to the one used in the current design practice for earthquake action. Under the conditions generally implied in the current codes and standards, the proposed MGLF is numerically the same as the traditional DGLF.

## 9 ACKNOWLEGEMENT

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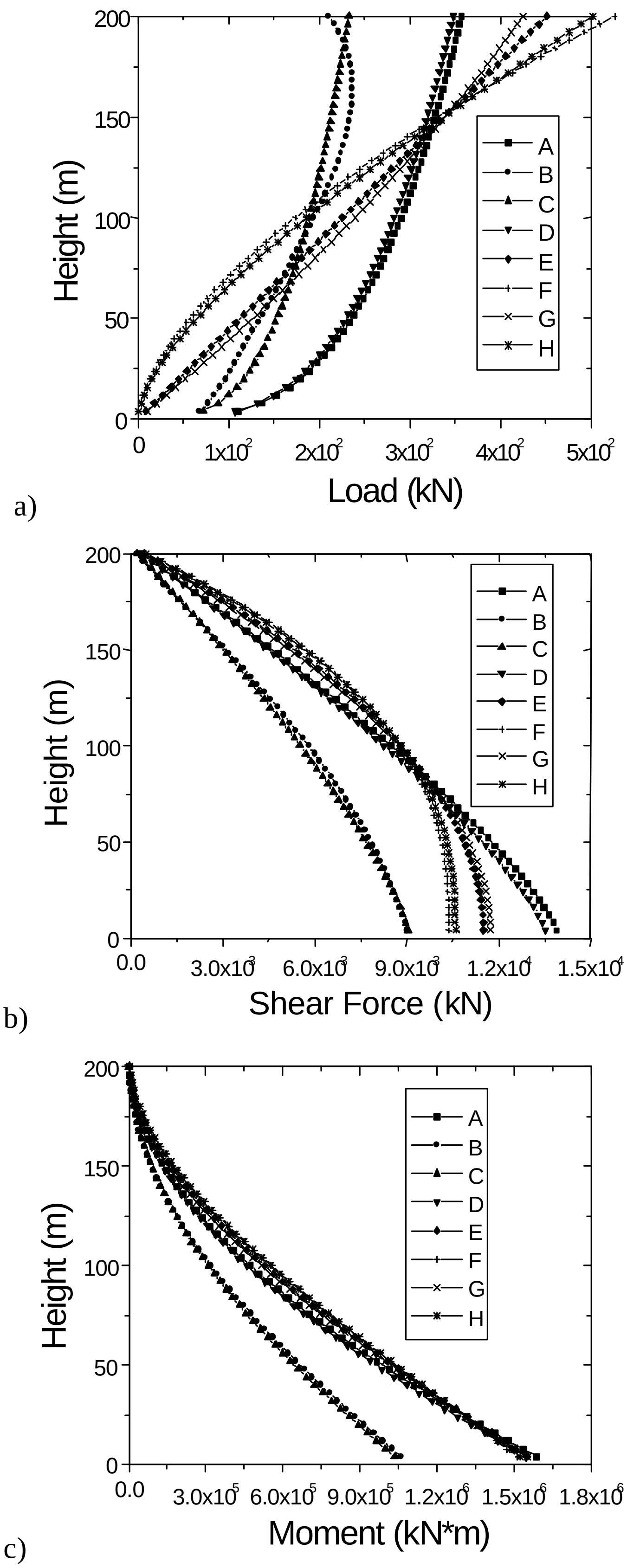


Figure 3. Wind loading by DGLF and MGLF methods, A: mean wind force; B: background wind loading relating to base moment response (Zhou et al. 1998b); C: background wind loading by DGLF; D: resonant wind loading by DGLF; Resonant wind loading by MGLF: E: case 1; F: case 2; G: for case 3; H: case 4

Table 2. Comparison of the gust loading factors

| Case | DGLF Method: Displacement, base moment and shear and all non-zero responses $G_B$ | $G_R$ | $G$ | MGLF Method: Base moment $G_B$ | $G_R$ | $G$ | Base shear force $G_B$ | $G_R$ | $G$ |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.652 | 0.974 | 2.172 | 0.652 | 0.976 | 2.174 | 0.652 | 0.829 | 2.055 |
| | | | | (1.000) | (1.002) | (1.000) | (1.000) | (0.851) | (0.946) |
| 2 | 0.652 | 0.974 | 2.172 | 0.652 | 0.953 | 2.155 | 0.652 | 0.748 | 1.992 |
| | | | | (1.000) | (0.978) | (0.992) | (1.000) | (0.768) | (0.917) |
| 3 | 0.652 | 0.974 | 2.172 | 0.652 | 0.976 | 2.174 | 0.652 | 0.845 | 2.067 |
| | | | | (1.000) | (1.002) | (1.000) | (1.000) | (0.868) | (0.952) |
| 4 | 0.652 | 0.974 | 2.172 | 0.652 | 0.959 | 2.160 | 0.652 | 0.763 | 2.004 |
| | | | | (1.000) | (0.985) | (0.994) | (1.000) | (0.783) | (0.923) |

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