ALONG-WIND RESPONSE OF FREE-STANDING LATTICE TOWERS

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INTRODUCTION

Since the nineteen-sixties, many papers have been written on the along-wind dynamic response of tall structures, e.g. [1], [2], [3], [4]. The approach used is a semi-analytical one, with a simple model of the relationship between the upwind turbulent velocity fluctuations, and the fluctuating forces on the structure. The dynamic response of the structure is treated using random vibration theory and modal analysis. Usually the result is presented in the form of a 'gust response factor', representing the ratio of the average peak response to the mean response, averaged over a suitable time period.

In the Australian Standard for Wind Loads, AS1170.2 [5], a method for the calculation of the along-wind gust response factor is given in Section 4.4.2. This is based on the work described in Reference [2]. The approach used in that paper was computation of a gust response factor for the modal coordinate a (t) where the horizontal deflection of the structure is described by the following equation:

$$x(z,t) = \mu_1(z) \, . \, a(t) \qquad (1)$$

where $\mu_1(z)$ is the mode shape for the first mode of vibration of the structure.

When implemented in the Standard, the additional assumption has been made that the mode shape varies linearly with height. This is a reasonable assumption for many tall office buildings, but is not a particularly good one for free-standing steel lattice towers. However, it has been generally assumed that the effect of nonlinear mode shape on the final computed gust response factor is small.

The question of the applicability of the previous work, especially Reference [2], to structural load effects on free-standing lattice towers, in particular the shear force and bending moment at any height on a tower, is the subject of the present study. This subject has recently become topical in Australia, with the construction of several television broadcasting towers to heights of 150 metres or greater, as part of the implementation of the 'equalisation' and 'aggregation' policies of the government for television services to non-metropolitan areas of the country. These towers are expected to have first mode natural frequencies significantly less than 1 Hertz, and hence be prone to resonant dynamic response. However, experience has shown that for broadcasting or transmission towers, less than about 100 metres in height, the resonant response is not large.

ANALYSIS

A general lattice tower, as shown in Figure 1, was considered and the following assumptions were made:

i) The width varied linearly with height, so that at any height z:

$$w = \left[w_b - \left(\frac{w_b - w_t}{h} \right) z \right] \qquad (2)$$

where w_b and w_t are the tower widths at the base and tip of the tower respectively.

(ii) A uniform solidity of members in the front face was assumed. This results in a constant tower section drag coefficient.

(iii) The first mode natural frequency, n_1, is assumed to be equal to:

$$n_1 = 750 \left(\frac{w_b + w_t}{h} \right) \text{Hertz} \qquad (3)$$

This approximate formula is based on measurements or predictions of the frequencies of several towers.

(iv) The mode shape is assumed to follow a power law:

$$\mu_1(z) = \left(\frac{z}{h}\right)^{\beta} \qquad (4)$$

(v) The mean wind speed over the height of the tower, h, is also assumed to follow a power law:

$$\frac{\bar{u}_z}{\bar{u}_h} = \left(\frac{z}{h}\right)^{\alpha} \qquad (5)$$

A logarithmic law is more appropriate for the mean velocity profile, but an equivalent power law exponent can be obtained from:

$$\alpha \simeq \left[\ln\left(\frac{h}{2z_o}\right)\right]^{-1} \qquad (6)$$

(vi) The longitudinal r.m.s. turbulent velocity, $\sqrt{\overline{u'^2}}$, is assumed to be invariant over the height of the tower.

Based on the above assumptions, and others used in Reference [2], the following expressions were derived for the gust response factors for shear force, G_s, and for bending moment, G_m, at any arbitrary height s on the tower.

$$G_s = 1 + \frac{r\sqrt{g_B{}^2\, B_s\, F_2 + g_R{}^2\, \frac{S\,E}{\zeta}\, F_3\, F_4\, F_5}}{F_1} \qquad (7)$$

$$G_m = 1 + \frac{r\sqrt{g_B{}^2\, B_s\, F_7 + g_R{}^2\, \frac{S\,E}{\zeta}\, F_3\, F_4\, F_8}}{F_6} \qquad (8)$$

In these expressions, r, S, E, ζ, are the Roughness Factor, Size Factor, Gust Energy Factor and structural damping ratio, respectively, as used in the Australian Standard [5].

g_B is a peak factor for the background response given by:

$$g_B = g_v\left(1 + \frac{g_v\, r\, \sqrt{B_s}}{4}\right) \qquad (9)$$

where g_v is the peak factor for the upwind velocity fluctuations, which can be taken as 3.7.

B_s is a background response factor. It is mainly a function of the covariance of the upwind velocity fluctuations over the part of the structure between the level s and the top of the structure, h. It is a weak function of the taper ratio and mean wind profile, and can be taken as independent of these variables with very little error.

It is not identical with the Background Factor, B, in the Australian Standard [5], but they are very similar. Use of the latter, with h replaced by h-s, (as in [7]), is slightly conservative.

g_R is the peak factor for resonant response:

$$g_R \simeq \sqrt{2 \log_e (3600\, n_1)} \quad (10)$$

$F_1, F_2, \ldots\ldots\ldots F_8$ are functions of s, w_b, w_t, α and β.

F_3 includes a correction to the Size Factor, S, for mode shape based on a low correlation limit [2, 6].

DISCUSSION

Equations (7) and (8) for the gust response factors show that these factors are different depending on the structural effect under consideration, on the height on the tower where the effect is being calculated, on the mode shape, represented by the exponent, ß, and on the mean wind velocity profile. The sensitivity of the gust response factor to these variables need to be investigated and may be relatively small.

However, as an indication of the variation in the gust response factors, values were calculated for a representative tall broadcasting tower. The assumptions and the results of the calculations are given in Table I. For the purpose of these calculations, the formula for the Background Factor given in the Australian Standard [5], with h replaced by h-s, was used to calculate B_s. This is not strictly correct, as discussed previously, but the errors are likely to be small.

Also shown in Table I are the computed gust response factors from the Australian Standard for Wind Loads [5], and the Interim Australian Standard for Design of steel lattice towers and masts AS3995 (Int) - 1991, [7]. The latter gives the same result as AS1170.2 for the base shear and bending moment (s=0), but different results at $s={}^h/_2$, due to height dependent terms.

Table I shows that both Standards slightly underestimate the gust response factor for the base shear and bending moment. For $s={}^h/_2$, AS3995 slightly underestimates the g.r.f.'s, but AS1170.2 underestimates them by larger amounts (7-9%).

Although the net errors in the estimates of g.r.f. from Refs [5] and [7] are not high, the errors in the background and resonant components are considerably higher. For the example used, the background contribution is underestimated, and the resonant contribution is overestimated.

CONCLUSIONS

An analysis of the along-wind response of tapered free-standing lattice towers, has been carried out. Separate gust response factors for shear and bending moment at any height have been computed, and the effect of non-linear mode shapes included.

The computed gust response factors increase with increasing height level on the structure of the load effect of interest, and are generally higher than those predicted by direct application of current Australian Standards.

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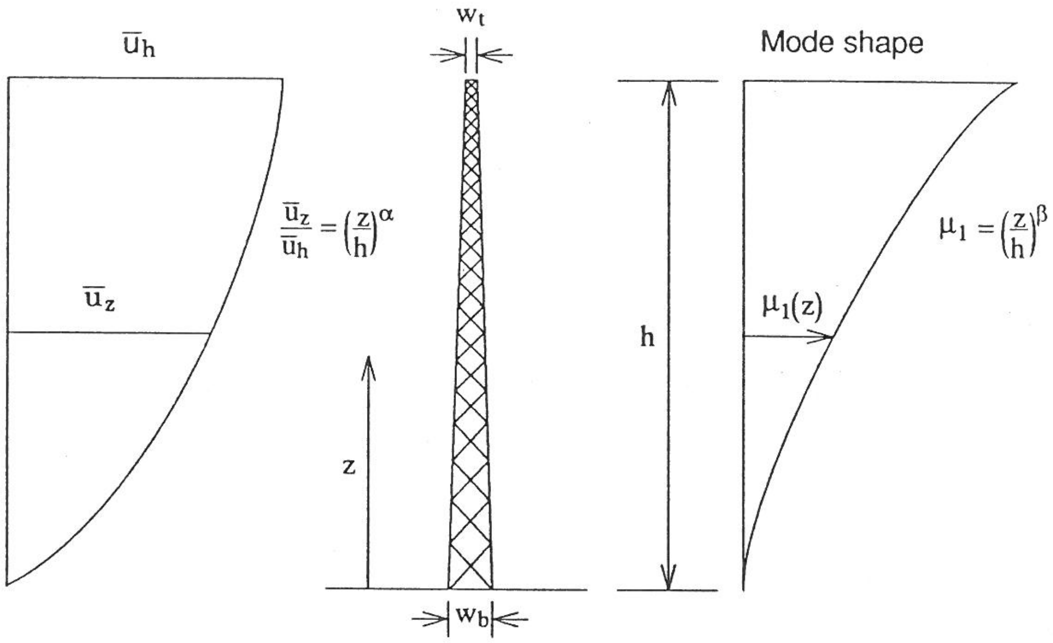

Figure 1. A general linearly-tapered lattice tower

Table I Calculated Gust Response Factors

Assumptions: $h=160m$. $w_b=20m$. $w_t=4m$. $\alpha=0.15$. $\bar{u}_h=30m/s$
$n_1=0.7Hz$. $\beta=3.0$. $\zeta=0.007$

Structural Response	This Paper	AS1170.2 [5]	AS3995 [7]
Shear at base	2.00	1.92	1.92
B.M. at base	1.98	1.92	1.92
Shear at $s = h/2$	2.06	1.92	2.05
B.M. at $s = h/2$	2.12	1.92	2.05