BBAA VI International Colloquium on:
Bluff Bodies Aerodynamics & Applications
Milano, Italy, July, 20-24 2008

EQUIVALENT STATIC WIND LOADS ON TALL BUILDINGS

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Keywords: Wind Loads, Tall Buildings, Wind-Exposed Structures; Wind-Tunnel.

Abstract. The results of experimental campaigns on two tall buildings are presented. Tests have been carried out in the CRIACIV boundary layer wind-tunnel, by pressure taps measurements and aerodynamic balance tests on both models. Numerical studies have been conducted afterwards to define the equivalent static background pressure maps and dynamic wind-loads distributions able to reproduce the quasi-static and dynamic Gumbel extremes values of the design base forces, respectively The effect of the structure three-dimensionality has been considered directly in the case of the design quasi-static pressure maps, whereas the equivalent static dynamic wind loads have been proposed by a statistical procedure combining the towers modal loads, starting from the quasi-static base resultant forces logged by an aerodynamic balance.

1 INTRODUCTION

Among the tall buildings built-up in Italy, those studied herein are of great concern within wind-exposed structural design as, most probably, they are going to be the tallest buildings of Italy. So, a careful design against both wind-induced local pressures and base resultant forces are a must in these cases. In particular, the subjects of the present paper are the towers of UNIPOL (in Bologna) and Piazza Garibaldi-Repubblica (in Milano). Both the towers have been studied by wind-tunnel experimental tests and numerical approaches to define design pressure maps and base resultant forces, useful in design purposes. Moreover, equivalent static background and resonant wind-loads have been proposed considering the three-dimensionality of the structures under examination.

2 EXPERIMENTAL TESTS

The typical wind profile of an urban zone has been reproduced in wind tunnel, as well as the atmospheric turbulence, within the well-known approximations in simulating real turbulence length scales. Moreover, the towers model and the surrounding urban contexts have been reproduced and placed in the text-section of the wind-tunnel, as shown in Fig. (1). In particular, both the models are 1:350 scaled and equipped by 125 and 140 pressure taps in the case of the Unipol and Garibaldi-Repubblica towers, respectively. Pressure fields have been logged within 16 wind directions, equally spaced by 22.5° degrees, by a sampling frequency of 250Hz during 30 seconds. For each pressure tap, the Gumbel extremes values (Ref. [2]) have been computed, given a return period of 50 years corresponding to an occurrence probability equal to 0.02. Nevertheless, with the aim of defining the design values of the base resultant forces, the integration of the extreme pressure maps might be too conservative as such extremes values would be supposed to act simultaneously. For this reason, the time history of each base resultant forces has computed in the time domain by integrating the pressure field at first, then their extremes values have been computed, as shown if Fig. (2). Once it has been possible to obtain the time instant during which such extreme values took place independently, the pressure maps belonging to this time instant have been obtained (see Fig. (3)). In this way, these maps reproduce the local pressure corresponding to the design values of each force component (F_x, F_y, M_x, M_y, M_z) and should be agreed upon as quasi-static forces as no dynamic effects have been considered within this first procedure.

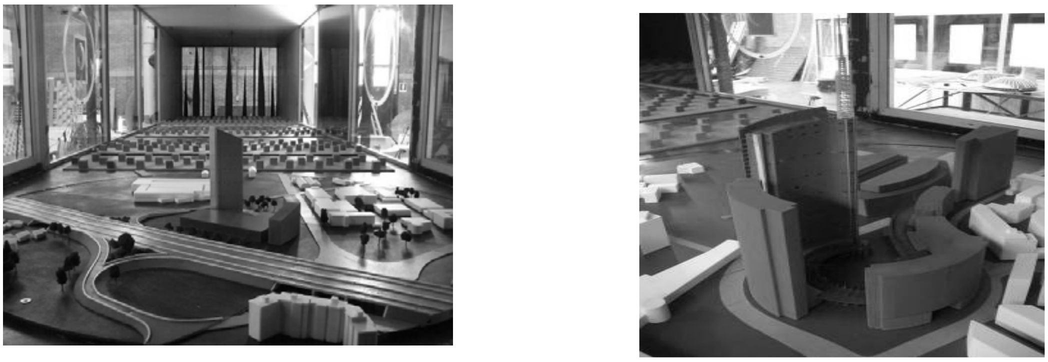

Figure 1: Showing of the wind-tunnel samples: (left) UNIPOL tower; (right) Garibaldi-Repubblica tower.

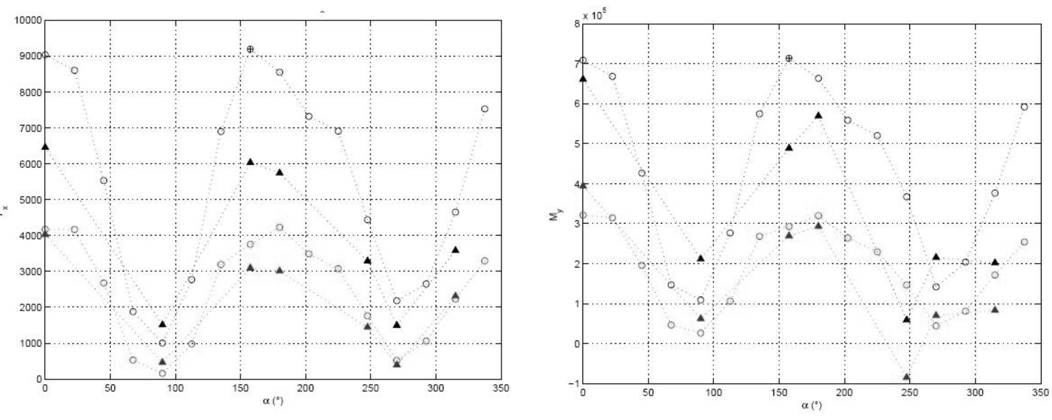

Figura 2. Garibaldi-Repubblica tower: Gumbel extremes of F_x and M_y: ▲ aerodynamic balance tests; O integration of pressure maps. + design value.

As it is possible to see in Figs (2) and (3), the base forces and moments are expressed in m^2 and m^3, respectively. To get the full scale forces, it is necessary to multiply those values by the reference dynamic pressure, q_{10}, the exposure coefficient c_e, and the dynamic coefficient c_d, as provided in Eurocode-1 (Ref. [1]). Pressure taps measurements are of great concern in designing wind-exposed structures, but clear and inevitable approximations occur by integrating pressure maps since at each tap is associated a certain influence area, whereas the real wind-induced pressure field is continuous itself. Moreover, because of the similitude criteria, it is not always possible to choose the opportune sampling frequency allowing to simulate the real frequency contents of the wind-induced pressures, generally in the range between 0Hz and 4Hz. For this reasons, the base resultant forces of the two towers have been logged by aerodynamic balance tests as well, by a sampling frequency of 1000 Hz. A comparison between the extremes values of the base forces are shown in Fig (2) and Fig (4).

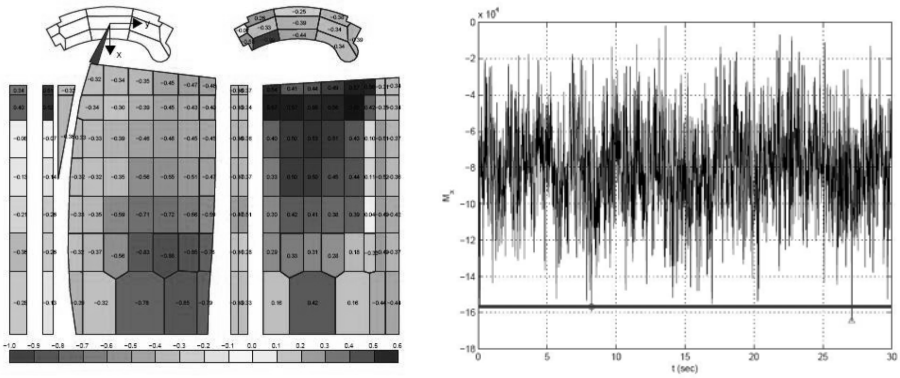

Figure 3: Left) pressure coefficient map belonging to the extreme value of M_x; Right) time history of M_x at a wind angle of attack α=157.5°; - Gumbel threshold.

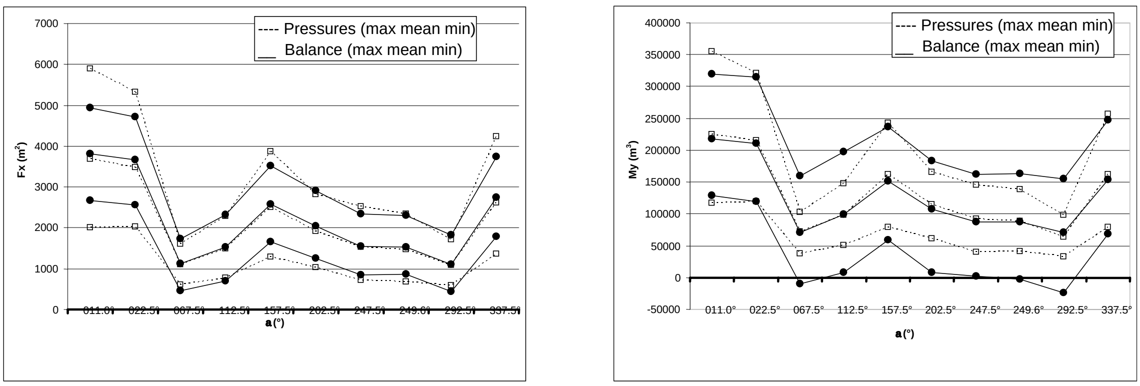

Figura 4. UNIPOL Tower: Gumbel extremes of F_x and M_y

Starting from the results of the aerodynamic-balance tests, it has been possible to get the design wind loads acting on the towers, within the hypothesis of cantilever-like structure. In particular, such loads are obtained, by the logged moments, M_x, M_y, M_z at the base of the models, in the following manner (Ref. [3]):

$$F_D(z) = \hat{M}_D \frac{m(z)\varphi(z)}{\int_0^H m(z)\varphi(z)\lambda(z)dz} \qquad (1)$$

where m(z) is the mass at the height above ground, z, φ(z) is a mode shape, λ(z) is the influence function (equal to z in the case of M_x and M_y, and equal to 1 in the case of M_z). The design moment is given by the following formula:

$$\hat{M}_D = \overline{M} + g_{qs}\tilde{M}_{qs} + g_{ris}\tilde{M}_{ris} \qquad g_{ris} = \sqrt{2\ln(f_n T)} + \frac{0.5772}{\sqrt{2\ln(f_n T)}} \qquad \tilde{M}_{ris} = \sqrt{\frac{\pi}{4\nu_n} f_n S_{M_{qs}}(f_n)} \tag{2}$$

Where $\overline{M}_D$ is the mean value of the generic moment, whereas $\tilde{M}_{qs}$ and $\tilde{M}_{ris}$ are the standard deviations of the quasi-static and resonant parts, respectively. The peak factor is denoted by g whereas, f_n and ν_n are the natural frequency and the modal damping of the generic modal shape, respectively. Finally, $S_{M_{qs}}(f_n)$ is the value of the quasi-static spectrum of M_{qs} at f_n.
From Eq. 1, it is possible to get the design wind-loads which consider the dynamic amplification induced by the towers motion. Nevertheless, these loads do not act on the structure simultaneously. So it is necessary to find a statistical combination of them. To achieve this purpose, the following procedure has been implemented: given then design value of M_x, for instance, the time instants at which the time history crosses the Gumbel threshold are individuated. The values of M_y and M_z at these time instants define the processes M_y^* e M_z^*, whose mean values are computed obtaining the following coefficient to combine the three design values statistically:

$$\gamma_y = \frac{\overline{M}_y^*}{\hat{M}_{y,D}} \quad \gamma_x = 1 \quad \gamma_z = \frac{\overline{M}_z^*}{\hat{M}_{z,D}} \tag{3}$$

Finally, the design wind-load is obtained as below:

$$\vec{F}_D(z) = \hat{M}_{x,D} \frac{m(z)\varphi(z)}{\int_0^H m(z)\varphi(z)\lambda(z)dz}\vec{i}_y + \gamma_y \hat{M}_{y,D} \frac{m(z)\varphi(z)}{\int_0^H m(z)\varphi(z)\lambda(z)dz}\vec{i}_x + \gamma_z \hat{M}_{z,D} \frac{I(z)\varphi(z)}{\int_0^H m(z)\varphi(z)dz}\vec{i}_z \tag{4}$$

The same procedure may be computed for the other moments to obtain the following table:

Given	γ_x	γ_y	γ_z
$\hat{M}_{x,D}$	1	-0.03	-0.28
$\hat{M}_{y,D}$	-0.01	1	0.09
$\hat{M}_{z,D}$	0.70	0.21	1

Table 1. Coefficients to be used in combining the base resultant forces and respective equivalent static wind-loads, statistically.

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