Wind effects on a tall building with permeable envelopes

Andrea Giachetti [a], Gianni Bartoli [a], Claudio Mannini [a]

[a]*CRIACIV @ Department of Civil and Environmental Engineering, University of Florence, Via di S. Marta 3, Italy*

ABSTRACT: The comprehension of the wind effects on permeable building envelopes represents a challenging task. This work deals with three-dimensional wind tunnel tests on a reference geometry representing a tall building equipped with some permeable envelopes. The aim of the study is to understand if and how permeable façades may cause local or global effects on the building aerodynamics. The early results from pressure measurements seem to indicate that, in certain configurations, flow mechanisms of interaction between internal and external flows can occur, similar to those observed for preliminary two-dimensional studies.

KEYWORDS: permeable envelopes, double-skin facades, tall buildings, wind tunnel tests.

1 INTRODUCTION

A modern façade is a crucial element in the design of a tall building. In particular, permeable building envelopes are often used, and the request to reach high aesthetic, acoustic and energetic standards makes these envelopes expensive components, which have to be properly designed.

Despite the many works carried out on permeable building envelopes (*e.g.* [1-2]), in certain configurations the flow mechanisms acting on the system building + façade are not fully understood; the wind loading codes also lack of design values for permeable façades (*e.g.* [3]). Moreover, in addition to studies on wind-induced pressures on commonly used permeable building envelope (*e.g.* [4-5]), innovative façade solutions have been recently investigated, aiming also to improve the building-aerodynamic performances (*e.g.* [6]) or to convert the wind action through energy harvesting devices (*e.g.* [7]).

From an aerodynamic point of view, a permeable building envelope can be considered as an additional layer fixed to one (or more) building face, which creates one (or more) internal cavity somehow connected to the exterior. In order to accurately define the wind loads on such building façades, it is necessary to evaluate both internal and external pressures. However, given that the internal cavity is connected to the exterior, the wind-driven internal and external flows may mutually interact, possibly changing the aerodynamics of the resulting fluid-dynamic system building + façade. As it was observed by the authors in a previous exploratory work [8], internal oscillating flows can play a fundamental role with regard to the effects of the additional layer.

The multi-scale behavior of the problem can make the use of standard wind-engineering tools difficult. Indeed, one of the most complicated aspects to take into account is the reliability of the study of such geometries on scaled models, usually being the internal cavity gaps one order of magnitude smaller than the building characteristic cross-flow dimension. A further complication is that a wide range of configurations are possible, since the cavity between the building face and the external layer can be connected to the exterior in a number of ways, often compartmentalized through horizontal and/or vertical sub-structures.

The complexity of the problem and the lack of studies on configurations of tall buildings with permeable building envelopes stress the need for a research effort on this topic. The current work deals with a three-dimensional experimental investigation on a tall building model with side ratios equal to 1:1:5. In particular, this study is considered a continuation of the two-dimensional exploratory tests performed by the same authors [8] on a square cylinder equipped with an airtight screen fixed at a small distance. Therein, it was found that, even for a flow perpendicular to the face equipped with the screen, the pressure distribution clearly proves the occurrence of an aerodynamic modification caused by the screen. Global aerodynamic quantities, such as the lateral force coefficient for a small angle of attack, are also strongly affected.

2 EXPERIMENTAL SET-UP

The experimental campaign was carried out in the CRIACIV (Inter-University Research Centre on Building Aerodynamics and Wind Engineering) Boundary Layer Wind Tunnel.

The model of a tall building consisting in a rigid square prism with side ratios 1:1:5 was tested (a picture of the experimental set-up is reported in Fig. 1). The reference model was equipped with about 200 pressure taps (simultaneously acquired at a rate of 500 Hz with a PSI DTC Initium system), which were distributed mainly on the upper part of the model, where large effects of the screen are expected. In particular, the measurement points were increased close to the building edges. Different screen configurations were tested: the presence of one or two airtight screens (on opposite faces) and different arrangements of horizontal compartmentations (in terms of number and locations) were taken into account. The cavities were connected to the exterior through lateral openings located at the edges of the building.

The reproduced approaching boundary layer was the one typical of a suburban environment (the mean wind profile was characterized by an exponent of about 0.3). The tests were carried out for various wind directions (in most of the case, from 0° up to 90°).

Figure 1. Picture of the model inside the CRIACIV wind tunnel, from the working section to the inlet, showing the set-up adopted for the tests.

3 RESULTS

In order to understand the aerodynamic effects caused by the presence of the permeable building envelope, the results obtained without and with screens were compared for different configurations. However, the results herein reported refers to a specific case. Maps of the mean pressure coefficient are presented in Figure 2 for the wind perpendicular to the building face with the screen (placed at a distance equal to 1/20 of the building cross-section side length and with the cavity divided by ten horizontal compartmentations). When the screen is present, the mean pressures on the lateral sides are significantly lower close to the upstream edges, while those on the rear face are only slightly reduced. What is more, Figure 3 shows that the mean pressures in the cavity are lower than those on the lateral side, close to the openings of the screen. These results are in line with the two-dimensional study described in [8] and confirm that the pressures behind the screen cannot simply be estimated from those close to the lateral openings.

The aerodynamic effect of the screen on the integral wind loads on the building is more evident for a wind with an angle of attack with respect to the direction perpendicular to the face equipped with the permeable envelope. This is also in agreement with the findings of the two-dimensional investigation [8]. However, in certain configurations the Strouhal frequency is significantly affected by the presence of the screen even for a wind perpendicular to it.

4 CONCLUSIONS

The three-dimensional experimental study on a tall building with certain permeable building envelopes has emphasized the crucial aerodynamic role played by solid screens with lateral openings fixed at small distances from one or more building faces. In particular, in certain configurations some portions of the building exhibit flow features similar to those highlighted by a previous exploratory two-dimensional investigation. The present results stress the importance of the mutual interaction that may occur between internal and external flows, so that the accurate reproduction of small internal cavities is often mandatory in wind tunnel tests and numerical simulations.

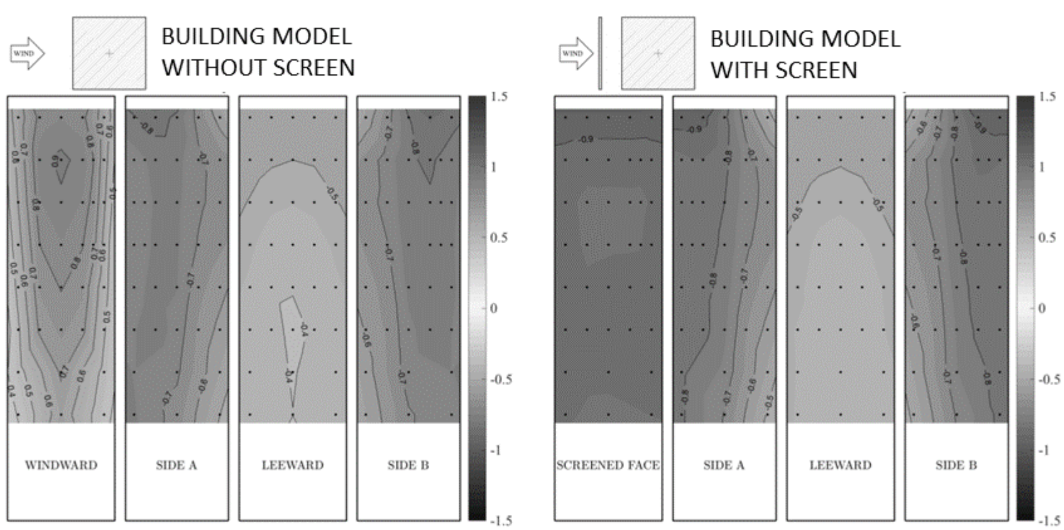

Figure 2. Mean pressure coefficients on the building faces for a wind perpendicular to the screen. On the left, the case without screen; on the right, the case with an airtight screen (laterally opened), with ten horizontal compartmentations, fixed at a distance equal to 1/20 of the building cross-section side length.

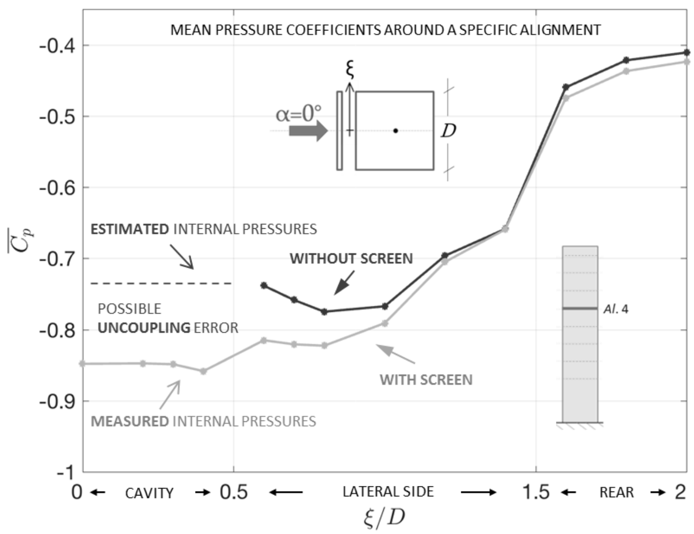

Figure 3. Mean pressure coefficient in correspondence of a section at 65% of the total height of the building for the same test case reported in Figure 2.

ACKNOWLEDGEMENTS

The wind tunnel tests have been performed thanks to the "Student Research Competitions 2017" award promoted by the CTBUH (Council on Tall Buildings and Urban Habitat) Research Division and to the sponsor Underwriters Laboratories.

REFERENCES

1 H.J. Gerhardt and F. Janser, Wind loads on wind permeable facades, J Wind Eng Ind Aerod, 53 (1994) 37–48.
2 C. Geurts, C. Van Bentum, O. Bronkhorst and C. Hulsbosch, Pressure distributions over permeable skins; a sensitivity study. In Proc. 14th Int. Conf. on Wind Engineering, Porto Alegre, Brazil, (2015) 1-13.
3 EN1991-1-4:2005. Eurocode 1: Actions on Structures – General Actions, Part 1-4: Wind Actions (2005).
4 F. Marques da Silva and M. Glória Gomes, Gap inner pressures in multi-storey double skin facades. Energ Buildings, 40, (2008) 1553–1559.
5 W. Lou, M. Huang, M. Zhang and N. Lin, Experimental and zonal modeling for wind pressures on double-skin facades of a tall building. Energ Buildings, 54 (2012) 179–191.
6 G. Hu, K.C.S. Kwok and K.T. Tse, Mitigating wind-induced response of a tall building with an innovative façade system. In Proc. 8th Int. Coll. on Bluff Body Aerodynamics and Applications, Boston, USA, (2016) 993–998.
7 S. Hassanli, G. Hu, K.C.S. Kwok and D.F. Fletcher, Utilizing cavity flow within double skin façade for wind energy harvesting in buildings. J Wind Eng Ind Aerod, 167 (2017) 114–127.
8 A. Giachetti, G. Bartoli and C. Mannini, Two-dimensional study of a rectangular cylinder with a forebody airtight screen at a small distance. J Wind Eng Ind Aerod, (under review).
9 A. Giachetti, Wind effects on permeable building envelopes: a two-dimensional exploratory study. PhD Thesis, University of Florence – TU Braunschweig (2018).