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The role of Permeable Double Skin Façades in vortex shedding mode of high rise buildings

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SUMMARY:
The application of stand-alone permeable screens for the mitigation of vortex shedding problems is a well-known option in wind engineering, usually adopted for bridges. Nevertheless, their employment in buildings is still in its early stages. Porous coverings are usually adopted for aesthetic reasons and, recently, also for their capability to reduce the energetic impact of the building. Within this framework, the Permeable Double Screen Façades (PDSFs) are becoming popular in the architectural trends, but their effects on the building's aerodynamics is still an open topic. Specifically, it is still unclear which could be the role of the permeable layer on the vortex shedding mechanism, which currently represents one of the main design issues for tall and super tall buildings. The present study proposes an experimental investigation of the role of the PDSF in the vortex-induced vibrations (VIVs) of a prismatic building model with an aspect ratio $B/D = 3.33$. A semi-aeroelastic model of the building is tested for different Scruton numbers and a comparison between the PDSF and the solid façade case is proposed. Results highlight that the effectiveness of the PDSF in structural response mitigation appears to be dependent on the Scruton number and a threshold over which the PDSF successfully mitigates the VIV is found out.

Keywords: Porous Double Screen Façades, Vortex-Induced Vibrations, VIV, Rectangular Cylinder, Wind Tunnel Testing

1. INTRODUCTION

Permeable Double Screen Façade (PDSF) is a multilayer cladding system characterized by an outer porous screen installed on the building's solid façade, leaving a gap for air recirculation. Due to its capability to improve the energetic performance of a building, they have been adopted by architects in several recent projects. When it comes to the building design, being the PDSF system directly exposed to environmental action, an accurate assessment of the wind loading must be addressed. If compared to the single façade case, wind interaction with a PDSF poses several peculiar difficulties, which have been still very little investigated by the scientific community. As a matter of fact, the presence of an outer porous façade in the cladding system is expected to alter the aerodynamic behavior of a building if compared to the single-layer façade case, both for the cladding and the structural design: it has been already shown by (Pomaranzi, Daniotti, et al., 2020) and (Pomaranzi, Bistoni, et al., 2021) that the porous layer is capable to provide reduced pressure distribution on the inner façade that could be up to 50% compared to the single layer case. In addition, the global aerodynamics of the structure can be affected by some façade details, either for the mitigation of the structural response of the building (this is the case of setbacks and

openings along the height, often deployed in tall or super tall buildings) or for the overall forces exerted on the building (Jafari and Alipour, 2021).
For the PDSF, it has been shown that the permeable screen is able to induce some modifications in the separated flow region (Pomaranzi, Pasqualotto, et al., 2022) and this rises questions about the vortex shedding (VS) phenomenon, which is strongly dependent on the behavior of the separated shear layers from the leading edges (A. Teimourian and H. Teimourian, 2021). For this purpose, the present work aims to experimentally investigate the role that the PDSF can play in the vortex shedding of a prismatic model representative of a high-rise building. A parametric investigation of the structural response to VS at different values of the mass-damping coefficients (Scruton number) is proposed and a comparative study between the single layer façade and the PDSF is presented to highlight the modifications induced by the porous layer.

2. SETUP AND METHODOLOGY

2.1. Semi-aeroelastic model

The model is a rectangular cylinder of aspect ratio $B/D = 3.33$; it represents a tall building scaled by a factor of fifty, according to geometric similitude. The rigid prism is mounted over an elastic base designed to allow low-frequency mono-harmonic oscillations in the cross-wind direction. To reproduce the PDSF configuration, a perforated mesh (porosity = 55 %) can be installed at a distance $d = 20\,mm$ from the solid façade. Table 1 sums up the mechanical and geometric characteristics of the model in the two configurations. It is possible to vary the adimensional damping of the cross-wind oscillation mode (ξ_1) thanks to a set of external parasite current dampers.

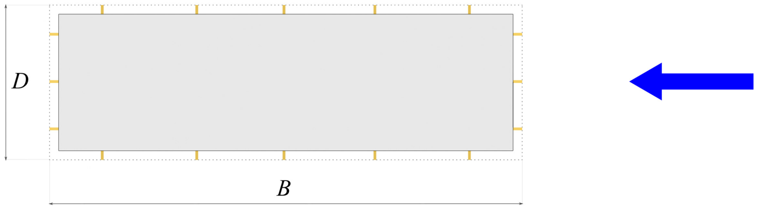

Figure 1. Quoted sketch of the top view of the model with PDSF. The blu arrow indicates the wind direction.

Table 1. From the left: natural frequency in still-air, adimensional structural damping (cross-wind vibration mode), dimensions of the cross-section and height of the model without and with PDSF.

Configuration	f_1 $[Hz]$	$\xi_{1,s}$ $[\%]$	B $[m]$	D $[m]$	H $[m]$
Naked	1.95	0.6	1.00	0.30	2.00
PDSF	1.88	0.6	1.04	0.34	2.00

2.2. Tests configurations

All tests have been performed in the atmospheric boundary layer section of the wind tunnel of Politecnico di Milano (GVPM). Since the objective is to investigate VIV, smooth-flow conditions were adopted ($I_u < 2.0\,\%$). The model is free to oscillate with the incoming wind perpendicular to the short edge D: in Figure 1 a quoted sketch of the top view. The different mass-damping configurations tested are described in Table 2. The model is instrumented with 4 accelerometers (two 'top accelerometers' at $h = 2\,m$ and two 'middle accelerometers' at $h = 0.6\,m$ from the base) and 254 pressure taps distributed on the model surface, allowing measuring the time-space variation of the pressure field. Pressure taps are acquired through a high-frequency pressure scanner with a

(a) Naked model.

(b) Model with porous mesh installed.

Figure 2. Comparison between the front view of the model without and with the mesh. Two dampers configuration.

sampling frequency equal to $500\,Hz$. The pressure data are fully synchronized with the building motion, allowing monitoring of the evolution of the pressure field during the oscillations build-up and the steady oscillation regimes. Figure 2 shows the model - with naked and PDSF configuration - in the wind tunnel test section.

Table 2. Adimensional damping, mass-damping, and Scruton number (cross-wind vibration mode) for the different tested configurations.

ξ_1 $[\%]$	$m_1 * \xi_1$ $[kg/m * \%]$	$Scruton$ $[-]$
0.6	27.1	4.7
1.0	45.2	7.9
1.3	58.8	10.2
2.1	94.9	16.5

2.3. Methodology

The model has been tested both without and with the porous mesh. The steady-state response is summarized in the so-called bell-shaped curve, showing the amplitude of oscillation at different reduced wind speed $U_n = U/U_{St}$. The critical vortex shedding velocity U_{St} has been computed according to Equation 1, while the incoming velocity U (measured with a Pitot tube at $1\,m$ from the ground) is increased by approximately $0.1\,m/s$ for each acquisition.

$$U_{St} = \frac{f_1 D}{St} \tag{1}$$

The acquisitions have been repeated increasing the Sc number, up until VIV stops and no more relevant vibration is measured, even at U_{St}. According to the methodology of (Zasso et al., 2008), at the critical speed, before and after the peak, the build-up displacement transient has been compared with the wind excitation. In particular, the phase shift between the response of the structure and the input force has been analyzed to characterize the phenomenology of the vortex-shedding. The latter has been computed through space integration of the pressure signals on the two façades parallel to the wind direction.

3. RESULTS

Results to be shown in the full paper will include an in-depth analysis of the role of the outer porous skin in the VIV of the tall building model by means of characterization from the steady-

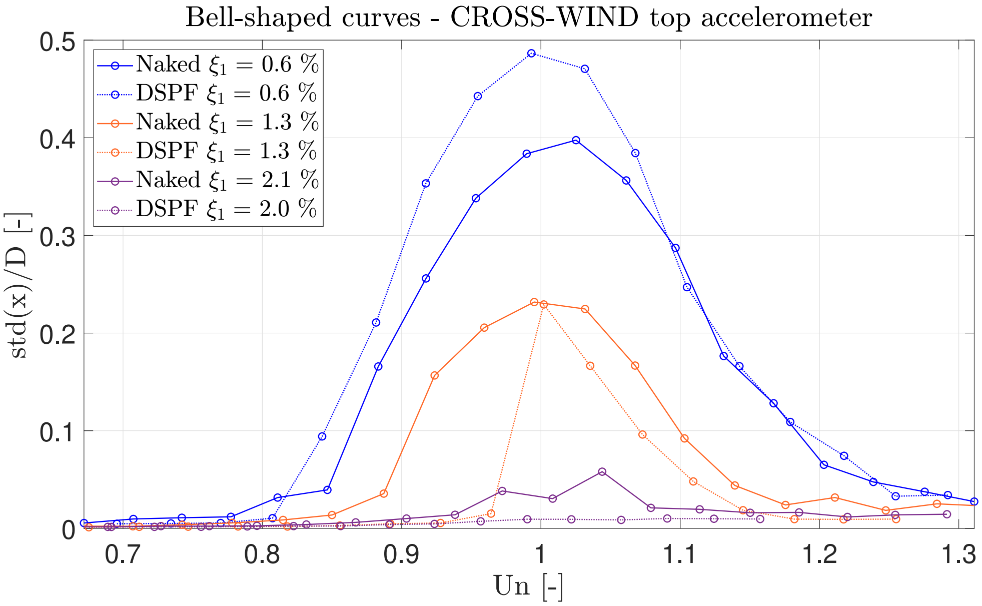

Figure 3. Bell-shaped curves of the model in the Naked (continuous line) and PDSF (dashed line) configuration at different adimensional damping ratios ($\xi_1 = [0.6, 1.3, 2.1]\%$). Non-dimensional standard deviation of the top displacement versus reduced wind velocity.

state response and the build-ups. As an example, Figure 3 shows a comparison between the two sets of bell-shaped curves at different mass-damping values. It appears that the role of the outer skin is strongly dependent on the Sc number: for the lowest value, the presence of the PDSF is actually not affecting the vortex generation and the bell shape is compatible with a solid model with a wider cross-section. Increasing the Sc number ($\xi \simeq 2.0\%$), the PDSF is instead able to mitigate the vortex shedding, as demonstrated by the flat dotted curve for the PDSF configuration. To further characterize the differences between the two configurations and the dependency on the Sc number, VIV will be studied in terms of response and instantaneous pressure distribution on the building surface, highlighting differences between the configurations in the synchronization of the lift force with the oscillation frequency. The results will allow getting a deeper understanding of the VIV mechanisms when the building is endowed with a permeable double skin.

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