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EXECUTIVE SUMMARY OF THE THESIS

Design and testing of the semi-aeroelastic model of a rectangular cylinder to assess the role of double screen porous façades in mitigation of VIV

LAUREA MAGISTRALE IN MECHANICAL ENGINEERING - INGEGNERIA MECCANICA

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1. Introduction

Double Skin Porous Façade (DSPF) is nowadays a popular cladding solution in civil engineering. This type of cladding is characterized by an empty gap between the building's façade and the porous mesh. The advantage of the permeable element is that it isolates the building while granting an almost unobstructed view of the outside (Example in Figure 1). It is employed mainly as an energy-saving and aesthetic element, but it has also some important aerodynamic effects. Thanks to the air recirculation, the wind pressure on the inner façade is sensibly lower with peak values reduced up to 30% with respect to the system without a shred [3]. The aerodynamic effect due to the presence of the porous cladding could also benefit the dynamic behavior of the structure by introducing some passive damping: the shroud breaks the coherence of the flux and inhibits vortex shedding, thus reducing Vortex Induced Vibrations (VIV). With an accurate design, the façade becomes a structural element that actively contributes to dynamics, allowing the installation of smaller damping systems and saving money.

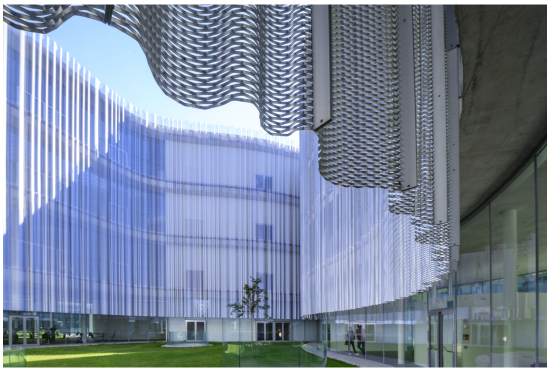


Figure 1: The New Bocconi Campus in Milan, an example of application of DSPF.

This thesis work deals with the design of a semi-aeroelastic model of a high-rise building to assess the role of DSPF as a VIV mitigation feature. The model employed represents a $100\,m$ high-rise building shaped as a rectangular prism with an aspect ratio of 3.33, mounted over an elastic base designed ad hoc to observe the aerodynamic effect of vortex shedding. The objective of the research is to provide a working semi-aeroelastic model together with some insights for further development and testing.

2. Aim of the work

This study is the follow-up of a previous experimental campaign in the Wind Tunnel of Politecnico di Milano (GVPM). Pomaranzi et al. [4] investigated the effect of two DSPF on a still model under turbulent wind at different speed. They demonstrated that the installation of DPSF reduces sensibly the negative peaks of the local pressure loads on the façade. The model of Pomaranzi et al. is a rigid structure, it was not designed for aeroelastic tests. Nevertheless, by measuring the power spectral density of the total cross-wind force, the naked model exhibits a peak at $St = 0.13$, while the shrouded configurations show a clear reduction in the module at the same reduced frequency. This result hints at the possibility that the porous façade could sensibly mitigate VIV by preventing a coherent vortex formation. An important remark is that the model has a high damping ratio, estimated at around 5%. This property precluded the possibility of measuring any relevant dynamic answer. The current study starts from this premise and tries to set up new tests to assess the role of the porous mesh on VIV.

3. Semi-aeroelastic model

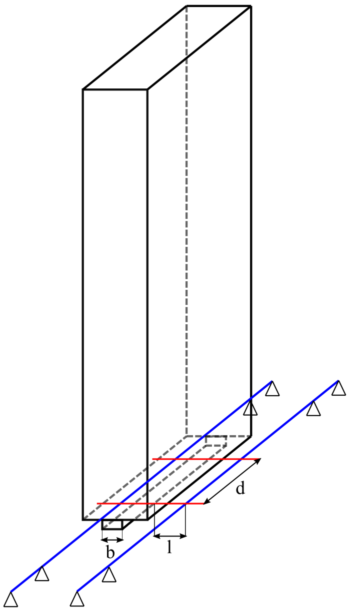


Figure 2: Schematic representation of the model of the building with the elastic base. Focus on the design parameters.

The previous setup has been revised to allow the investigation of aeroelastic effects. Considering the geometric and inertial characteristics of the old model, an elastic base has been designed such that the first natural frequency corresponds to the vortex shedding frequency at $U \simeq 4.5\,m/s$, while higher modes will not participate.

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

In Figure 2 a representation of the vibrating structure. The red elements are the couple of flexural springs: they are made of harmonic steel and they have been designed to allow cross-wind oscillations at $2\,Hz$ (according to St definition, Equation 1, considering $D = 0.3\,m$). The rigid model is bolted to the elastic element via an aluminum slab, to ensure light weight. The whole system is connected to the testing rig of the wind tunnel with a couple of steel bars (blue elements). All the calculations are made using a simplified 1 DOF model of the system, based on the displacement method applied to Euler-Bernoulli bar elements. The numbers have been verified with FEM simulations and the complete model has been characterized off the line before testing in the wind tunnel. The dynamic characteristics of the model are summarized in table 1.

Methodology	$f_1\,[Hz]$	$f_2\,[Hz]$
Analytical model	3.30	5.90
FEM analysis	1.92	4.26
Experimental characterization	2.05	4.21

Table 1: Comparison between designed frequencies and results from FEM and the experimental characterization.

It is possible to install two porous screen on the façade: the perforated mesh (with porosity $\beta = 55\,\%$, and pressure loss coefficient $k = 1.7$) and the expanded mesh ($\beta = 33\,\%$, $k = 2.3$). They are mounted at a distance $d = 20\,mm$.

4. Wind tunnel testing

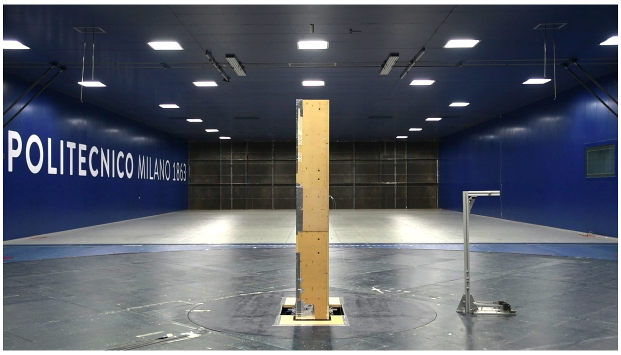
The experimental campaign has been conducted in the atmospheric boundary layer section of the GVPM. The model has been excited perpendicularly to the short edge D by wind in smooth flow at different speed. To verify the effect of the Sc coefficient (definition in Equation 2), the three damping configuration reported in Table 2 have been tested both with (Figure 3a) and without mesh (Figure 3b).

$$Sc = 2\pi \frac{\xi_1 m}{\rho B D} \tag{2}$$

Conf.i	ξ_1 [%]	Sc [−]
#1	0.4	3.2
#2	1.0	7.9
#3	1.7	13.4

Table 2: Sc coefficient calculated for the different damping configurations.

(a) Porous mesh.



(b) Naked model.

Figure 3: Comparison between the front view of the model in the naked and the meshed configuration.

From the data of the accelerometers, the classic bell-shaped plots have been drawn. Before each configuration change, a build-up curve has been acquired, to better understand how energy is introduced into the system.

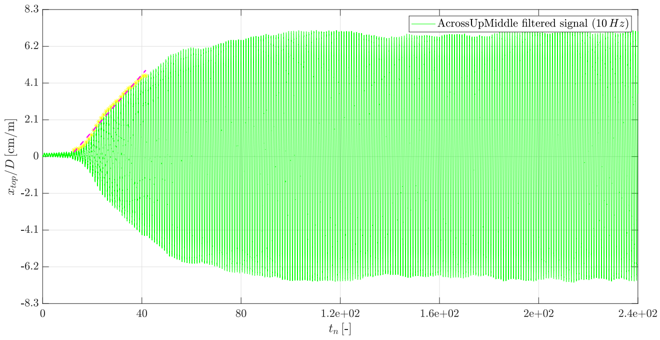
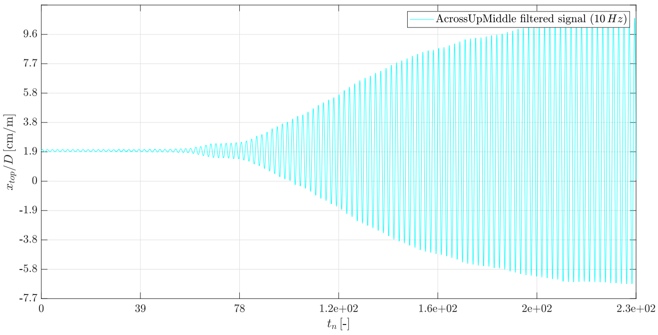
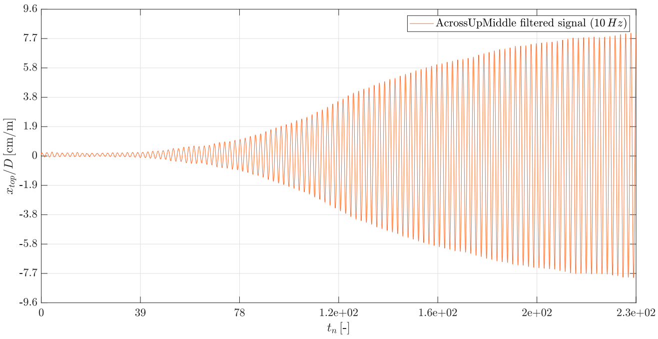


Figure 4: Build-up test of the naked model ($\xi_1 = 0.4\%$) at $U = 4.5\, m/s$. Adimensional top displacement versus adimensional time.



(a) Model with expanded mesh ($\xi_1 = 0.4\%$).



(b) Model with perforated mesh ($\xi_1 = 1\%$).

Figure 5: Zoom on the first cycles of the build-up curves of the shrouded model. Adimensional top displacement versus adimensional time.

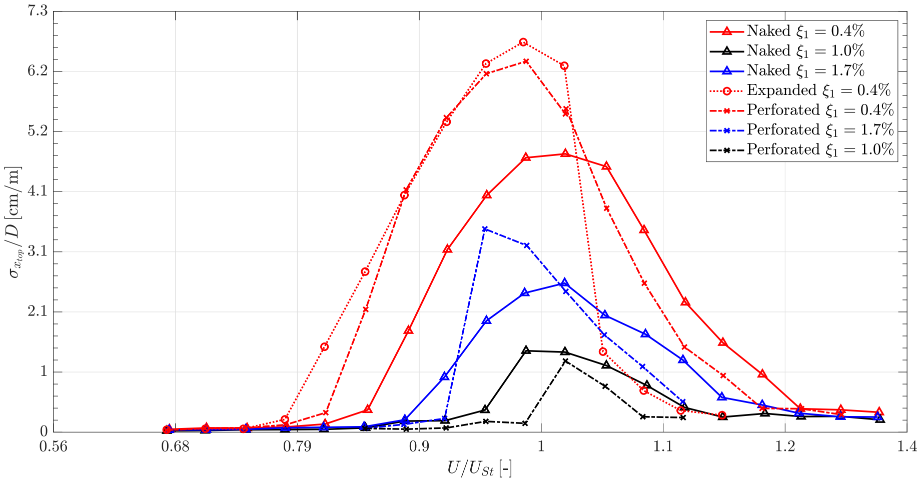


Figure 6: Bell-shaped curves of the model with and without porous facade (naked model Δ, expanded mesh $\circ$ and perforated mesh X) at different damping ($\xi_1 = [0.4, 1.0, 1.7]\%$). Adimensional standard deviation of the top displacement versus reduced wind velocity. Cross-wind direction.

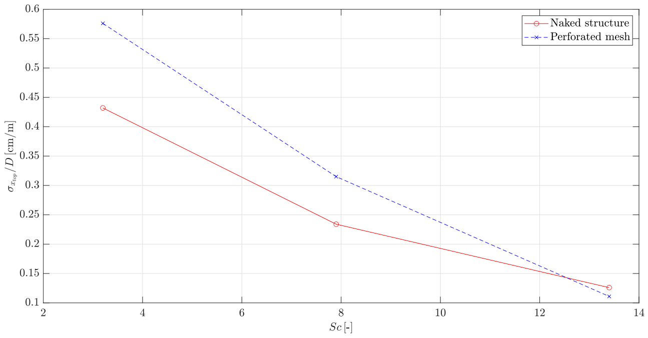


Figure 7: Trend of the adimensional standard deviation of the top displacement versus Sc number. The red curve represents the naked structure, and the blue one the perforated configuration.

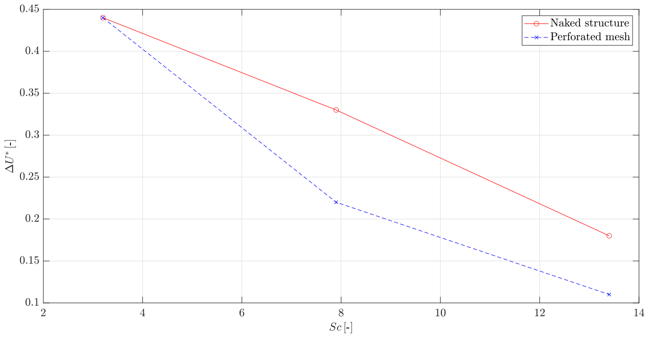


Figure 8: Trend of the width of the bell versus Sc number. The red curve represents the naked structure, and the blue one the perforated configuration.

5. Testing results and conclusions

From the wind tunnel tests on the semi-aeroelastic model, the following conclusions can be made.

- The designed elastic base behaves as predicted, allowing the model to vibrate in the cross-wind direction at the desired frequency ($f_1 = 2\,Hz$) under the predicted wind speed ($U_{cr} = 4.4\,m/s$). No participation of higher modes has been observed, a clean mono-harmonic signal revealed the VIV phenomenon.
- The testing with and without porous mesh confirmed the effect of the Scruton number on VIV (Bells in Figure 6): the higher Sc, the smaller the amplitude of vibration (Figure 7) and the width of the bell (Figure 8). The reduction of the latter is higher in the shrouded configurations, probably due to the contribution of the porous element. Moreover, it is proportional to the damping.
- The effect of both the shrouded configurations is not relevant when considering low damping ratios ($\xi_1 < 1\,\%$). The maximum amplitude of vibration increases notably instead of reducing, up to 36% of the reference value. This result indicates that the porous screen does not alter significantly the way vortex is shed with very low damping ratios.

- Further tests need to be performed, varying the distance from the facade ($d = 20\,mm$) and increasing the damping of the structure, since these two parameters seem to be governing the VIV phenomenon. In particular, the gap in experimental data from $\xi_1 = 1.7\,\%$ to $\xi_1 = 5\,\%$ should be filled: by increasing the damping ratio the aerodynamic effect of the DSPF should get more relevant and the same results of Pomaranzi et al. should be observed.
- From the study of the build-up transients, the rate of increase of the amplitude of vibration is almost constant, equal to 1% with and without mesh, both at $\xi_1 = 0.4\%$ and $\xi_1 = 1.0\%$ (see Figure 4). This result proves once again that the mesh in this setup does not change the way energy is introduced into the system.
- Both both the expanded (Figure 5a) and perforated (Figure 5b) presents a short meta-stable transitory in the build-up curve. This state is characterized by low oscillations (from 6% to 8% of the steady-state value) and last few cycles (maximum 20). The described behavior could be related to a change in the vortex shedding mode induced by the presence of the mesh. Maybe the screen disturbs the coherent vortex formation just when the amplitude of oscillation is below a certain threshold and when the structure starts vibrating noticeably the flux no longer 'sees' the porous mesh and behaves as if the façades were solid. Such suggestions are based on what has been observed, but to have a clear understanding of the ongoing phenomena once again further investigation is required. New tests should be performed, synchronizing the displacement acquisition with the pressure signal. The phase shift between the forcing and the answer is crucial to understand the vortex shedding pattern [1]. Information on pressure distribution is required to fully understand the dynamics of the shear layer.
- Due to the aspect ratio of the model ($B/D = 3.33 < 4$) there is the possibility of coupling between dynamic instability and vortex shedding that could influence the VIV results [2]. To better understand the role of galloping a detailed characterization of the model is required: the force coefficient curves, with a special focus on small attack angles, should be acquired.

References

[1] Giorgio Diana, Alberto Zasso, Marco Belloli, Stefano Giuseppe Giappino, and Sara Muggiasca. Vibrazioni indotte dal fenomeno di distacco di vortici su un cilindro a sezione circolare. In *IX Convegno Nazionale di Ingegneria del Vento IN-VENTO 2006*, pages 1–8, 2006.

[2] Stefano Giappino, Lorenzo Rosa, Gisella Tomasini, and Alberto Zasso. An aerodynamic and aeroelastic experimental study on a sectional and three-dimensional rectangular tall building. *The Structural Design of Tall and Special Buildings*, 25(3):139–157, 2016.

[3] G Pomaranzi, N Daniotti, P Schito, L Rosa, and A Zasso. Experimental assessment of the effects of a porous double skin façade system on cladding loads. *Journal of Wind Engineering and Industrial Aerodynamics*, 196:104019, 2020.

[4] Giulia Pomaranzi, Giada Pasqualotto, and Alberto Zasso. Investigation of the effects due to a permeable double skin façade on the overall aerodynamics of a high-rise building. *Wind and Structures*, 2021.