August 27-31, 2023
FLORENCE - ITALY
16th International
Conference on
Wind Engineering

Modelling Permeable Façades as Porous Medium

Giulia Pomaranzi[1], Yuriy Marykovskiy[2], Paolo Schito[3], Alberto Zasso[4]

[1]*Department of Mechanical Engineering, Politecnico di Milano, Via La Masa 1, 20156, Milan, Italy, giulia.pomaranzi@polimi.it*
[2]*Structural Mechanics and Monitoring, ETH Zurich, Stefano-Franscini-Platz 5, 8093, Zurich, Switzerland, marykovskiy@ibk.baug.ethz.ch*
[3]*Department of Mechanical Engineering, Politecnico di Milano, Via La Masa 1, 20156, Milan, Italy, paolo.schito@polimi.it*
[4]*Department of Mechanical Engineering, Politecnico di Milano, Via La Masa 1, 20156, Milan, Italy, alberto.zasso@polimi.it*

SUMMARY:
The application of porous panels as cladding elements for buildings poses new challenges for wind interaction issues: the simultaneous effects of the largest scale of the building within the Atmospheric Boundary Layer and the local boundary layer that develops at the façade openings define a multi-scale problem that must be properly managed. Addressing it with a purely experimental approach shows evident limitations, mainly related to the poor representation of the porous elements in a scaled model for wind tunnel tests. This could represent an issue, especially in case wind loading must be predicted on the permeable element. A viable alternative could be to make advantage of porous media models available in the CFD framework. Such a modelling technique allows having a macroscopic representation of the porous elements, avoiding the explicit reproduction of the porous geometry in the computational domain. The present paper proposes the application of the porous media model to the case of a Permeable Double Skin realized by a perforated metal. The porous media model will be introduced along with the identification procedure for the input parameters of such a model. The approach will be finally applied to a generic prismatic high-rise building model, with a permeable double-skin façade. The numerical modelling will be finally validated by comparison with wind tunnel data.

Keywords: CFD, Permeable Screens, Forchheimer Coefficients, Permeable Double Skin Facades, OpenFoam

1. INTRODUCTION

High-efficiency façades such as permeable double skins (PDSF) are often adopted in order to reduce the energy demand of the system. Such façade systems are realized by an inner skin usually made of glass panels and an outer porous cladding. An example is shown in Figure 1. Despite the effectiveness of the porous façade in the improvement of the energy performance of a building has been widely ascertained by the current literature, minor attention has been paid to the wind interaction issue: the fluid dynamic characterization of the PDSF and the interaction mechanism between the two façade layers pose new challenges that have not been addressed so far. As a matter of fact, the presence of a porous layer in the cladding system is expected to alter the aerodynamic behaviour of a building if compared to the single-layer façade case: it is expected that the porous skin may act as a shielding device for the glass layer (leading to a modification in the design

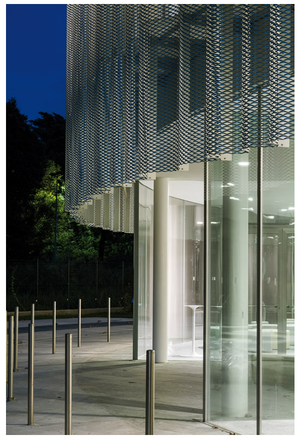

Figure 1. An example Permeable Double Skin Façade

pressures), but wind effects must be predicted also on the permeable elements, being directly exposed to that action. It is therefore evident that a rigorous method to estimate wind loading on buildings with PDSF is essential to guarantee a safe and optimized design.

The assessment of the wind effects on a PDSF poses a typical multi-scale problem: the largest scales, associated with the effects of the atmospheric boundary layer on the structure coexist with small scales, due to the local boundary layer that develops at the level of the porous façade openings. The latter, strongly dependent on the geometry of the porous skin together with its position along the whole façade, are generally at least three orders of magnitude smaller than the largest scales. Hence, addressing the aerodynamics of PDSFs implies first managing the multi-scale problem properly. Experimental approaches, typically based on wind tunnel tests on scaled models, usually rely on *Re* number equivalency when scaling the porous elements (Idelchik, 1986). This may lead to a not-satisfactory representation of porous elements characterized by complex geometries, like expanded metals or louvers, that are responsible for flow deflections. Within the CFD framework, there exists the possibility to avoid the explicit modelling of the geometry of the permeable element that would result in an unaffordable computational effort, being the porous element installed on a building. The alternative way is to rely on homogenized models - like the porous media approach - allowing no reproduction of the openings' geometry; despite such a modelling approach is commonly adopted in several engineering fields (Patursson et al., 2010; Zhao, Bi, Dong, et al., 2013; Zhao, Bi, Liu, et al., 2014), their application to the PDSF case is still at the earliest stages (Xu et al., 2022; Yang and Lee, 1999). The strong potentiality of the porous media approach relies on the possibility to catch wind-induced loading on porous screens, even when they are characterized by complex geometries.

The paper introduces the application of the porous media approach to a Permeable Double Skin realised by a perforated metal, installed on a prismatic high-rise building. The computation of the input parameters for the porous media model will be first addressed; then, the numerical modelling will be applied to a single portion of a perforated screen to finally arrive at the case that includes the application over a building. For the latter case, a comparison with experimental data will be provided, as validation of the CFD approach.

2. METHODOLOGY

2.1. The porous media model

Within the computational fluid dynamic framework, the porous media approach proposes to represent the porous element by means of a 3D volume, where a momentum sink term is used to account for the porosity effects. Such momentum sink, introduced on the right-hand side of the Navier-Stokes Equation, is based on Darcy-Forchheimer law (Darcy, 1856; Forchheimer, 1901):

$$S_i = -\sum_{j=1}^{3} d_{ij}\mu u_j + \frac{1}{2}\sum_{j=1}^{3} f_{ij}\rho U u_j \tag{1}$$

The first term of Equation 1 can be dropped in the present application, being the viscous stresses negligible. This is a valid simplification for modelling windscreens on building facades as a porous medium. Thus, assuming inviscid and incompressible steady-state flow, the governing equation becomes:

$$u_j \frac{\partial u_i}{\partial x_j} = \frac{1}{\rho}\frac{\partial p}{\partial x_i} - \frac{1}{2} f_i U u_i \tag{2}$$

To proceed with the application of the porous media model to the case of a PDSF, the parameters (f_{ij}) defining the porous volumes must be computed. To do that, the following procedure will be applied:

- a set of preliminary steady-state simulations will be run, by considering a sample of perforated metal, that will be explicitly modelled in the computational domain (the high-fidelity model)
- forces on such sample will be extracted, varying the angle of attack
- by relying on an analytical solution, a relation between the set of forces measured in the high-fidelity model and model coefficients will be obtained
- a least-squares optimisation will evaluate Forchheimer tensor resistance coefficients with input from high-fidelity computational fluid dynamics simulations

When available, the set of coefficients, describing the Forchheimer tensor, will be used to simulate a permeable double skin applied on a prismatic high-rise building. The case here presented will involve a PDSF realized by a perforated mesh applied over a solid façade. Figure 2 shows the geometry of the porous panel: holes' diameter is 6mm, their spacing is 8mm and the thickness of the metal is 2mm.

2.2. Experimental validation

The application of the porous model in simulating the aerodynamic behaviour of a PDSF will be validated through a comparison with experimental data coming from wind tunnel tests. A set of pressure data, recorded on the inner skin of a PDSF installed on a rigid model of a high-rise building is available from previous studies Pomaranzi et al., 2022. The CFD simulations will be

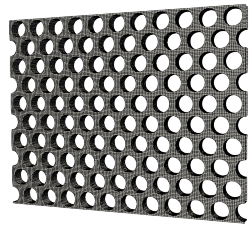

Figure 2. The geometry of the perforated metal that will be used as outer skin of PDSF.

designed to reproduce the same inflow conditions as the ones from the wind tunnel tests to finally make possible a comparison between pressure fields from CFD and experimental approaches. This will allow for effectively assessing the capability of the porous media model to reflect the aerodynamic behaviour of a PDSF.

3. RESULTS

Results to be shown in the full paper will cover first the outcomes from the calculation of the input parameters of the tensor of the porous media model: this will include the set of forces on the explicitly modelled porous panel from the preliminary set of simulations. Then, post the computation of the tensor's components, the porous media model will be applied to a prismatic high-rise building to simulate the PDSF realized with the perforated metal. Results from such CFD simulations will be presented and validation with respect to wind tunnel measures will be provided, in terms of the mean pressure field. CFD simulations will also provide some insights into the development of a certain gap flow between the two layers of the PDSF. Results presented in the present paper can lay the groundwork for the application of the CFD porous media approach in case of building PDSF, with potential extension towards more complex geometries of the porous layer or unsteady approaches to predict wind loading on the building.

REFERENCES

Darcy, H., 1856. Les fontaines publiques de la ville de Dijon: exposition et application des principes à suivre et des formules à employer dans les questions de distribution d'eau... un appendice relatif aux fournitures d'eau de plusieurs villes au filtrage des eaux. Vol. 1. Victor Dalmont, éditeur.

Forchheimer, P., 1901. Wasserbewegung durch boden. Zeitschrift des Vereines Deutscher Ingenieure 45, 1781–1788.

Idelchik, I. E., 1986. Handbook of hydraulic resistance. Washington.

Patursson, Ø., Swift, M. R., Tsukrov, I., Simonsen, K., Baldwin, K., Fredriksson, D. W., and Celikkol, B., 2010. Development of a porous media model with application to flow through and around a net panel. Ocean Engineering 37, 314–324.

Pomaranzi, G., Pasqualotto, G., Zasso, A., et al., 2022. Investigation of the effects due to a permeable double skin façade on the overall aerodynamics of a high-rise building. Wind and Structures 35, 213–227.

Xu, M., Patruno, L., Lo, Y.-L., Miranda, S. de, and Ubertini, F., 2022. On the numerical simulation of perforated bluff-bodies: a cfd study on a hollow porous 5: 1 rectangular cylinder. Wind and Structures 34, 1–14.

Yang, J. and Lee, S., 1999. Effect of anisotropy on transport phenomena in anisotropic porous media. international Journal of Heat and Mass transfer 42, 2673–2681.

Zhao, Y.-P., Bi, C.-W., Dong, G.-H., Gui, F.-K., Cui, Y., Guan, C.-T., and Xu, T.-J., 2013. Numerical simulation of the flow around fishing plane nets using the porous media model. Ocean Engineering 62, 25–37.

Zhao, Y.-P., Bi, C.-W., Liu, Y.-X., Dong, G.-H., and Gui, F.-K., 2014. Numerical Simulation of Interaction Between Waves and Net Panel Using Porous Media Model. Engineering Applications of Computational Fluid Mechanics 8, 116–126.