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Aerodynamic characteristics of buildings with porous surfaces: The effect of building aspect ratio

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SUMMARY:
Aerodynamic characteristics of building models equipped with porous permeable façades were studied experimentally in a boundary layer wind tunnel. The focus was on the building aspect ratio. High-frequency force balance was used for acquisition of integral aerodynamic loads. Five building models of various geometric aspect ratios were studied. The aspect ratios defined by width : length : height for the building models were 1:2:5, 1:3:5, 1:1:3, 1:1:4 and 1:1:5. The outer, porous façades were made of thin aluminum sheets with laser-drilled circular openings arranged in a hexagonal pattern to achieve a porosity of 65%, calculated as the ratio between the total area of the openings divided by the total area of the façade. A decrease in the building model height and width proved to have a favorable effect in decreasing the integral across-wind moment coefficient. The 65% porosity façade system yields an increase in the across-wind moment coefficient for the 1:1:3, 1:1:4, and 1:1:5 building models.

Keywords: Buildings, porous façade systems, wind-tunnel experiments

1. INTRODUCTION

A double-skin facade is a permeable building envelope with a porous screen. The building envelope consists of an inner airtight façade and an outer porous façade. There are several advantages of such systems, e.g., thermal insulation, rain protection, sun shading and visual appeal, Škvorc and Kozmar 2021.

Given that buildings may be sensitive to wind loads, it is important to investigate the effect of porous building envelopes on the aerodynamic characteristics of buildings. The choice of the façade system on a building is important because it is the main structural element that separates the interior and exterior of buildings. Safety issues need to be accordingly addressed since the failure of a single façade element may cause substantial structural damage and failure.

In the past, it was indicated that the geometric aspect ratio of buildings may substantially affect wind loads on structures, e.g., Irwin 2008, Tanaka et al. 2012.The focus of the present study is accordingly the effect of the building aspect ratio on aerodynamic characteristics of buildings with porous surfaces. This topic was addressed in terms of integral aerodynamic loads on five building models equipped with porous façade systems. The smooth single-skin building models (without porous façade systems) were used as a reference.

2. EXPERIMENTAL SETUP

Experiments were performed in the CRIACIV (Inter-University Research Centre on Building Aerodynamics and Wind Engineering) boundary layer wind tunnel at the University of Florence, Italy. The ABL simulation was created to model suburban wind conditions. The goal was to achieve the ABL simulation comparable to the EN1991-1-4:2005 (2005) terrain category III wind conditions.

The building models were made of aluminum to limit their weight while maintaining stiffness. Five building models with aspect ratios of 1:2:5, 1:3:5, 1:1:3, 1:1:4, and 1:1:5 were used. The dimensions of the 1:1:3 building model were 100 mm width, 100 mm length and 300 mm height. The 1:2:5 and 1:3:5 building models were created by connecting two and three tubes of the 1:1:5 aspect ratio, respectively. A specific steel part was manufactured to serve as a connector between the building models and the high-frequency force balance (HFFB).

Porous outer façades were made of 1 mm thick aluminum plates. Circular openings of 10 mm diameter were laser-cut in a hexagonal pattern in the aluminum to achieve the desired porosity. The porosity of the façades was determined as the ratio between the total area of the openings and the total area of the façade. The gap between the inner and outer façades is 4 mm.

Integral aerodynamic loads acting on building models were acquired using a HFFB. Integral across-wind and along-wind moments were measured from 0° to 45° flow incidence angles at an increment of 5°, for the 1:1:3, 1:1:4 and 1:1:5 building models, while it was not necessary to perform experiments for 0° to 90° flow incidence angles for the 1:2:5 and 1:3:5 building models due to their symmetry.

3. RESULTS

The integral along-wind and across-wind moment coefficients were calculated as:

$$C_{MD} = \frac{M_D}{1/2\,\rho v^2 D H^2}, \tag{1}$$

$$C_{ML} = \frac{M_L}{1/2\,\rho v^2 D H^2}, \tag{2}$$

where C_{MD} and C_{ML} are along-wind and across-wind moment coefficients, M_D and M_L are the integral moments recorded by the HFFB, ρ is the air density, v is the flow velocity in the free stream, D and H are the width and height of the building model, respectively.

The mean pressure coefficients were obtained relative to the mean pressure in the undisturbed flow at the height of 500 mm, i.e., the height of the 1:1:5 building model.

Figure 1 shows the integral across- and along-wind moment coefficients of the building models with square cross-section, with and without PDSF systems.

For the 1:1:5 building model, which is the tallest of the three building models, $\overline{C_{ML}}$ is the largest at its peak at α = 15°, which can be expected due to the height of this building model. With decreasing height of the building model, the maximum $\overline{C_{ML}}$ decreases.

Since the ABL model is the same for all building models tested, lower building models are more exposed to lower mean flow velocity because of the characteristic ABL simulation profile.

The application of the 65% porosity PDSF system further decreases $\overline{C_{ML}}$ for the 1:1:4 and 1:1:5 building models, likely due to the increased surface roughness caused by the openings in the outer façade.

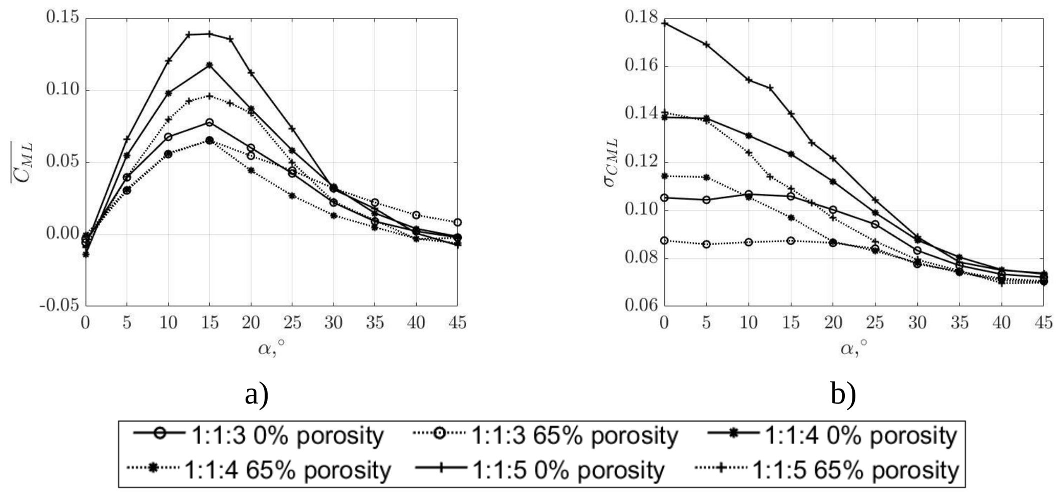

Figure 1. Mean across-wind and along-wind moment coefficients ($\overline{\boldsymbol{C_{ML}}}$, $\overline{\boldsymbol{C_{MD}}}$) for the 1:1:3, 1:1:4 and 1:1:5 single-skin building models and 65% PDSF systems

For the 1:1:3 building model, however, $\overline{C_{ML}}$ slightly increases, particularly at $\alpha > 25°$. From the HFFB recordings alone it is difficult to precisely understand why this slight increase occurs, however, it is important to point out that the 1:1:3 building model is not considered a tall building, as its slenderness is rather low. This means that it is difficult to compare it with slender building models, and its aerodynamic characteristics should be compared with the aerodynamic characteristics of low-rise buildings.

A similar trend is reported for $\overline{C_{MD}}$, i.e., $\overline{C_{MD}}$ is lower on lower building models. The 65% PDSF system yields a further decrease in $\overline{C_{MD}}$ for the 1:1:4 and 1:1:5 building models, while it slightly increases $\overline{C_{MD}}$ for the 1:1:3 building model, Figure 1b.

The characteristic length used for the calculation of moment coefficients is d = 0.2 m and d = 0.3 m for 1:2:5 and 1:3:5 building models, respectively.

The mean across-wind moment coefficient $\overline{C_{ML}}$ (Figure 2a) exhibits the characteristic shape with $\overline{C_{ML}}$ ~0 for $\alpha = 0°$ and $\alpha = 90°$. The maximum $\overline{C_{ML}}$ is ~25% lower for the 1:2:5 building model, which can be attributed to the smaller width d of this model compared to the 1:3:5 building model. The 65% porosity PDSF system on both building models does not affect $\overline{C_{ML}}$.

The along-wind moment coefficient $\overline{C_{MD}}$ is shown in Figure 2b.

Its peak is at $\alpha = 0°$, which is expected since in this orientation the longer surface is perpendicular to the flow. $\overline{C_{MD}}$ steadily decreases to a minimum at $\alpha = 0°$, a configuration with the shorter surface perpendicular to the flow.

The results overlap for both building models in the range of $0° < \alpha < 20°$, as $\overline{C_{MD}}$ for the 1:2:5 building model is slightly lower compared to the 1:3:5 building model.

The 65% porosity PDSF system does not have a significant effect, except for the slight increase of $\overline{C_{MD}}$ for the 1:2:5 building model.

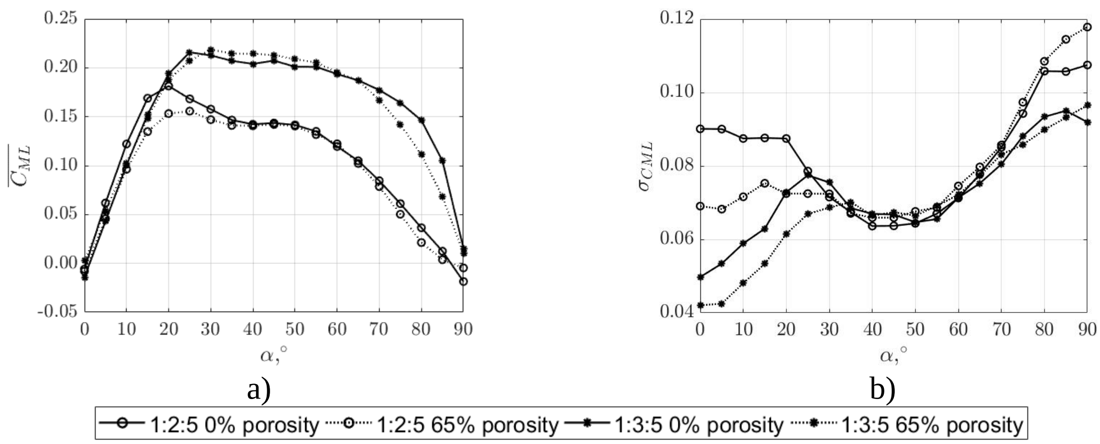

Figure 2. Mean across-wind and along-wind moment coefficients for the 1:2:5 and 1:3:5 single-skin building models and 65% PDSF systems

4. CONCLUSIONS

The effect of the geometric aspect ratio of buildings with porous double-skin façade systems was experimentally studied in a boundary layer wind tunnel. A model ABL was created to simulate suburban wind conditions recommended in EN1991-1-4:2005 (2005) category III. It is shown that a decrease in the building height and width have favorable effects on building aerodynamic characteristics. This is predominantly regarding a decreasing integral across-wind moment coefficient. The 65% porosity PDSF system effects only the aerodynamic characteristics of square-base buildings, where its application yields a decrease of the across-wind moment coefficient on the 1:1:4 and 1:1:5 building models, while there is also a decrease of the across-wind moment coefficient for the 1:1:3 building model.

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