Performances of parametric laws for computing the wind speed profile in the urban boundary layer. Comparison to two-dimensional building water channel experiment.

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Introduction

The expression generally used to determine the wind speed profile above the canopy is based on the log-law in (1):

\[ u(z) = u_0 + \frac{\nu}{\kappa} \ln \frac{z}{z_0} \]  

(1) where \( u \) is the average wind velocity, \( u_0 \) the von Karman constant, \( \nu \) the friction velocity, while \( z_0 \) and \( z_0^* \) are the roughness length and displacement height, respectively.

These are generally estimated on the basis of the morphometric or the aerodynamic methods, while \( u \) is usually referred to the ISL. In what follows, algorithms that relate \( z_0 \) and \( z_0^* \) to geometric parameters such as \( H \), \( L \) and \( d \) are presented.

The aim of this work is to compare wind speed profiles determined using (1) and the formulation proposed by Pellicceri et al. (2015) with experimental data measured in the water-channel.

Experiments

FLOW CHARACTERISTICS

- height: 3.5 m
- length: 7.40 m
- width: 0.25 m
- water depth: 0.16 m

The test section is located 5.0 m downstream of the inlet, where the boundary layer under neutral conditions is fully-developed. This condition is reached thanks to small plates to keep the channel bottom upsilon the building.

- obstacle: B=H=0.02 m in the middle section of the channel (y=0)
- free stream velocity \((u_0) \): 0.33 m /s
- Reynolds number: \( \text{Re} \) (considering the friction velocity)

GEOMETRICAL CONFIGURATIONS

- AR = 1.5 and 1.15 (\( x = 0.5 \) and 0.4)
- AR = 1.75 and 2 (\( x = 0.36 \) and 0.31)

Morphometric methods

Two classes of morphometric methods are considered: (i) methods that use \( H \) (height-based approach); (ii) methods that use \( H \) and \( L \). In the first, simpler method, \( z_0 \) and \( z_0^* \) are calculated as a fraction of the average building height, viz:

\[ z_0 = \frac{L}{\gamma} \]  

\[ z_0^* = \frac{L}{\gamma'} \]  

(2) where \( \gamma \) and \( \gamma' \) are empirical coefficients. Several choices of this couple of coefficients have been proposed in the literature; one of the most utilized, i.e. \( \gamma \) and \( \gamma' = 0.5 \), was proposed by Grimmond and Oke (1999, G099).

Among the parameterizations based on the second method, the one by Kubokata (1980, K11), based on field experiments, viz:

\[ z_0 = \frac{L}{\gamma} \]  

\[ z_0^* = \frac{L}{\gamma'} \]  

(3)

That proposed by Crowther (1971, CT1), basis of wind-tunnel experiments viz:

\[ z_0 = \frac{L}{\gamma} \]  

\[ z_0^* = \frac{L}{\gamma'} \]  

(4)

on the equation (4) is valid only for \( 1.0 < L / z_0 < 2.5 \). CT1 proposed a curve for \( z_0^* \) ranging from \( z_0 > 0 \) to \( z_0 = 0 \). Using this curve, the validity of the law can be extended by means of the polynomial expression valid for \( 0.25 < z_0 < 0.5 \):

\[ z_0 = \frac{1}{0.33} \]  

\[ z_0^* = \frac{1}{0.33} \]  

(5)

where the coefficients \( C \), \( C_0 \), \( C_2 \), \( C_4 \), \( C_5 \), \( C_6 \) and \( C_7 \) are determined by fitting the original curve proposed by CT1. One of the expressions for \( z_0 \) and \( z_0^* \) based on the second method is that proposed by Kastner-Klein and Rytz (2004, KR04), obtained by using wind-tunnel data:

\[ z_0 = \frac{1}{0.33} \]  

\[ z_0^* = \frac{1}{0.33} \]  

(6)

Table 1: \( z_0 \) and \( z_0^* \) calculated with the morphometric methods based on \( H \) and \( \gamma \). The corresponding friction velocities based on the profiles shown in Figure 1 are also reported.

<table>
<thead>
<tr>
<th>Method</th>
<th>( z_0 ) (m)</th>
<th>( z_0^* ) (m)</th>
<th>( u_0 ) (m/s)</th>
<th>( d ) (m)</th>
<th>( d_0 ) (m)</th>
<th>( d_0^* ) (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G099</td>
<td>0.02</td>
<td>0.014</td>
<td>0.004</td>
<td>0.016</td>
<td>0.016</td>
<td>0.016</td>
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<tr>
<td>K11</td>
<td>0.097</td>
<td>0.008</td>
<td>0.007</td>
<td>0.010</td>
<td>0.012</td>
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<tr>
<td>KR04</td>
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<td>0.033</td>
<td>0.018</td>
<td>0.019</td>
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<tr>
<td>PML15</td>
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<td>0.009</td>
<td>0.009</td>
<td>0.015</td>
<td>0.016</td>
<td>0.016</td>
</tr>
</tbody>
</table>

5) Conclusions

Trends for \( H \) differs substantially from the others: it suggests that the transition between the skimming flow and the wake interference regime coexists with that of the 3D flow \( (z_p=0.35) \), rather than with that conventionally recognised for 2D flows \( (z_p=0.5, \text{ for } y=0) \).

For \( z_p=0.5 \) (skimming flow), all the models underestimate observations. Overall, K11 shows the larger discrepancy between modelled and observed velocity; the other four models overestimate the measurements close to the canopy layer, while they show a large underestimation above it. In contrast, for \( z_p < 0.3 \) a substantial lowering of the gap with observations occurs for all the two models, both close to the canopy and at higher levels. The agreement improves particularly for G099, KR04 and PML15, while K11 and CT1 show again a general underestimation of the velocity.

The computation with observation is reasonably good \( (R^2=115) \) for G099, KR04 and PML15 when \( z_p=0.33 \), while large errors occur for K11 and CT1. It means that all models work reasonably well for \( z_p=0.5 \), i.e. for the wake interference regime.

References

- Pellicceri, A., P Monti and G Leuzzi, 2015: An alternative wind profile formulation for urban areas in neutral conditions. JPM, 15, 125-146.