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Influence of Upstream Fetch for Environmental Wind Engineering Applications

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SUMMARY
With the rapid urbanization process, concern has increased about the wind environment in urban/suburban areas. However, current wind load provisions and studies mainly concentrate on wind load on structures and the approaching wind profile characteristics. Indeed, studies related to environmental wind engineering are limited. The objective of this study is to investigate the influence of upstream fetch length on environmental wind engineering problems such as pedestrian level winds (PLW). The suburban area of Westmount, Montreal is selected for case study. Both experimental and numerical methods are adopted. The results indicate that the upstream fetch length that influence the PLW estimation is as short as 300 m in suburban areas.

Keywords: environmental wind engineering, upstream exposure, pedestrian level wind

1. INTRODUCTION

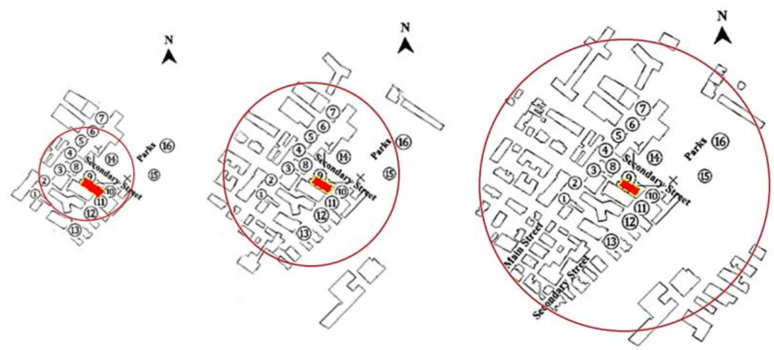
The rapid urbanization process in numerous cities around the world has brought the improvement of infrastructure and rapid economic growth but, at the same time, urban construction leading to significant changes in upstream exposure, which will affect the wind environment. The large pedestrian level wind (PLW) speed will affect pedestrian comfort and safety as well as reduce residents' pleasant and healthy feelings, while a too small PLW speed will cause pollution diffusion problem and heat island effect. Therefore, the assessment of PLW velocity is a significant topic in the rapid urbanization process. The prediction of PLW is usually conducted by either numerical or experimental methodologies. The region of interest with surrounding buildings of a certain upstream fetch that influence the PLW are modelled in both method types.

In previous studies, the influence of upstream fetch length on approaching velocity profile has been studied by Letchford et al. (2001), Weng et al. (2010) and Yu et al. (2021) et al.; and of wind load on structures by Wang and Stathopoulos (2006). However, the length of the upstream fetch that has an impact on PLW velocity is still not clear. In this study, the influence of upstream fetch length on PLW is investigated by considering a neighbourhood of the Westmount, Montreal as a case study.

2. CASE STUDY

The exposure of Westmount, Montreal belongs to Suburban consisting of low-rise to mid-rise sparsely distributed buildings. Three upstream fetch lengths of 100 m, 200 m, and 300 m are adopted to analysis the influence of upstream exposure on wind environment of pedestrian level, - see the red rectangular in Figure 2. The corresponding areas with building layout is shown in Figure 3. Sixteen (16) locations on the main street and secondary streets close are selected to observe the PLW velocity. Three most critical wind directions are selected for investigation, namely N, NNE, NE.

Figure 1. Westmount, Montreal case.



(a) R = 100 m (b) R = 200 m (c) R = 300 m

Figure 2. Models of different upstream fetch lengths.

3. EXPERIMENTAL METHOD

The wind tunnel test of Westmount, Montreal was conducted at the Building Aerodynamics Laboratory of Concordia University in Montreal, Canada, - see Figure 3. This wind tunnel test was designed to verify the accuracy of the computational method. The scaling down of the investigative area model is 1:400, and the blockage ratio of the test is 3%, which is less than 5% to minimize constraining blockage effects. The PLW velocities were measured by the Cobra probe at the height of 0.005 m above the ground in the scaled model, corresponding to 2 m of pedestrian level at full scale.

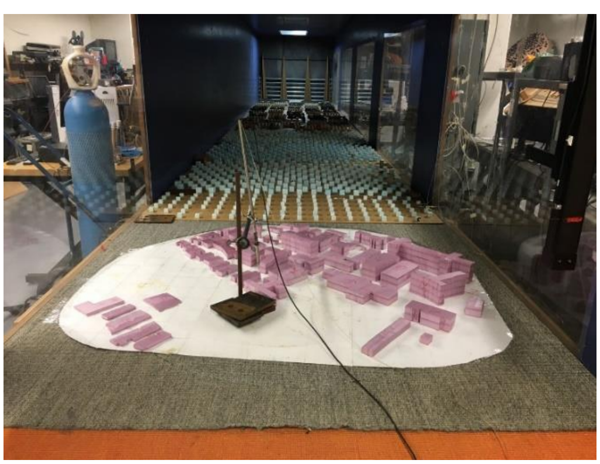


Figure 3. Wind tunnel test of Westmount, Montreal.

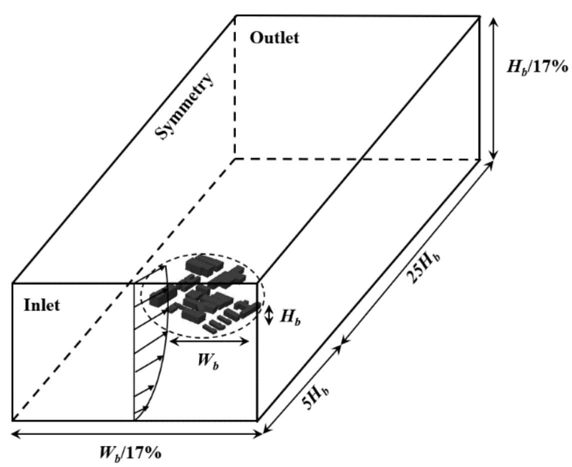


Figure 4. Schematic view of the computational domain.

4. NUMERICAL METHOD

The numerical method, as an alternative to the wind tunnel test approach, was adopted for the investigation of the influence of different ranges of upstream fetch on PLW. The Realizable k-ε turbulence model was used. The size of computational domain is chosen according to the AIJ guidelines (Tominaga et al., 2008) and Best Practice Guidelines (Frank, 2010), - see Figure 4. The appropriate meshing strategy is obtained by independent tests. Most of the cells are hexahedral and the others are prismatic. This meshing strategy can avoid the convergence problems caused by tetrahedral or pyramid cells. The height of the first layer is 0.03 m. The accuracy of the numerical method is verified by comparing the PLW results with those of the wind tunnel test.

5. RESULTS

To examine the influence of different upstream fetch lengths on PLW, the velocity ratio R_i is adopted, - see Eq. 1. The larger the value of R_i, the stronger the increase of PLW velocity, with longer upstream fetch length.

$$R_i = V_{upstream\ fetch\ of\ 300m}/V_{upstream\ fetch\ of\ 100\ m} \tag{1}$$

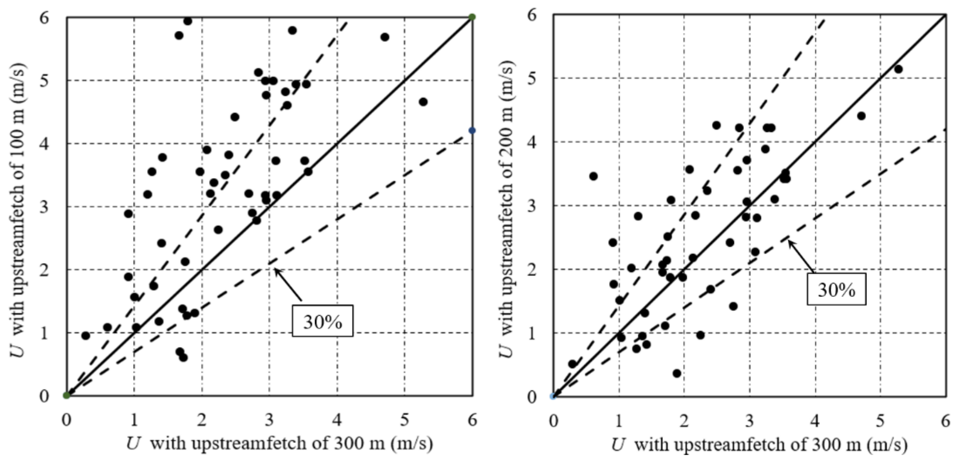
In Figure 5, observation locations of each wind directions are colored by the value of R_i to illustrate the influence of different upstream fetch lengths. For the wind directions of N, NNE, and NE, $R_i < 1$ for most of the locations, means that the PLW velocity of 300 m upstream fetch length is smaller than that with the upstream fetch of 100 m. In these wind directions, most of the observation locations are sheltered by the upstream buildings from the approaching wind, and the shelter effect of the upstream fetch of 300 m is clearly larger than that of 100 m with the increasing of upstream buildings, except some increasing at the section where the wind accelerates due to the interaction of wake flow.

(a) N wind direction (b) NNE wind direction (c) NE wind direction

Figure 5. Observation locations colored by Ri in the wind direction of N, NNE and NE.

● $0 < R_i < 1$ ● $1 < R_i < 2$ ● $2 < R_i < 4$

Figures 6 show the differences of PLW velocity with upstream fetch of 100 m *versus* 300 m, and 200 m *versus* 300 m. The deviations between the results of the upstream fetch length of 200 m and 300 m are much smaller than that of the upstream fetch length of 100 m and 300 m, means that the variation of PLW velocity becomes steady with the increasing of fetch length. Although there are shelter and channeling effects for different wind directions, the deviation of PLW velocities of the upstream fetch length of 200 m and 300 m at most locations are within 30%. It can be concluded that for the PLW environment investigations, the upstream fetch length of 300 m can be adopted in suburban exposure.



(a) 100 m *versus* 300 m (b) 200 m *versus* 300 m

Figure 6. Comparison of R_i with upstream fetch length. Dashed black lines represent 30% deviations, as indicated.

6. CONCLUSIONS

The minimum upstream fetch length specified in previous research has been always focused on the wind load on buildings or the approaching wind characteristic profiles. This paper examines the influence of upstream fetch length on environmental wind engineering problems. If the considered upstream fetch length is not large enough, the assessment of the wind environment may not be accurate. In contrast, if the considered upstream fetch length is too large, the computational efficiency will be reduced. The case study of a neighbourhood in Westmount, Montreal has been adopted, with the upstream fetch of 100 m, 200 m and 300 m. The results show that the PLW velocity of Westmount, Montreal with the upstream fetch of 200 m and 300 m is within 30% for most observation locations, and the upstream fetch length of 300 m can be adopted in suburban exposure for the PLW investigations. The study will be also presented in non-dimensional parameters for more universal applicability.

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