Modeling flow and scalar dispersion around Cheomseongdae

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1. Introduction

Understanding building-scale flow and dispersion is a basis for understanding urban-scale flow and dispersion and can help to solve numerous urban environmental problems such as ensuring sunshine, reducing heat island effects, optimizing ventilation, etc. (Chan, *et al.*2001). Extensive studies have been made to understand mean flow, turbulence statistics, and scalar dispersion around obstacles. These include numerical, fluid experimental, and observational studies. In almost all previous numerical and fluid experimental studies, obstacles considered are simply shaped and in terms of obstacle aspect ratio relatively short. Buildings in urban areas have various shapes and heights. Especially, buildings in central business districts are tall and slender. Therefore, it might be interesting to simulate and understand flow and dispersion around an obstacle that is complex compared with the simple obstacles in geometry. This will enhance our understanding of flow and dispersion in the presence of complex obstacles. This motivated the present study. This study aims to find a three dimensional flow structure around a single but rather complex obstacle and investigate the effects of ambient wind speed and turbulence intensity on mean flow and scalar dispersion around the obstacle. For this, Cheomseongdae, an ancient astronomical observatory in Gyeongju, Korea, is selected as a model obstacle because of its unique shape and also its historical and scientific importance.

2. Numerical model and experimental design

The numerical model used in this study is the same as that of Kim and Baik (2004). For computational efficiency, a non-uniform grid system with 116, 89, and 83 cells in the *x*-, *y*-, and *z*-directions, respectively, is used. Nine numerical experiments are performed with different meteorological conditions and obstacle shapes. In the control experiment, U_r is 5 m s^{-1} and turbulent kinetic energy is 0.5% of mean flow kinetic energy at the inflow boundary.

3. Results

We first examine the mean flow field in the control experiment. Based upon the analysis of simulated mean flow field, three dimensional structure around Cheomseongdae is schematically drawn in Fig. 1. Flow impingement on the upwind face produces a stagnation point, hence resulting in upward motion above the stagnation point and downward motion below it. Near the ground surface, a horseshoe vortex is generated due to the downward motion. The horseshoe vortex expands downwind, wrapping around the lower part of Cheomseongdae. Flow separation near the upwind edge of the roof produces flow reattachment on the roof and a recirculation zone above it.

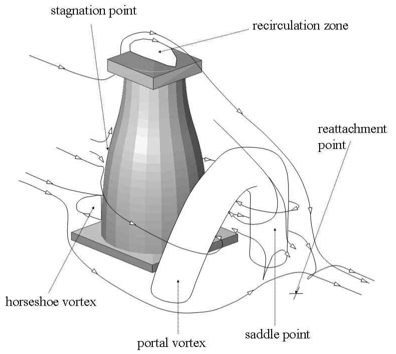


Fig. 1. Schematic illustration of mean flow field around Cheomseongdae.

In the wake of Cheomseongdae, a portal vortex whose ends touch down the ground surface is generated. The vertical cross-section of the portal vortex at y = 0 is named as a recirculation zone. The horizontal cross-section of the portal vortex shows a double-vortex circulation behind Cheomseongdae.

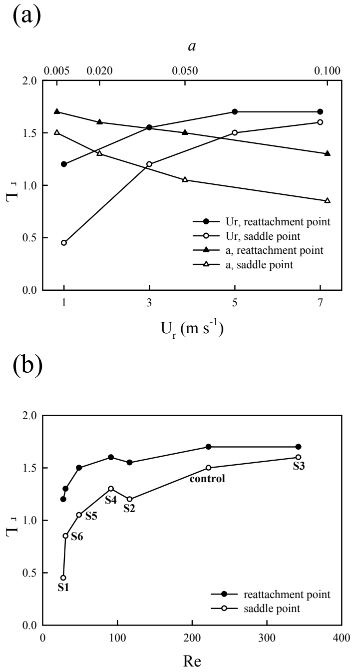
Fig. 2 shows the opposing effects of ambient wind speed and turbulence intensity on the size of the recirculation zone. To take account of the effects of these two factors together, we define the effective Reynolds number Re for a given space (S) as

$$\mathrm{Re} = \frac{\overline{V}H}{\overline{v}_t},$$

where $\overline{V}$ and $\overline{v}_t$ are the average mean wind speed and turbulent diffusivity given by

$$\overline{V} = \frac{1}{S}\int_s V ds, \quad \overline{v}_t = \frac{1}{S}\int_s v_t ds.$$

H is the height of Cheomseongdae. Fig. 2b shows the distance to the saddle point and flow reattachment point on the ground surface as a function of the effective Reynolds number. As Re increases, the distance to the saddle point (also flow reattachment point) increases except for the S2 experiment. This implies that inertial force plays a role in increasing the distance, while eddy force in decreasing the distance. Also, it is implied that flow with relatively strong inertial force can produce the recirculation zone above the roof by enhancing flow separation there.



Acknowledgements

This research was supported by the Climate Environment System Research Center sponsored by the SRC Program of the Korea Science and Engineering Foundation and also by the Brain Korea 21 Project.

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