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Study of wind flow over a 6 m cube using improved delayed detached Eddy simulation

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ABSTRACT

The proper selection of a turbulent model greatly influences the prediction of wind in an urban environment. The purpose of this study is to evaluate the capabilities of the improved delayed detached eddy simulation (IDDES) model in a wind flow simulation. A cube (Silsoe cube, 6 m in dimension) with a normal wind direction under typical atmospheric conditions was simulated. Some computational parameters were thoroughly evaluated and analyzed, including the grid resolution, the discretization time step and the sampling time. The selected time-step (0.002 s) and sampling time (10 min) are the most economic and effective. The experimental results and large eddy simulation (LES) results were used to evaluate the performance of the IDDES model. The simulation results include the mean, maximum, minimum, and standard deviation of the pressure coefficients, and the reattachment length. The IDDES model shows results similar to those obtained using the LES model. The distributions of instantaneous velocity field and pressure field around the cube were also discussed, we concluded that the IDDES model is able to provide the acceptable prediction of the mean and unsteady features compared with full-scale experimental data around the Silsoe cube. Our study suggests that the IDDES model could be able to simulate the wind-structure interaction around a Silsoe cube. For the simulation of wind flow over an urban area, IDDES model could be potentially suitable but need to be further verified because of more complex nature flow than cube.

1. Introduction

Wind has an influence on daily life, and design professionals such as planners, architects and engineers need to analyze the wind environment around a building to improve the design (Liu and Niu, 2016; Liu et al., 2012; Tominaga and Stathopoulos, 2009). Before starting an urban development project and planning, wind-structure interaction often needs to be properly considered owing to the wind-structure interaction governing the effects of buildings on the atmospheric flow (Zhang et al., 2015). Wind tunnel tests and numerical calculations are two acceptable ways to evaluate an outdoor wind environment. However, wind tunnel tests are expensive, require lengthy periods of experimentation, and are difficult to study under multiple types of situations (Lim et al., 2009; Richards and Hoxey, 2012a; Tominaga et al., 2008). The computational fluid dynamics (CFD) method has been widely used in outdoor environmental simulations (Blocken, 2014) owing to its mathematical accuracy, capabilities, and cost-effectiveness; however, the proper choice of a numerical method remains a challenge, and hence, validation is always required for CFD to ensure that the simulation can generate reliable predictions of a complicated wind flow.

Because the flow around a cube includes the flow separation, vortex shedding, reattachment, and many other unsteady flow features, Richards and his co-workers (Richards and Hoxey, 2002, 2004, 2006, 2008; Richards et al., 2001; Richards and Quinn, 2002) constructed the cube (6 m in dimension) in an 'open country' at Silsoe, UK to provide a facility for the fundamental studies of interactions between the wind and various structures. They measured the surface pressure on a vertical and horizontal center line using tapping points, they also measured the wind velocity with ultrasonic anemometers. These full-scale experimental data were used to evaluate the computational fluid dynamic (CFD) models.

Richards and Quinn, 2002 summarized previous studies that used Reynolds averaged Navier-Stokes simulation (RANS) model to simulate wind flow around Silsoe cube and concluded that the k-ε model is slightly less reliable than a wind tunnel. Wright and Easom, 2003 used the RANS,

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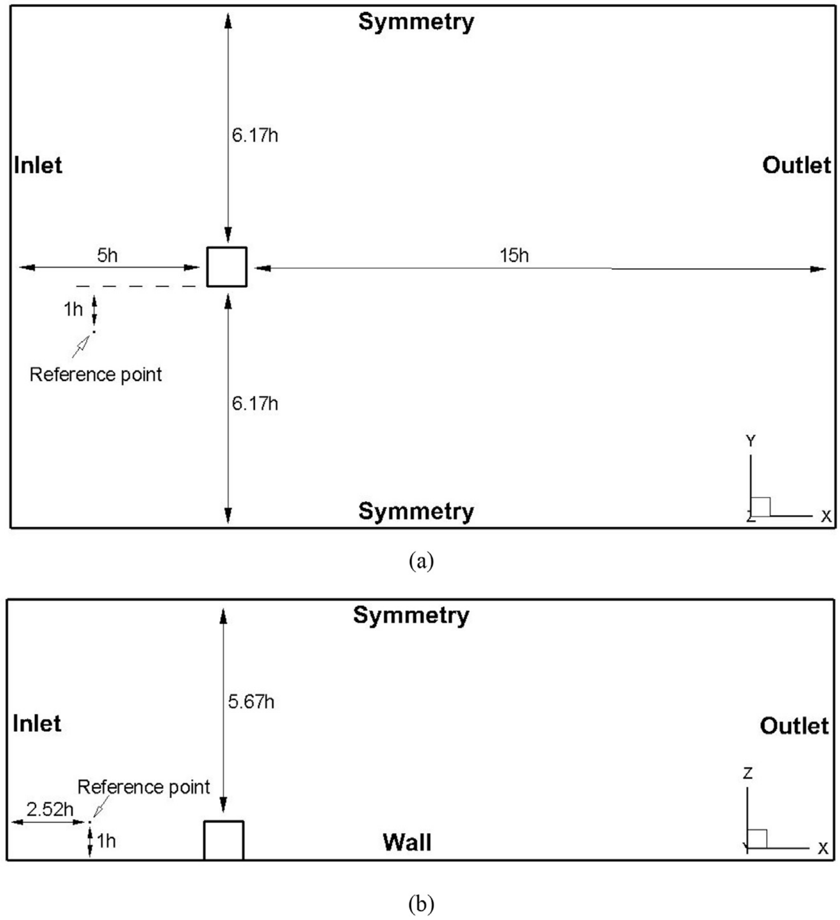

Fig. 1. Computational domain: (a) top view and (b) front view.

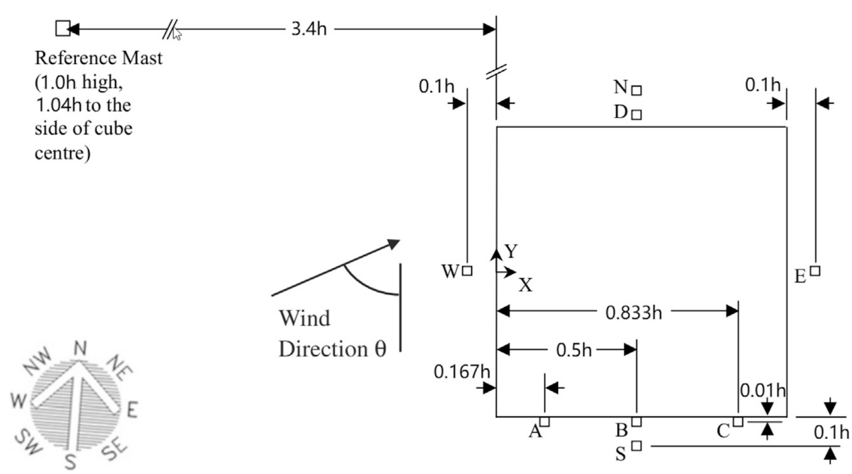

Fig. 2. Plan view of Silsoe cube showing the measurement positions at mid-height (Richards and Hoxey, 2002).

a nonlinear k-ε turbulence model, to simulate the Silsoe cube, and were able to reproduce the pressure distribution on the windward face of the cube, but had difficulty on the top, side, and leeward faces. It was determined that isotropic turbulence models are inadequate in this type of case. Tominaga and Stathopoulos, 2009 also used a standard k-ε model to simulate the flow field over a cube, but not the Silsoe cube, and concluded that the standard k-ε model cannot reproduce the reverse flow on a roof. Later, they (Tominaga and Stathopoulos, 2010) used a large eddy simulation (LES), and concluded that simple LES modeling provides better results than RNG modeling. Lim et al., 2009 used the LES to model the flow around a surface-mounted cube placed in a typical wind environment, and concluded that if provided properly formulated inflow and boundary conditions, the LES is a viable tool for the simulation of flow over an isolated body. More recently, Richards and Hoxey, 2012a, b provided the standard deviation, and maximum and minimum pressure coefficient data, and Richards and Norris, 2015 used the LES to understand some of the unsteady phenomena observed at full scale.

As a hybrid unsteady RANS/LES approach, detached eddy simulation (DES) combines unsteady RANS (URANS) for modeling the dissipation at small scales near the wall with the LES for modeling the unsteady