

Introduction of unstructured-grid system on LES for wind pressure estimation on a building in cities

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ABSTRACT: This paper discusses the availability of LES on the wind-resistant design of buildings in cities. In order to predict the wind pressures on actual complicated-shaped buildings with good accuracy, we introduce the unstructured-grid system which is formulated on the open source CFD code. Especially the hybrid method is employed consisting of the Cartesian grid for the accurate turbulence structures in the urban canopy, and the unstructured-grid for the accurate wake flows around the specified building inside the densely arrayed buildings in the center of cities. The obtained results of pressure distributions, focusing on the corner of buildings, are estimated in comparison with the previous experimental data.

KEYWORDS: LES, unstructured grid, wind pressure, city

1 INTRODUCTION

This paper discusses the higher-accurate LES (Large eddy simulation) for the wind loading estimation on a specified building in cities. Thus far Urban winds have been often simulated by RANS model from an environmental point of view, where the wind velocity prediction is essential. This case showed good performance of RANS model ^[1]. On the LES of the urban wind, the Cartesian grid system with equal increment was often used and its accuracy was generally enough for the wind velocity prediction ^{[2], [3]}. However with regard to the wind pressure and force predictions, we have encountered a different story. This paper introduces the overset grid with finer mesh for the near region of the specified building by employing the unstructured grid system and realizes the accurate aerodynamic prediction by LES. In order to simulate numerically the turbulent flows around buildings in cities, we have to take care of the following issues:

- The approaching flow is a turbulent boundary layer over a rough wall.
- The other buildings exist neighboring to the specified building
- A pack of buildings cover a region with a relatively large area which forms a canopy locally.

Accordingly for constructing the numerical model we have to set up unsteady turbulent flow field at the inflow condition and impose the bottom boundary condition representing directly the surface shape of buildings and trees. The authors showed, on the preceding paper ^[3], the numerical model for urban flows in Fig. 1. This model consists of two driver regions for the approaching turbulent flow. One is for generating the turbulent boundary layer over rough surface by the rescaling technique ^[4] and the other is for arranging the boundary layer to develop along the fetch under the boundary condition imposed to the urban area. Also, the model has the domain which is used for LES of the flow over an actual urban area. Using the uniform grids with 2.5m in the horizontal direction and the stretching grid upward with sufficiently fine grid near the ground, the building are represented by using several tens meshes for the building

breadth. It is not fine enough for mesh to represent the building shape but the previous LES examples showed the success of the LES prediction for the flow field. Accordingly the Cartesian-grid based method can simulate the gap flows among the buildings and transportation problems of mass and gas in cities. However the predictive accuracy of the above method is ambiguous for the estimation of the wind pressures and forces on the specified building which is focused on in the city.

This study examines advantages and disadvantages for the LES model applied to the wind-resistant design of buildings under high wind and proposes the higher-accurate predictive method appropriate to practical usage.

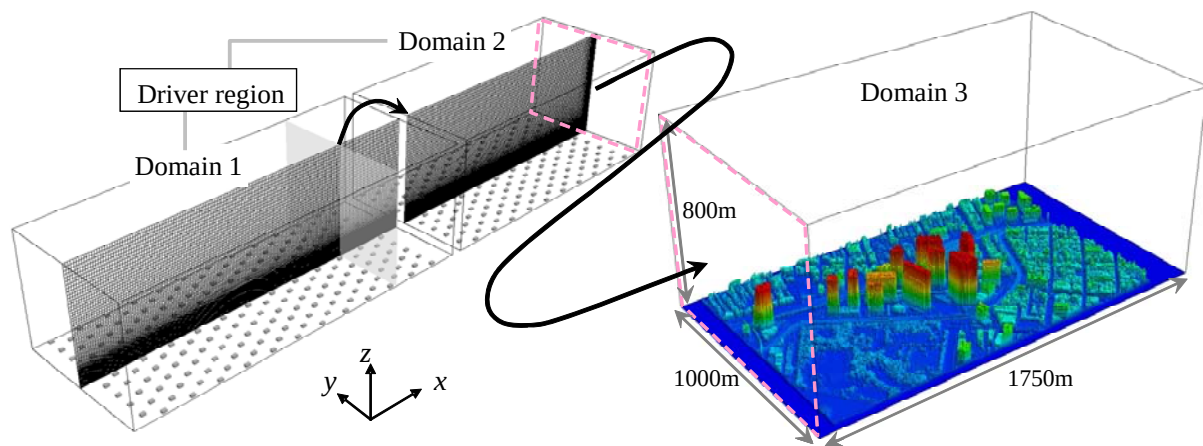


Figure 1. Numerical model of urban wind (Cartesian grid).

2 PROBLEM FORMULATIONS

2.1 Hybrid method

For the LES analysis for the specified building in the city center, it is important to set up how to resolve the flow around the building and its near region or the urban area consisting of many other buildings. As far as the prediction of wind velocity, it is not so significant to reproduce the shape of the building. The Cartesian grid method has been applied to this problem (see Figure 1). However in order to predict the wind pressures and forces, the overlaid method is sometimes employed, introducing the generalized coordinate system. When taking into consideration the building aspect in city, complexity level is very high due to the cladding, wall texture, window sash and balcony. Their representation requires multiple superposition of the overlaid area. These parts are so small that their influence on the wind pressure and force is weak, so they are possibly neglected. For checking it, this study introduces the numerical model which can estimate the effect of cladding, such as an unstructured grid system. Here we pick up OpenFOAM which is widely used as an open source code. Figure 2 illustrates the numerical model where the area including the specified building and its circumstances are clipped for the unstructured grid area obtained by the mesh generation software (SnappyHexa).

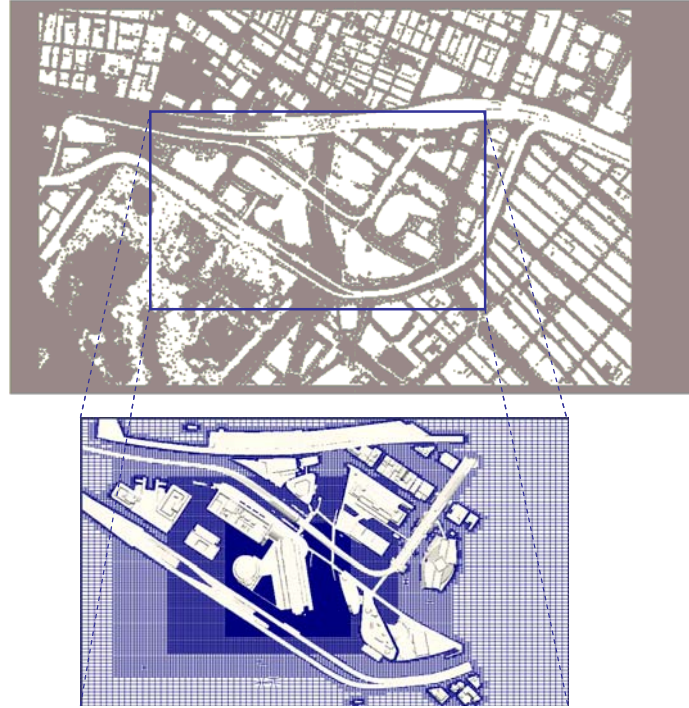


Figure 2. Unstructured grid for near-region of the building.

2.2 Turbulent simulation

The governing equations for LES are the filtered forms for the continuity and the incompressible Navier-Stokes equations as follows:

$$\frac{\partial \bar{u}_i}{\partial x_i} = 0 \quad (1)$$

$$\frac{\partial \bar{u}_i}{\partial t} + \bar{u}_j \frac{\partial \bar{u}_i}{\partial x_j} = -\frac{\partial \bar{p}}{\partial x_i} + \frac{\partial}{\partial x_j} \frac{1}{\text{Re}} \left(\frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i} \right) - \frac{\partial}{\partial x_j} \tau_{ij} \quad (2)$$

where u_i , p , Re and τ_{ij} stand for velocity, pressure, the Reynolds number and the sub-grid scale (SGS) Reynolds stress ($u_i u_j - \bar{u}_i \bar{u}_j$). Concerning the sub-grid scale modeling, the Smagorinsky type of dynamic procedure^{[5],[6]} was employed for representing the eddy viscosity concept.

$$\tau_{ij} - \frac{1}{3} \delta_{ij} \tau_{kk} = -2\nu_e \bar{S}_{ij} = -2C\bar{\Delta}^2 |\bar{S}| \bar{S}_{ij} \quad (3)$$

where C denotes the model coefficient for SGS modeling of velocity, S_{ij} the strain rate tensor, and $\bar{\Delta} = (\bar{\Delta}_x \bar{\Delta}_y \bar{\Delta}_z)^{1/3}$ grid-filter width, respectively. The model coefficients C are evaluated dynamically using the Germano identity.

$$C = -\frac{\langle L_{ij} M_{ij} \rangle}{\langle M_{ij} M_{ij} \rangle}, \quad L_{ij} = \tilde{u}_i \tilde{u}_j - \tilde{u}_i \tilde{u}_j, \quad M_{ij} = 2 \left(\tilde{\Delta}^2 |\tilde{S}| \tilde{S}_{ij} - \overline{\Delta}^2 |\overline{S}| \overline{S}_{ij} \right) \quad (4)$$

2.3 Unstructured grid embedded in the near region of the specified building

According to Figure 3, the curved surface of the building can be represented smoothly. On the inflow boundary of the unstructured grid area, turbulent flow is given by one-way method, which is obtained using LES on the Cartesian coordinate grid system. Appropriate resolution to the near region of the building, neighboring area and the surrounding buildings area is selected making use of the property of the unstructured grid such as the variability of the resolution on each area. Numerical method of OpenFOAM is summarized as follows^[7]. This code uses the finite volume method to solve the systems of partial differential equations ascribed on any three dimensional unstructured grid of tetra, prism, hexa and polyhedral cells. The temporal term of the governing equations is treated by using the Crank-Nicolson scheme, which is the second-order difference in time. Other terms of the governing equations are discretized using the second-order limited central difference. The governing equations are solved sequentially using the resulting PISO (Pressure-Implicit Splitting Operation) algorithm. The solution is performed implicitly by matrix inversion using the incomplete Cholesky conjugate gradient method. The code is parallelized using the message-passing interface (MPI).

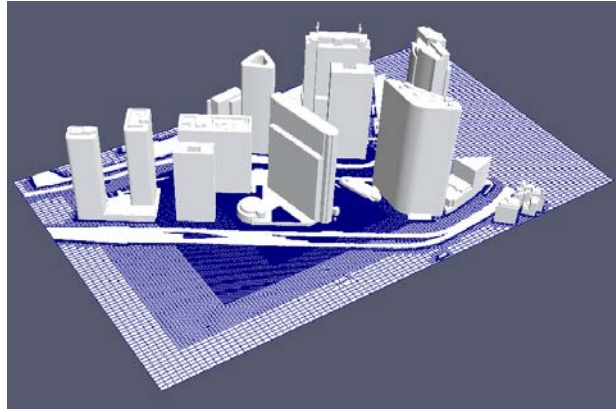


Figure 3. Unstructured grid system around buildings with smoothly curved surfaces.

3 LES RESULTS BY THE OPEN FOAM

This session shows the numerical results for turbulent flows around the buildings obtained by LES using Open FOAM as an open source code.

Figure 4 depicts the LES results for the wind velocity distributions among the densely arrayed tall buildings. It can be recognized that the flow with fully developed turbulence comes from the inflow boundary into the computational region. Also, the separated flow from a plate-shaped building at the center acts directly on the wing-type building behind and rolls into the wake formed between these two buildings. This rolling up is stronger at lower level. Also, it generates the high wind region in front of the wing-type building.

Figure 5 illustrates the turbulence structures developed behind a pack of the tall buildings. We can see that the wind velocity decreases in the wake, as increasing the fluctuation with small vortices generated there. These vortices exist in the higher altitude as well and influence widely the mechanism of unsteady flow patterns around the top edge of urban canopy.