

LES for wind load estimation by unstructured grid system

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ABSTRACT: Recent development of high-performance computers and techniques on computational fluid engineering has enabled us to simulate the complicated flow such as the wind in urban area. Large Eddy Simulation (LES) is expected to be adopted as an effective technique to evaluate wind load on buildings for wind-resistant design. In this research, the accuracy of LES to evaluate surface pressures on the 3D square cylinder model is examined. Especially, the availability of LES using unstructured grid system is studied to estimate fluctuating as well as mean component of pressures by comparison with experimental results. The computed results correlate highly with the experiments, including the case of a square cylinder with angle of attack for wind direction which introduces a local negative pressure on the side.

KEYWORDS: LES, Unstructured grid system, Fluctuating pressure, Square cylinder.

1 INTRODUCTION

As a result of wide spread of commercial or open source CFD software on the research as well as its practical usage, very large scale computations of complicated flow such as wind around a building and urban flows in cities have been often performed. Recent development of parallel computing technique based on the unstructured grid systems makes it possible to deal with the actual flow phenomena. While, it remains still important to investigate the accuracy of time variation of the physical quantities under the unsteady numerical simulation, such as Large Eddy Simulation (LES). So, using a fundamental object, many researchers have tried to predict the aerodynamic forces and pressures under the unsteady situations. Kataoka and Tamura ^[1] carried out the numerical prediction of the peak pressures on three-dimensional square cylinder by the overset structured grid system based on the generalized coordinate system. They suffered from the reproducibility of the minimum local negative peak pressure, because of the insufficient power of turbulence structures.

Unstructured grid systems are superior to conventional structured grid system in terms of not only the adaptability to configuration but also flexibility to element size density at each location in the computational region. Therefore the unstructured grid with local refinement can meet the sensitivity of aerodynamic forces on the square cylinder with a glancing angle ^[2]. This paper examines the accuracy of LES based on the unstructured grid system. Especially, focusing on the local pressure fluctuation, which is required to estimate the wind loads for claddings, the validity of LES is examined by comparison with experimental data.

2 BUILDING MODEL

A square cylinder model is chosen as an objective building and its width (B), depth (D) and height (H) are 30m, 30m and 90m respectively. Namely, the aspect ratio H/B is equal to 3. The design wind speed is set as $U_H=41.9\text{m/s}$ at the building's top.

3 WIND TUNNEL EXPERIMENT

The wind-tunnel experiment is carried out for obtaining reference data of fluctuating wind pressures. A 1/300 scaled model is used and wind pressures are measured at 308 points on the walls (figure 1 and 2). The experimental wind velocity is set as $U_H=11.6\text{m/s}$ and the experimental Reynolds number is 77,000. The time- histories of wall surface pressures are recorded at 1kHz sampling frequency. Then they are converted into the time- histories of 1-second mean pressures with real scale by taking moving average over consecutive 12 data. The 4 parts of 10-minute (real scale) time- histories are taken and the pressure coefficients (mean value, fluctuating value, maximum value and minimum value) are determined by taking ensemble averaging over 4 values obtained from each 10-minute time- histories.

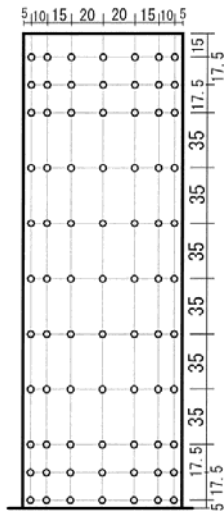


Figure 1. Measurement points

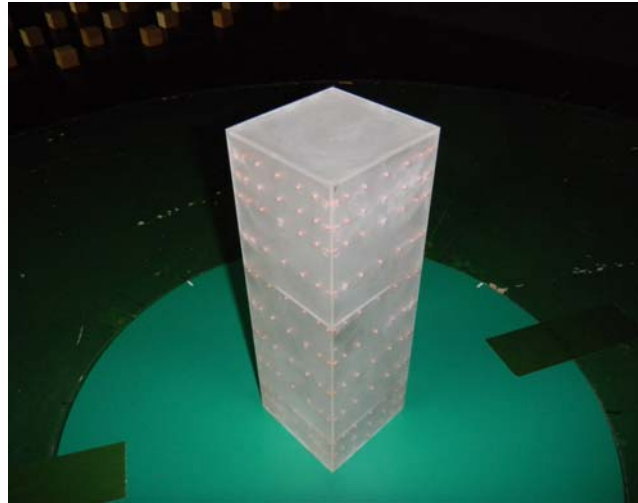


Figure 2. Experimental model

4 NUMERICAL METHOD

Three-dimensional incompressible Navier-Stokes equations are used as governing equations. The Reynolds number is set to 72,000. Equations are transformed into the discretized form by the finite volume method (FVM) and computational domain is divided using the tetrahedral and prismatic cells. As the flow velocities and the pressures are defined on the vertexes of cells, the configuration of control volume is polyhedral. The second-order central difference scheme is applied to the convective term and diffusion term. The time derivative term adopts the second-order implicit scheme. The physical time step is set as $\Delta t U_H/B=0.03$.

For subgrid scale model of LES, the standard Smagorinsky model is employed. The universal constant is equal to 0.15 and the filter size is automatically determined by a volume V of the con-

trol volume through $V^{1/3}$. Van Driest type of wall-damping function is applied for eddy viscosity of subgrid scale.

5 INFLOW TURBULENCE GENERATION

Inflow turbulence is numerically generated using the wind tunnel model shown in figure 3. Spires and roughness blocks are appropriately placed inside the wind tunnel model. Uniform flow is set on the inlet boundary and boundary-layer turbulence is developed in the model as is the case in the wind tunnel experiment. Time- histories of wind velocity are accumulated at each point on the section adjacent to the outlet boundary (shown in figure 3). The time- histories are saved in a file and applied to the inlet boundary of another model with a square cylinder described below as the inflow turbulence. Generated velocity profiles are shown in figure 4 with the reference wind tunnel data. The profiles of time averaged windward velocity $\langle u \rangle$ and turbulence intensity I are reproduced quite well. The power spectral density of windward velocity fluctuation is shown in figure 5 with the Karman-type spectrum. The computed spectrum power decreases rapidly at the non-dimensionalized frequencies nLx/U higher than 1.0.

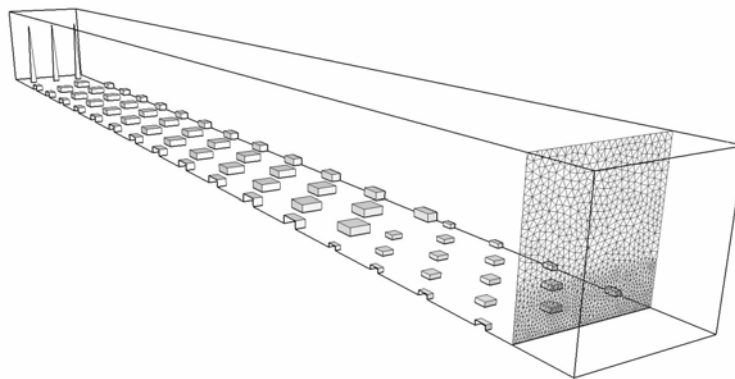


Figure 3. Computational model for inflow turbulence

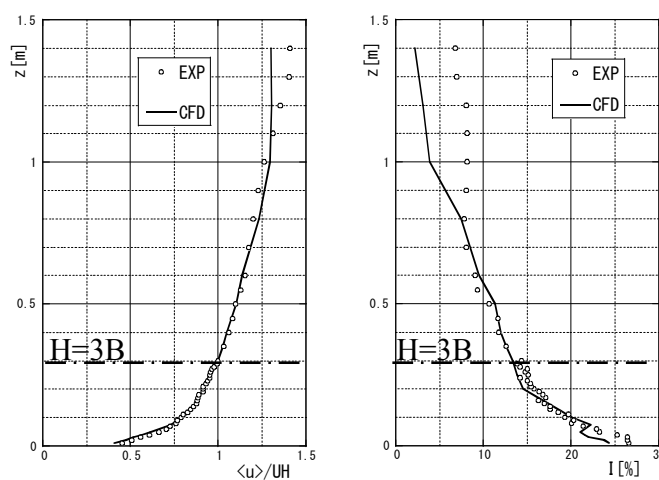


Figure 4. Generated velocity profiles

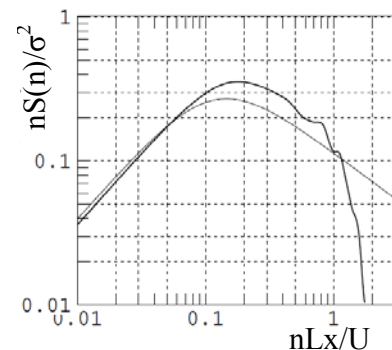


Figure 5. Power spectral density

6 GRID SYSTEM FOR 3D SQUARE CYLINDER

Figure 6 shows the unstructured grid system of whole domain for the 3D square cylinder model. The whole domain size is $20B \times 30B \times 15B$. The distance between inlet boundary and the center of square cylinder is $8B$. For the unstructured meshes the advancing front method is used to create the tetrahedral in the domain based on the volume mesh density at each location determined preliminarily. Then prismatic cells are inserted on the walls and the ground based on a triangular surface mesh. Figure 7 shows the grid systems near the square cylinder for wind directions of 0 and 15 degrees. These two grid systems are independently generated for the wind direction and possess the highest spatial resolution (approximately $B/64$) around the corner edges of the square cylinder. The number of cells is approximately 3,300,000 and the number of vertexes is approximately 660,000. The inflow turbulence, which is recorded as described in the last chapter, is imposed time-sequentially on the inlet boundary.

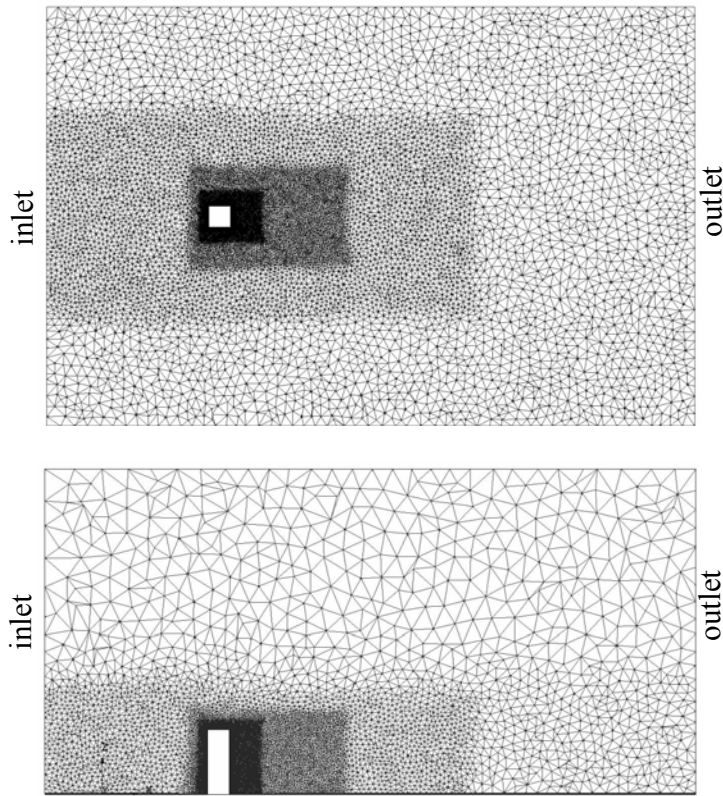


Figure 6. Unstructured grid system (whole domain)

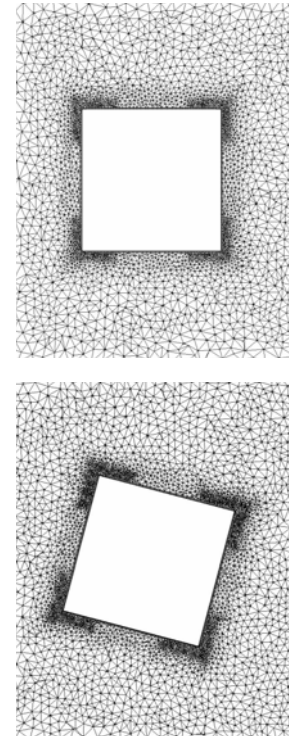


Figure 7. Unstructured grid system (near the square cylinder)

7 COMPUTED RESULTS

7.1 Distributions of surface pressure coefficients

Figure 8 and 9 show the distributions of surface pressure coefficients obtained by LES. The mean pressure coefficients C_{pm} and the fluctuating pressure coefficients C_{ps} are shown for wind directions of 0 and 15 degrees. For the case of 15-degree wind direction, surface pressure coefficients show asymmetrical distributions. The position of maximum C_{pm} value moves toward windward side of surface A and local negative pressure value, which is definitely lower than that of 0 degree, appear on the windward edge of surface B.

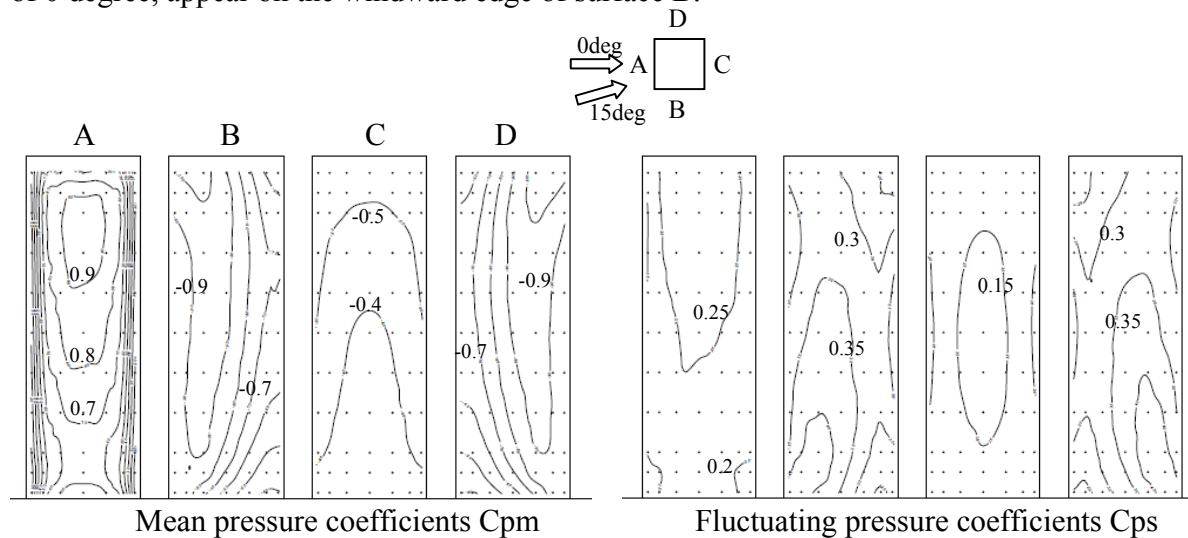


Figure 8. Distributions of surface pressure coefficients (wind direction 0 deg.)

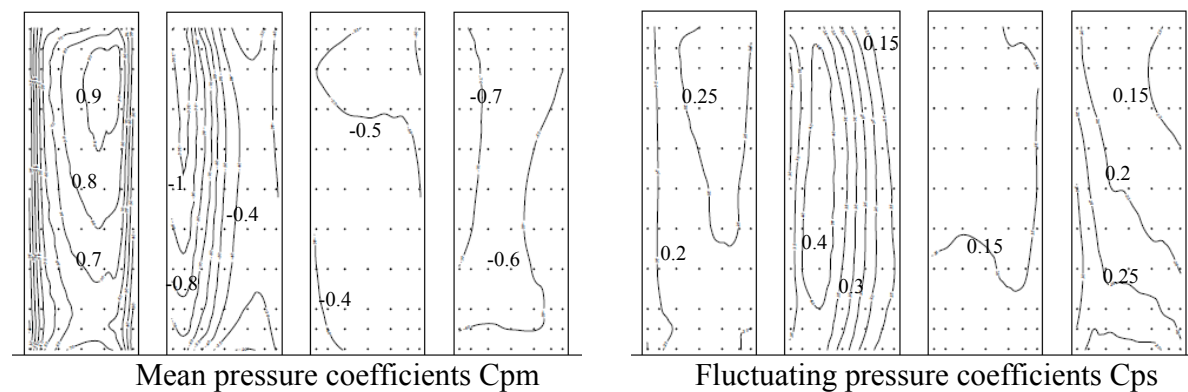


Figure 9. Distributions of surface pressure coefficients (wind direction 15 deg.)

7.2 Correlations of surface pressure coefficients with experimental results

Figure 10 and figure 11 show correlations of the computed surface pressure coefficients with the experimental results for wind directions of 0 and 15 degrees. The mean pressure coefficients C_{pm} , the fluctuating pressure coefficients C_{ps} , the maximum peak pressure coefficients C_{pmax} , and the minimum peak pressure coefficients C_{pmin} are shown. Each symbol represents the com-

puted and the experimentally-measured values at a corresponding sampling point. The computed mean pressure coefficients C_{pm} quite coincide well with the experimental data, including the case of 15-degree wind direction. The fluctuating and peak pressure coefficients C_{ps} , C_{pmax} and C_{pmin} also maintain high correlations although they show relatively disperse distributions compared with C_{pm} . The computed results slightly tend to overestimate the peak pressure coefficients. But we need to take care of an essentially-contained variability of experimental data and discuss the effects on the correlations.

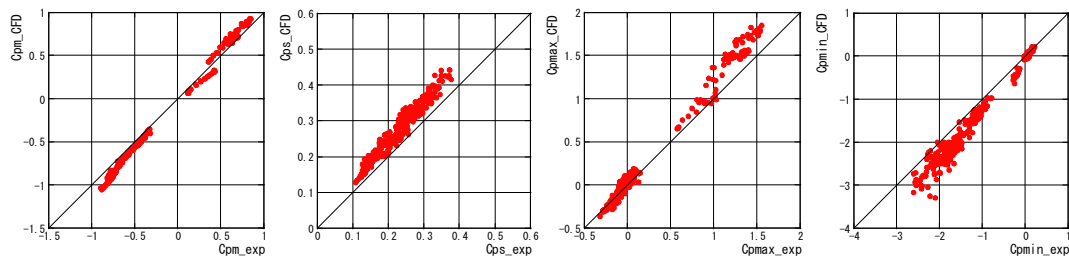


Figure 10. Correlations of pressure coefficients (0 deg)

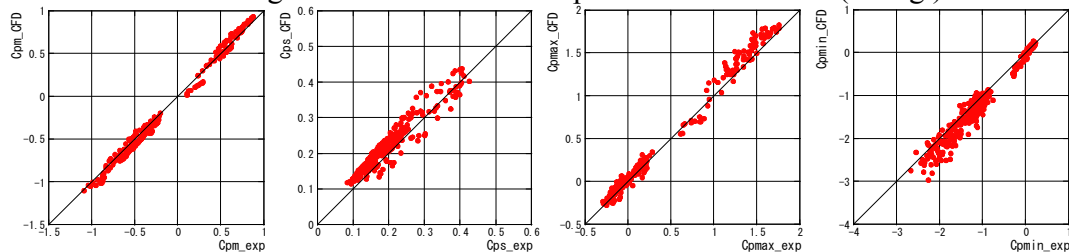


Figure 11. Correlations of pressure coefficients (15 deg)

8 CONCLUSIONS

The fluctuating as well as mean pressures on the square cylinder were computed by LES using unstructured grid system and compared with the wind tunnel experiments. On the whole, the computed results correlated highly with experiments though the computations slightly tended to overestimate the peak pressure coefficients. The reproducibility of inflow turbulence and appropriate spatial resolution at each location are required even in the case of unstructured grid system. It can be concluded that LES using unstructured grid system is effective to evaluate even the fluctuating component of the pressures on buildings for wind-resistant design.

9 REFERENCES

- 1 H.Kataoka and T.Tamura, Numerical prediction of the peak pressure distributions on square cylinder by LES, 2012, Proc. 13th International Conference of Wind Engineering, Netherlands.
- 2 M.Yoshikawa, Evaluation of wind pressure using LES with unstructured mesh system, 2010, Summaries of Technical Papers of Annual Meeting, Architectural Institute of Japan B-1 (in Japanese).