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Validation of the lattice boltzmann method for wind load assessment of a high-rise building

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SUMMARY

This study evaluates the accuracy and applicability the Lattice Boltzmann Method (LBM) for the wind load assessment of high-rise buildings. LBM simulations were conducted to assess wind pressures on an isolated building, and the results were compared with the reference experimental data. The effect of grid resolution on prediction accuracy was also investigated. With the finest grid resolution of $B/160$ (where B is the building width), the mean wind pressure coefficients showed good agreement with the measurement results. Furthermore, the standard deviations, as well as the maximum and minimum peak coefficients, were successfully captured within a ±20% range. These results demonstrate the potential of LBM as a promising approach for the wind load evaluation of high-rise buildings.

Keywords: *lattice boltzmann method, LES, wind pressure coefficient, square prism, grid resolution*

1. INTRODUCTION

In recent years, with advances in computational resources, the use of computational fluid dynamics (CFD) for predicting wind pressures and wind forces on buildings has accelerated. The calculation of design wind loads on buildings using CFD is specified in the AIJ Recommendations for Loads on Buildings (2015), and details of the calculation methods for wind-resistant design are described in the CFD guidebook (AIJ, 2017). Since 2020, CFD has been allowed for use in the performance evaluation of buildings based on time-history response analysis in Japan. This enables the numerical simulation of wind loads as part of practical building design. However, the computational cost of CFD remains substantially higher than that of conventional wind tunnel experiments. As a result, no high-rise buildings have yet been designed solely based on CFD evaluations of wind pressures.

The finite volume method (FVM) is widely used for CFD simulations. In contrast, the Lattice Boltzmann Method (LBM) offers high parallelization efficiency and is well suited for GPU computation, enabling faster simulations for large-scale CFD analyses. For evaluating wind environment for pedestrian, the grid resolution requirements were proposed by Han et al., (2020). However, LBM has not been widely used for wind load evaluation. To establish LBM as a practical option, it is necessary to clarify the computational conditions under which it can provide reliable and accurate results.

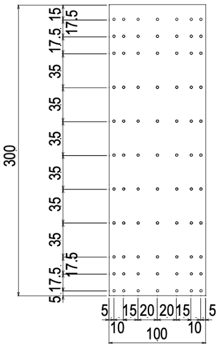
The objective of this study is to evaluate the feasibility of applying LBM to wind load evaluation by comparing the results with reference experimental data (Tanaka et al., 2012). LBM simulations were conducted for a single isolated square cylinder. By analyzing the statistical properties of wind pressures, such as the mean, standard deviation, and peak coefficients, the study aims to determine the grid resolution required to reproduce the experimental data with sufficient accuracy.

2. NUMERICAL SETUP

The target building is a square cylinder with a width *B*, depth *D*, and height *H* of 40 m, 40 m, and 120 m, respectively, at full scale. The geometric scale was set to 1/400 for both the wind tunnel experiments and CFD simulations. Figure 1 illustrates the locations of pressure taps on the target building. These locations are identical in both the wind tunnel experiments and the CFD simulation. The flow field was solved using the LBM with the Cumulant collision operator (Geier et al., 2015), employing a D3Q27 lattice model and the Smagorinsky subgrid-scale model ($C_s = 0.10$). The total simulation time was approximately 40 s in model scale. Data sampling for fluctuating wind pressures was conducted for 7 s in model scale, corresponding to 10 minutes in full scale, after the flow reached a statistically steady state. The results were averaged over five consecutive runs.

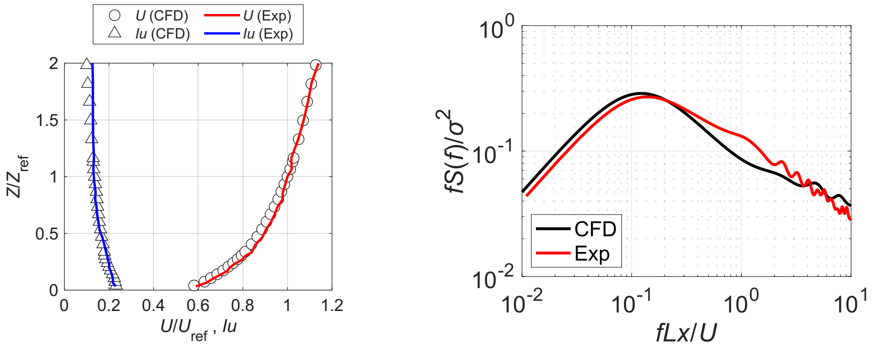
Figure 2 shows the vertical profiles of mean wind speed and turbulence intensity, as well as the power spectral density of fluctuating wind speed at model height *H*. The inflow used in the CFD simulation was generated by placing spires and roughness blocks in the computational domain. The experimental results are also plotted for comparison. These results indicate that the approach flow of the CFD simulation agrees well with the experiment.

Table 1 summarizes the computational setup, particularly the grid resolution and simulation time. All computational grids consisted of cubic cells, which were locally refined as they approached the target building. Three grid types (Grids A–C) were tested to examine grid sensitivity. Despite the high resolution exceeding 200 million cells, each simulation was completed within 12 to 24 hours per case using NVIDIA A100-SXM4-40GB 8GPUs. A previous finite volume method (FVM) simulation with over 100 million cells required 20–40 days per case using the 6,144 parallel CPUs on the *K* computer (Phuc et al., 2018). This result demonstrates a significant reduction in computational cost using GPU-based LBM simulation.



Unit [mm]

Figure 1:
Target building



(a) Profiles of inflow turbulence

(b) Power spectral density of fluctuating wind velocity in the along-wind direction at *H*

Figure 2: Characteristics of turbulent boundary layer

Table 1: Summary of computational setup

Grid type	Minimum cell size	Total number of cells* ($\times 10^6$)	Total simulation time (s)
A	2.5 mm	253.5	50,805
B	1.25 mm	260.9	64,844
C	0.625 mm	267.9	90,143

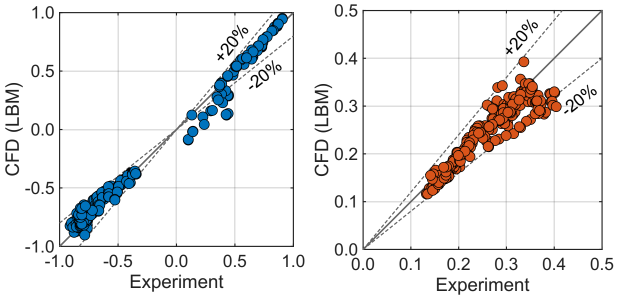
*Including flow generation region

3. RESULTS

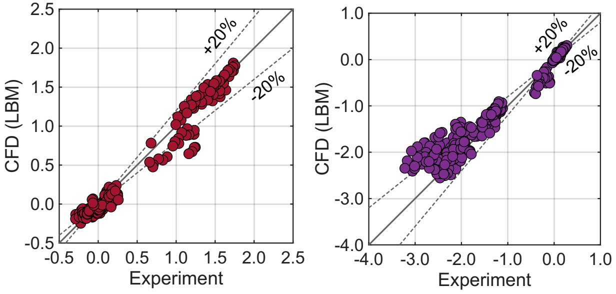
3.1. Validation with wind tunnel experiment and LBM

Figures 3 and 4 present scatter plots of wind pressure coefficients (C_p) comparing the LBM results with the wind tunnel measurements (Experiment) for two grid resolutions (Grids A and C). The plots include the mean ($C_{p\mathrm{mean}}$), standard deviation ($C_{p\mathrm{std}}$), maximum and minimum peak values ($C_{p\mathrm{max}}$ and $C_{p\mathrm{min}}$), as well as skewness and kurtosis. The dashed lines indicate a ±20% deviation threshold, which is a criterion commonly specified in Japanese CFD guidelines for structural engineering.

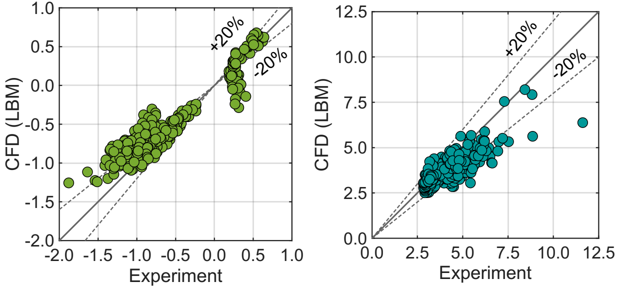
As shown in these figures, the scatter of the values decreases as the grid resolution increases. For Grid A, deviations are observed in regions with low absolute mean pressures, and the scatter is relatively large for $C_{p\mathrm{std}}$ and the peak values. In contrast, the results for Grid C align closely with the experimental data for $C_{p\mathrm{mean}}$, $C_{p\mathrm{std}}$, $C_{p\mathrm{max}}$ and $C_{p\mathrm{min}}$, demonstrating a significant improvement in accuracy with finer grid resolution. Skewness also falls within the ±20% range for Grid C. However, kurtosis shows only modest improvement even with the finest grid. This discrepancy is likely attributed to the stochastic nature of higher-order moments and experimental uncertainties, rather than insufficient grid resolution alone.



(a) $C_{p\mathrm{mean}}$ (b) $C_{p\mathrm{std}}$

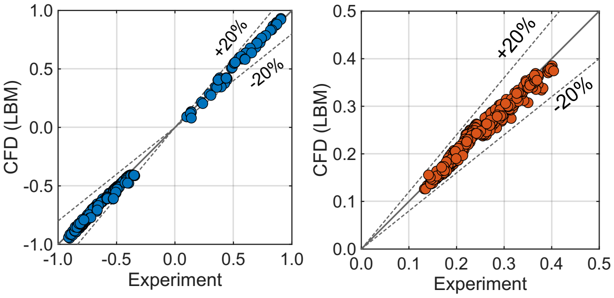


(c) $C_{p\mathrm{max}}$ (d) $C_{p\mathrm{min}}$

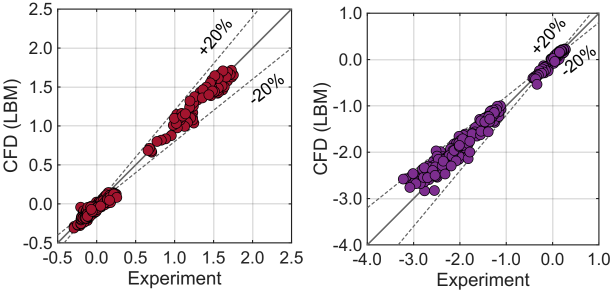


(e) Skewness (f) Kurtosis

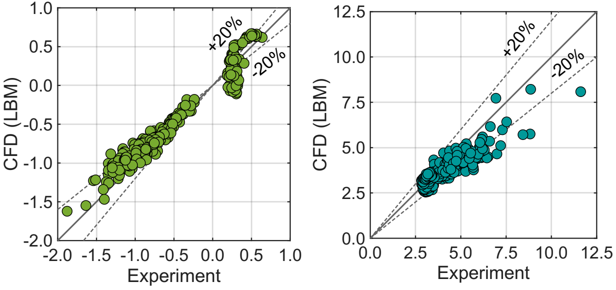
Figure 3: Correlation between wind tunnel and CFD results (Grid A)



(a) $C_{p\mathrm{mean}}$ (b) $C_{p\mathrm{std}}$

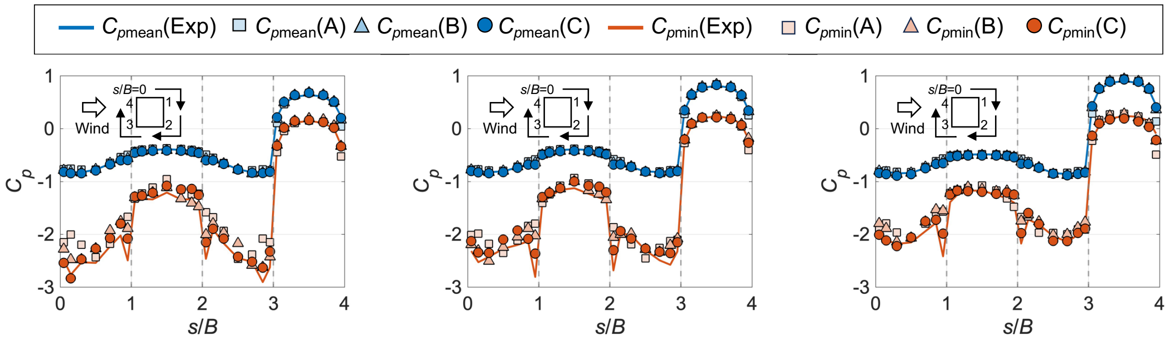


(c) $C_{p\mathrm{max}}$ (d) $C_{p\mathrm{min}}$



(e) Skewness (f) Kurtosis

Figure 4: Correlation between wind tunnel and CFD results (Grid C)



(a) $z/H = 0.25$ (b) $z/H = 0.50$ (c) $z/H = 0.83$

Figure 5: Circumferential distributions of wind pressure coefficients

3.2. Circumferential distribution of mean and minimum peak wind pressure coefficients

Figure 5 shows the circumferential distribution of $C_{p\mathrm{mean}}$ and $C_{p\mathrm{min}}$ at $z/H = 0.25$, 0.5, and 0.83. The horizontal axis represents the distance s normalized by the width B. Results for three grid resolutions are compared. The mean pressure coefficients ($C_{p\mathrm{mean}}$) show good agreement with the experimental results for all grid resolutions. However, the sharp negative peak values of $C_{p\mathrm{min}}$ around $s/B = 1$ and 2 (i.e. the corner edges) were successfully reproduced only by Grid C, whereas coarser grids significantly underestimated these peaks. This result indicates that a grid resolution finer than $B/160$ is required to accurately capture the local negative peak pressures corresponding to the flow separation.

4. CONCLUSIONS

This study evaluated wind pressures on an isolated square cylinder using the Lattice Boltzmann Method (LBM). The results demonstrate that LBM offers higher computational efficiency compared to the conventional Finite Volume Method (FVM). Regarding accuracy, the mean and peak wind pressure coefficients showed good agreement with the reference wind tunnel experimental results. Specifically, a grid resolution finer than $B/160$ was found to be essential to accurately capture local negative peak pressures occurring near the corners. Consequently, this study validates the feasibility of LBM as a practical tool for wind load evaluation.

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