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LES AROUND A REALISTIC CITY BLOCK DESIBNED BASED ON A FUTURE CITY CONCEPT

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Abstract. *In this study, we discuss the flow field of the realistic city block model planned according to the concept of the future city, in the case of an actual typhoon and a winter monsoon hit. This study applied BCM-LES technique, which enables large scale simulation with high efficient of parallel computing. The fluctuating inflow of the actual typhoon was created by using the method of adding the turbulent component based on WRF-LES. From the computed results, we confirmed that properties of inflow and the location of high-rise buildings affect the flow field and the pressure distribution of target high-rise building.*

1 INTRODUCTION

As a concept of the city in the future, it is proposed to create a city where super high-rise buildings and low-rise buildings are combined based on an open space with abundant greenery. In this case, it is necessary to have a plan that fully considers not only comfort (heat environment, wellness) but also disaster prevention. In particular, in the case of considering safety under strong winds, a large-scale numerical simulation of CFD is required, since it is necessary to simulate a complicated flow field by reproducing detailed shapes including green areas, terrain, low-rise buildings and high-rise buildings.

To deal with these problems, BCM-LES technique is proposed in recent large-scale and complex simulation [1] [2], and we applied BCM-LES technique to the flow field of the realistic city block model planned according to the concept of the future city, in the case of an actual typhoon and a winter monsoon hit. The fluctuating inflow of the actual typhoon was created by using the meteorological model/Engineering LES hybrid approach [3] for adding the high frequency turbulent component.

In this study, we confirmed that properties of inflow and the location of high-rise buildings affect the flow field and the pressure distribution of target high-rise building.

2 NUMERICAL MODEL

2.1 Analysis area and target building

The target city has the aspect with widespread layout of high-rise buildings over 200m height, including the target building (Building A) over 330m height. In wind tunnel test, buildings and houses are reproduced within a radius of 500m-600m area. In this simulation, we reproduced low-ride buildings within a radius of 1000m and high-rise buildings within a radius of 1200m.

Figure 1 shows the positional relationship between the target building and the surrounding high-rise buildings. Low and middle-rise buildings spread out on the south side of Building A, and high-rise buildings spread out on the north side of Building A. Therefore, it flows over the low and middle-rise buildings and reaches Building A in the wind direction SSE. On the other hand, it passes through the high-rise buildings and reaches Building A in the wind direction NNW (see Figure 2).

The surface of Building A has horizontal fin sunshades, and these are reproduced.

Taible1 shows the calculation cases. The computational domains are 5.0km x 2.5km x 2.5km (Case 1) and 5.6km x 2.8km x 2.8km (Case 2), respectively.

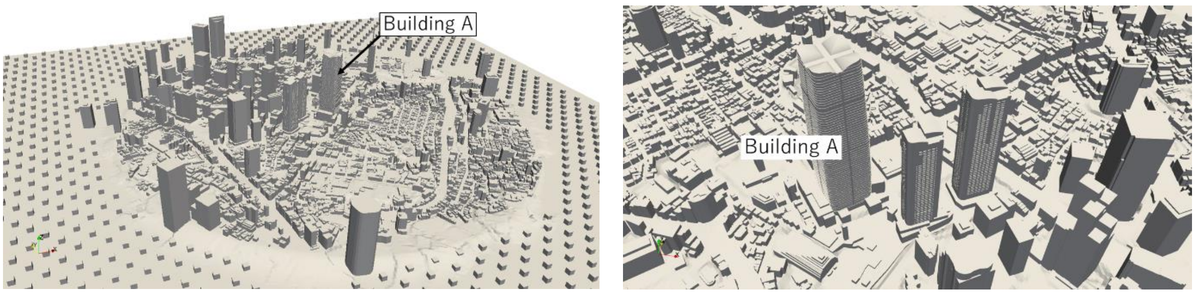

Figure 1: Calculation area including Building A and its surroundings

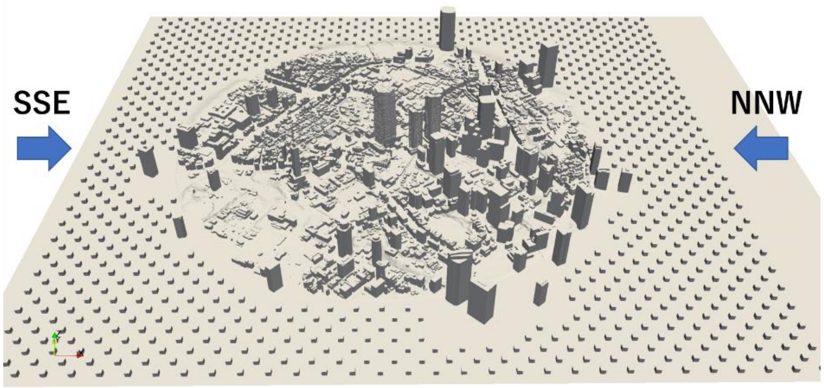

Figure 2: Wind direction for calculation area

Table 1: Calculation cases

	Wind direction	inflow
Case 1	SSE	Typhoon
Case 2	NNW	Strong winter monsoon

2.2 Calculation method

This study applies BCM-LES and BCM uses the mesh system consisting of cubes and cells in the Cartesian grid. Each cube has 16 by 16 by 16 cells, and then the algorithm of computation is quite simple. For the wall inside the cell, the approach of direct forcing of IBM is incorporated in BCM. This method allows the appropriate mesh to be generated even for the dirty CAD data such as zero-thickness walls or three-dimensional complicated geometries without any manual repair of the geometry. Figure 3 shows the distribution of cubes and cells around Building A.

The minimum gird resolution is 0.61m and total cell number is 850 million in Case 1.

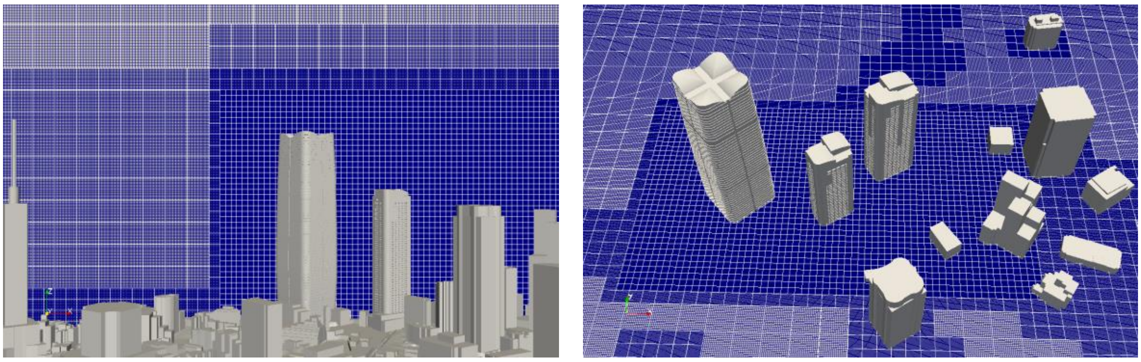

Figure 3: Distribution of cubes and cells around Building A

2.3 Inflow boundary

The inflow turbulence uses an actual typhoon and a winter monsoon. In the case of typhoon, WRF-LES was conducted for typhoon 1721 and spatial filtering and rescaling method was applied to create high frequency fluctuation components. Using this turbulent inflow, a wide-area simulation was calculated and picked up the turbulent flow for Case 1. For the monsoon in winter (Case 2), inflow turbulence generated by Lund's method [4] was used.

Figure 4 shows vertical wind profile for fluctuating inflow of actual typhoon in Case 1.

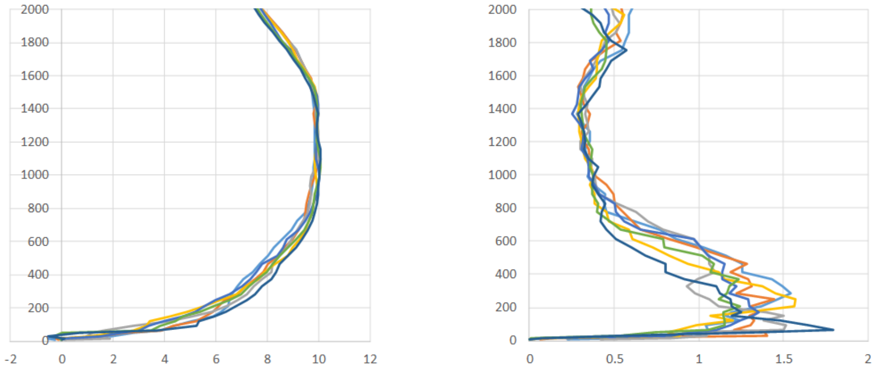

Figure 4: Distribution of cubes and cells around Building A
(Left : Uave, Right : Urms)

2.4 Calculation condition

This study employs the incompressible Navier–Stokes equation with the Immersed Boundary Method (IBM) forcing term and the continuity equation as the governing equations [5]. To solve the convection term, the second-order central-difference scheme is used. To perform time integration, the second-order Crank-Nicolson scheme is used. The boundary condition for surface of ground and building walls used IBM.

Table 2 shows the calculation condition.

Table 2: Calculation condition

Resolution	Δt=0.0025s, Δx=61cm (Minimum)
Time integration	2nd order Crank-Nicolson
Spatial discretization	Convection term : 2nd order Central + 5% Upwind Diffusion term : 2nd order Central
SGS model	Dynamic Smagorinsky model
Algorithm	Fractional Step Method
Boundary condition	Wall : Immersed boundary method Side, Top : Slip condition Inlet : Typhoon, Turbulent boundary layer Outlet : Convective

3 RESULTS AND DISCUSSION

3.1 Flow field around target area and Building A

Figure 5 shows instantaneous velocity with horizontal and vertical section. Comparing the Case 1 and Case 2, it is confirmed that typhoon case has a larger fluctuation than monsoon case. It is due to the effects of large-scale meteorological disturbances contained in the inflow.

Figure 6 shows averaged velocity with horizontal section. It can be confirm that the wake behind high-rise buildings are merged and stretched in the downstream direction.

Figure 7 shows the isosurface of Q criterion behind Building A. It can be confirmed that the flows is slightly bended at the corner and separate from the building surface, since the corner shape of Building A is rounded.

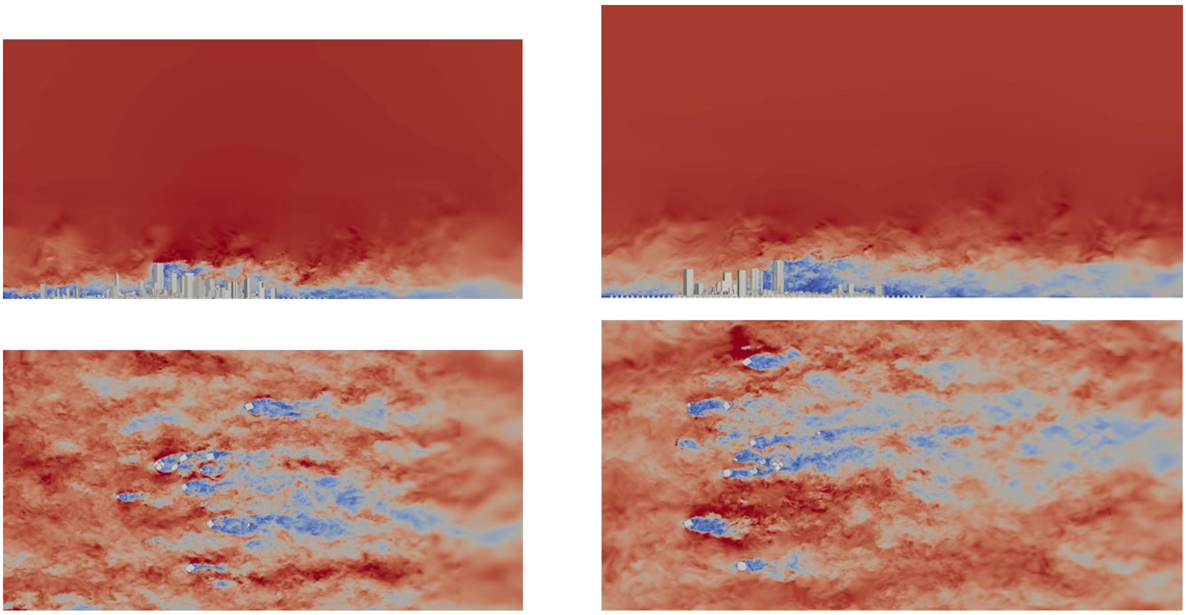

Figure 5: Instantaneous velocity with horizontal (z=200m) and vertical section
(Left : Case 1, Right : Case 2)

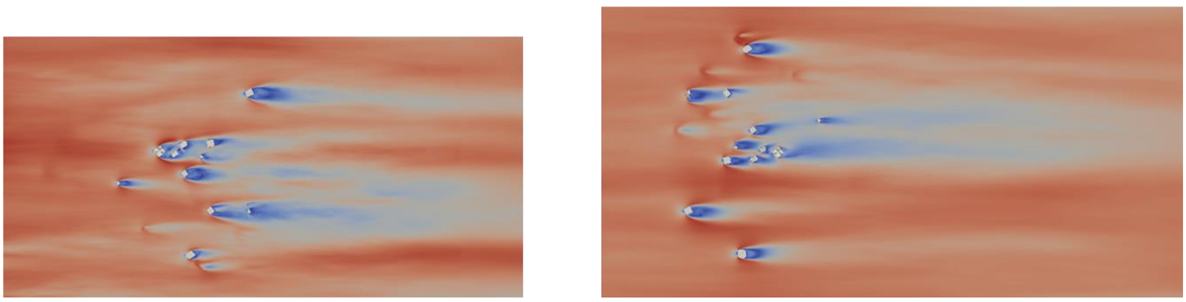

Figure 6: Averaged velocity with horizontal (z=200m)
(Left : Case 1, Right : Case 2)

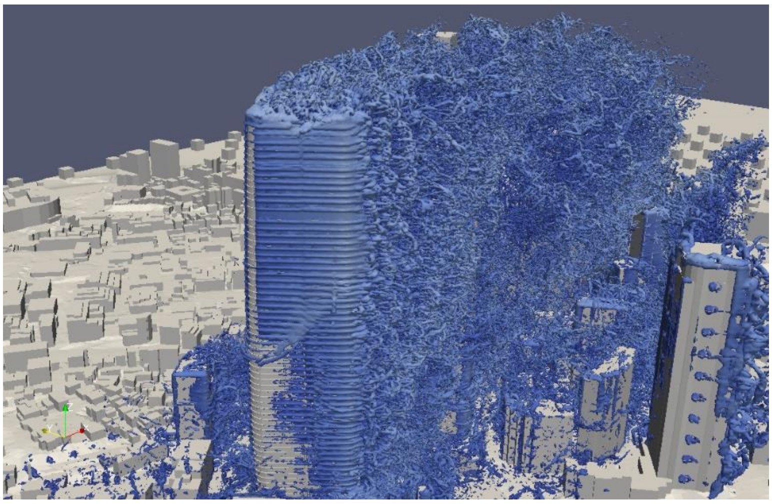

Figure 7: Turbulent structure behind Building A (Case 1)

3.2 Wind pressure acting on Building A

Figure 8 shows averaged velocity and wind pressure around Building A. It can be confirmed that a strong negative pressure is generated on the corner of the building, and it is separated, advected and affects the downwind buildings. It can also be seen that a strong negative pressure is maintained.

Figure 9 and Figure 10 shows averaged velocity and wind pressure around Building A. Strong vortex are formed at the corner of building and it can be recognized that the shape reproducibility of these parts is important for wind pressure evaluation. Also, it can be confirmed that the width of the wake changes in the height direction and the entrainment is a stronger in the low position where the turbulence is strong.

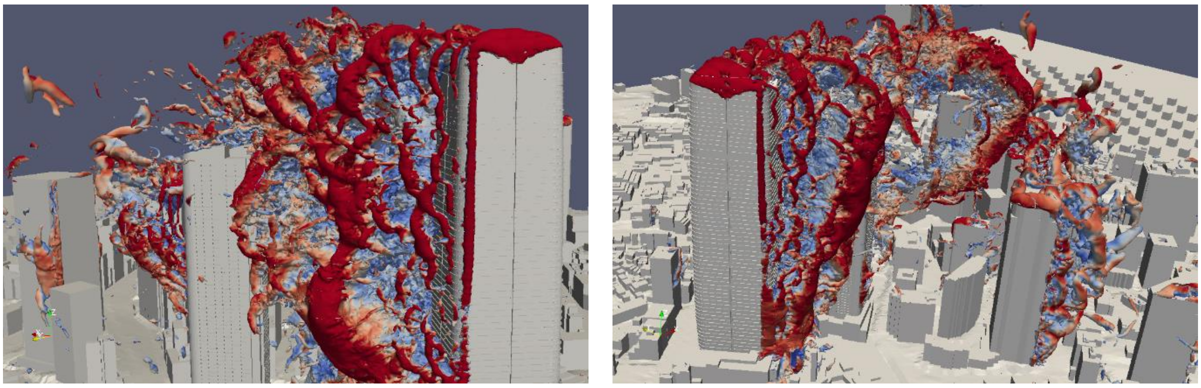

Figure 8: Turbulent structure behind Building A (Case 1)

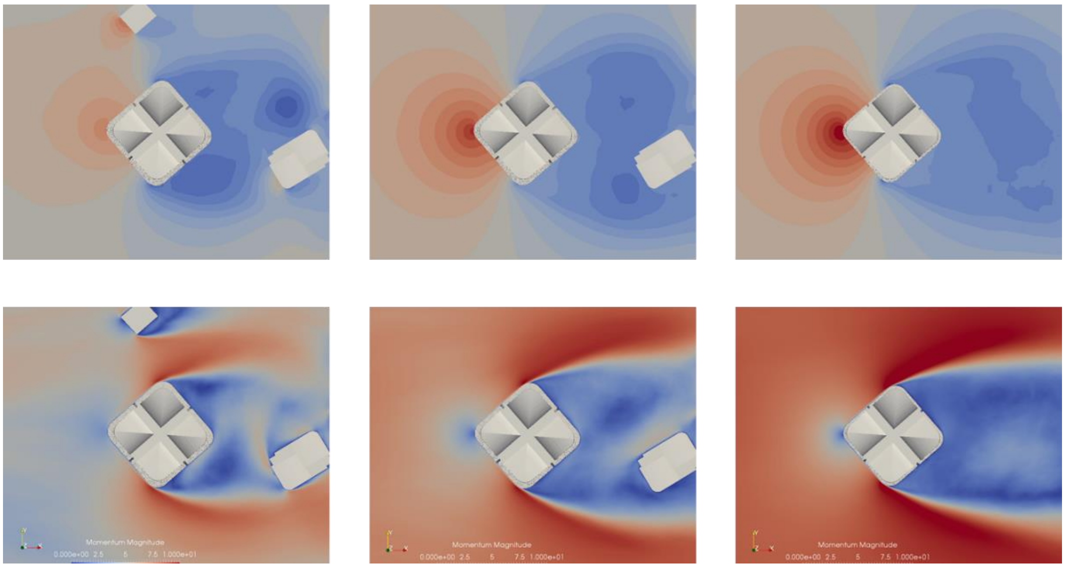

Figure 9: Averaged velocity and wind pressure around Building A (Case 1)
(Top : average wind pressure, Bottom : averaged velocity)

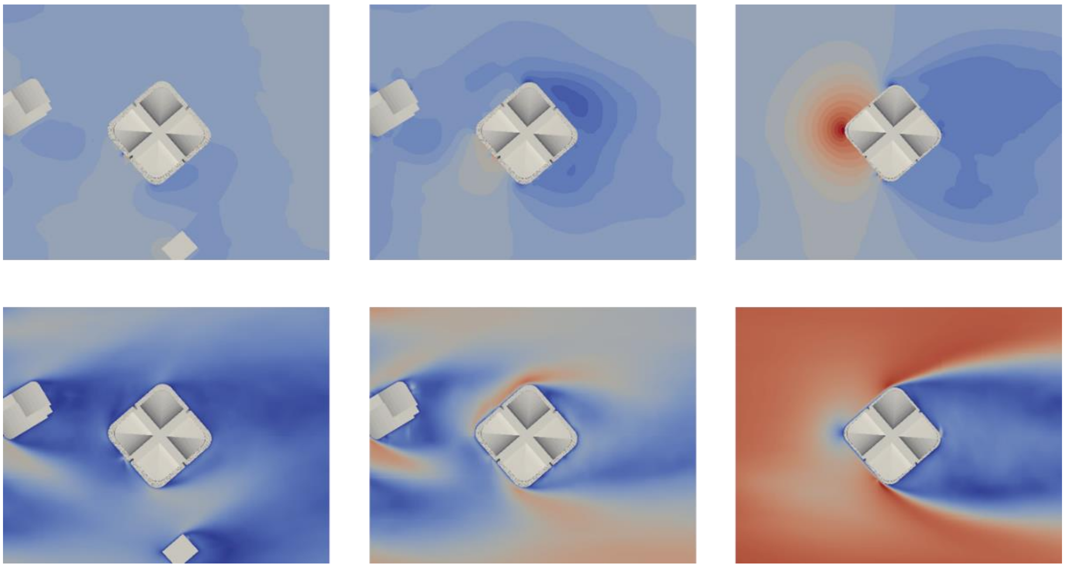

Figure 10: Averaged velocity and wind pressure around Building A (Case 2)
(Top : average wind pressure, Bottom : averaged velocity)

4 CONCLUSIONS

This study applied BCM-LES technique to the flow field of the realistic city block model, in the case of an actual typhoon and a winter monsoon hit. Also, we confirmed that properties of inflow and the location of high-rise buildings affect the flow field and the pressure distribution of target high-rise building. The conclusions of this study can be summarized as follows :

- Typhoon inflow case has a larger fluctuation than monsoon inflow case. It is due to the effects of large-scale meteorological disturbances contained in the inflow.
- The wake behind high-rise buildings are merged and stretched in the downstream direction.
- The strong negative pressure is generated on the corner of the building, and it is separated, advected and affects the downwind buildings.

Acknowledgements

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REFERENCES

[1] T. Tamura, H. Kawai, D. Duong, R. Bale, K. Onishi, M. Tsubokura, BCM-LES analysis of turbulent flows over and within actual urban canopy, 9th Asia-Pacific Conference on Wind Engineering (2017)

[2] Kawaguchi, M. and Tamura, T. An Analysis on the peak wind pressure in the center of Osaka city during the passage of Typhoon Jebi 2018., Summaries of technical papers of annual meeting Architectural Institute of Japan (2020), 119-120. (in Japanese)

[3] M. Kawaguchi, T. Tamura, T. Tao and H. Kawai, LES method for generating broad-banded turbulence for meteorological events, Proceedings of ETMM12 (2018), 138

[4] Lund, T.S., Wu, X., and Squires, K.D., Generation of turbulent inflow data for spatially-developing boundary layer simulations, Journal of Computational Physics (1998), 140, 233-258

[5] Onishi, K., Obayashi, S., Nakahashi, K., Tsubokura, M., Use of the immersed boundary method within the Building Cube Method and its application to real vehicle CAD data, 21st AIAA Computational Fluid Dynamics Conference (2013), AIAA-2013-2713