LOCAL PEAK PRESSURE ON SUPER HIGH-RISE BUILDING IN ACTUAL URBAN AREA

AZUSA ONO[1], TSUYOSHI NOZU[2], TETSURO TAMURA[3] AND HIDENORI KAWAI[4]

[1] Shimizu Corporation
3-4-17 Etchujima, Koto-ku, Tokyo, Japan
ono.azusa@shimz.co.jp

[2] Shimizu Corporation
3-4-17 Etchujima, Koto-ku, Tokyo, Japan
nozu@shimz.co.jp

[3] Tokyo Institute of Technology
2-12-1 Ookayama, Meguro-ku, Tokyo, Japan
tamura.t.ab@m.titech.ac.jp

[4] Ochanomizu University
2-1-1 Otsuka, Bunkyo-ku, Tokyo, Japan
kawai.hidenori@ocha.ac.jp

Key words: LES, Super High-rise Building, Peak Pressure, Conical Vortex

Abstract. *In this study, the characteristics and cause of local peak pressure observed on the surface of a super high-rise building with lower parts in an actual urban area are investigated through a relationship with the flow characteristics. A large-eddy simulation (LES) of a high-density area including several super high-rise buildings is carried out using the turbulent inflow boundary condition. It is confirmed that the large peak suction near the windward corner of the target building is induced by the development of strong conical vortex. The rotation of a conical vortex is accelerated by the separated shear layer generated by the windward building and the lower part of the target building when negative peak pressure occurs.*

1 INTRODUCTION

Researches on a local suction on side walls of a single square cylinder have been conducted in several studies [1,2]. It is very important for wind-resistant design of buildings to clarify this phenomenon. A large local suction also occurs on a building with edge discontinuities, e.g., a building with a lower stage or simply a change in edge shape [3]. However, the mechanism of this phenomenon has not been adequately investigated.

On the other hand, most high-rise buildings in urban areas are surrounded by other buildings. For wind-resistant design of buildings in urban districts, wind loads should be estimated in consideration of the flow fields affected by surrounding buildings.

In this study, a large-eddy simulation (LES) of the actual urban area is conducted, focusing on reproducing the complicated flow field around a super high-rise building with lower parts.

Then, the characteristics and cause of local peak pressure observed on the target building are discussed through a relationship with the flow characteristics.

2 COMPUTATIONAL MODEL AND CALCULATION CONDITIONS

Figure 1 shows the configuration of the target district and wind direction in the calculation. The target building of this study, which is composed of the super high-rise building and two low-rise buildings, is located near the center of the district. The height and width of the super high-rise building are 228 m and 59 m in real scale, respectively. Buildings within a 600 m radius of the target building are modeled, and several high-rise buildings to be constructed in the future are included in the model. The calculated wind direction is south-southeast (SSE).

The computational model and mesh are generated based on a practical guide of CFD for wind-resistant design [4]. The calculation is conducted in 1/400 scale. The unstructured grid system is applied in this simulation as shown in Figure 2. The minimum grid size is 0.45 m in real scale. The total number of grid elements is approximately 97.5 million.
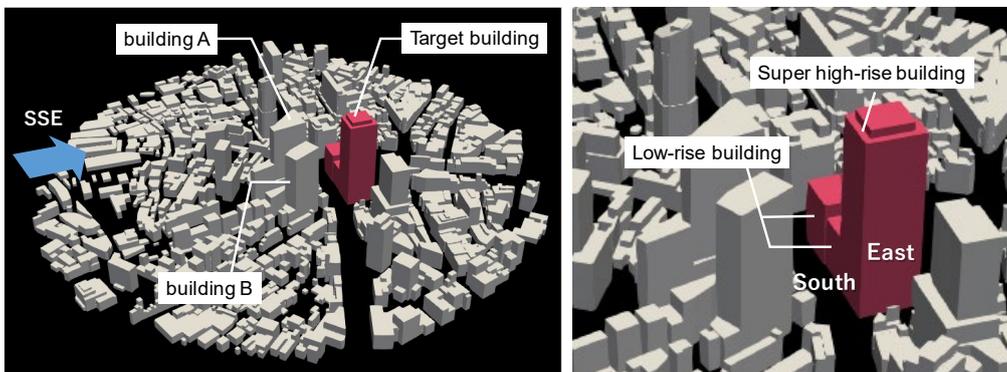
Figure 1: Real urban model and wind direction
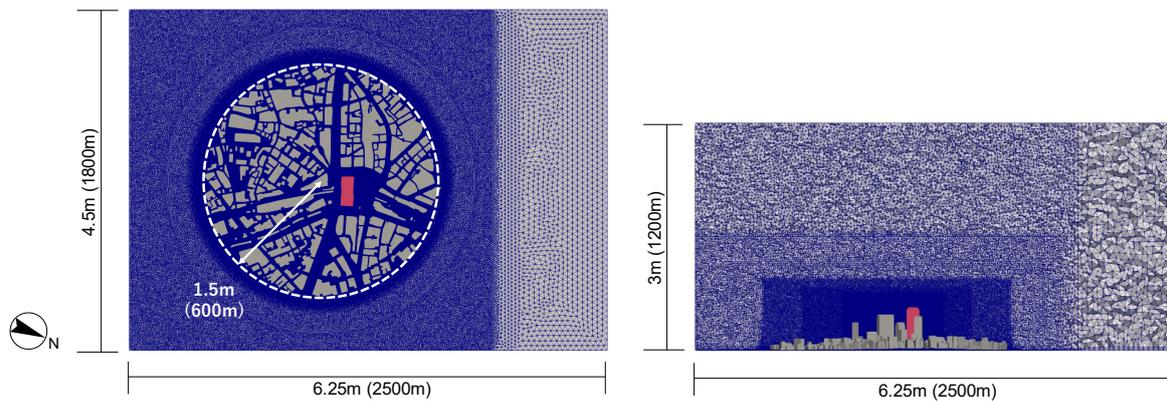
Figure 2: Computational domain and mesh

The code is FrontFlow/red, which has been optimized for high-performance computing (HPC). The standard Smagorinsky model is employed (C_s=0.1). A blend equation of 95% second-order central difference and 5% first-order upwind difference is applied to the convection term. A slip boundary condition is employed at the top and sides of the

computational domain. Spalding's log-low is employed at the bottom of the computational domain and the surface of the buildings. The outlet boundary condition is the Neumann condition for pressure and velocity. Inflow turbulence generated by a semi-periodic condition in the driver region is applied to the inlet boundary. The vertical profile of mean wind velocity in the generated turbulence data corresponds to that of roughness category III in the AIJ recommendation [5].

3 CALCULATION RESULTS

3.1 Flow field around the target building

Figure 3 shows the instantaneous flow field in the horizontal section around the target building at the height 0.5H. It can be observed that the target building is located in the wake region of a windward high-rise building (buildingB). The mean streamlines on the horizontal planes z=0.16H, 0.3H, 0.5H are shown in Figure 4. The pattern forms of the separated shear layers generated from windward buildings differ depending on the heights. A complex three-dimensional flow due to the influence of the windward buildings act on the target building.
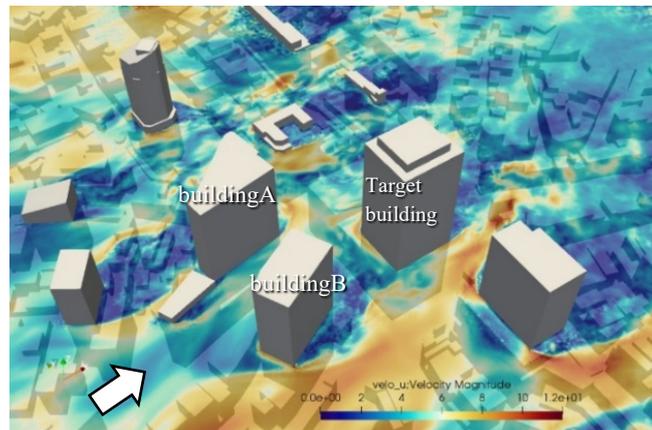
Figure 3: Horizontal distribution of instantaneous flow field around the target building (z=0.5H)

| (a) z=0.16H | (b) z=0.3H | (c) z=0.5H |
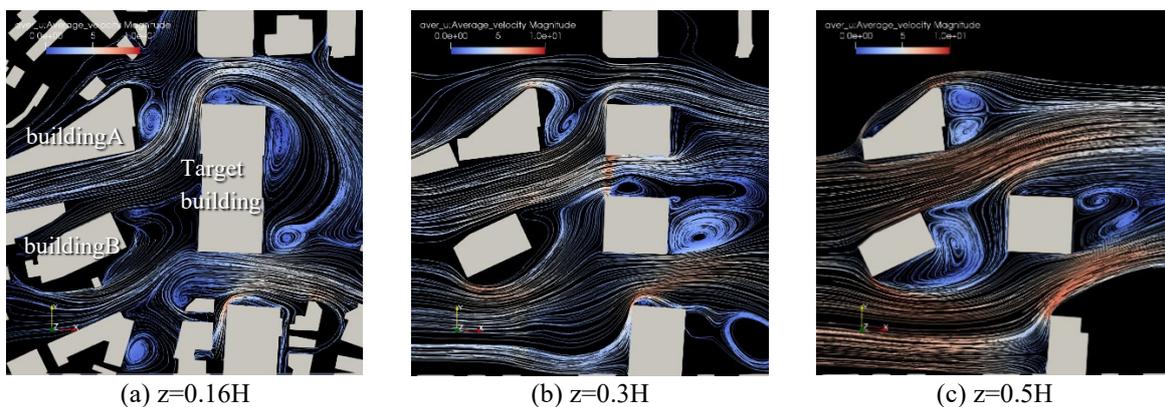
Figure 4: Mean streamlines on the horizontal planes

3.2 Distributions of surface pressure coefficients

The wind speed for a 100-year return period is taken for the structural design; its value is 54 m/s at the height of the target building (228 m) in real scale. The calculation results are evaluated based on a pressure time history for 10 minutes in real scale. The mean and minimum pressure coefficients are evaluated from the calculation results shown in Figure 5. The minimum pressure is the peak value after a 0.3 second moving average in real scale.

On the south surface of the super high-rise building shown in Figure 5(a), large positive mean pressure coefficients are observed at the upper portion, while negative mean pressure coefficients are observed at the middle portion. This can be understood by considering the flow field around the target building, which is influenced by the windward building mentioned above. A distinctive minimum pressure distribution with large negative pressure is observed at the windward corner on the west surface. The strong negative pressure occurs in a limited region close to the corner edge of the target building.

(a) Mean pressure coefficients (b) Minimum pressure coefficients
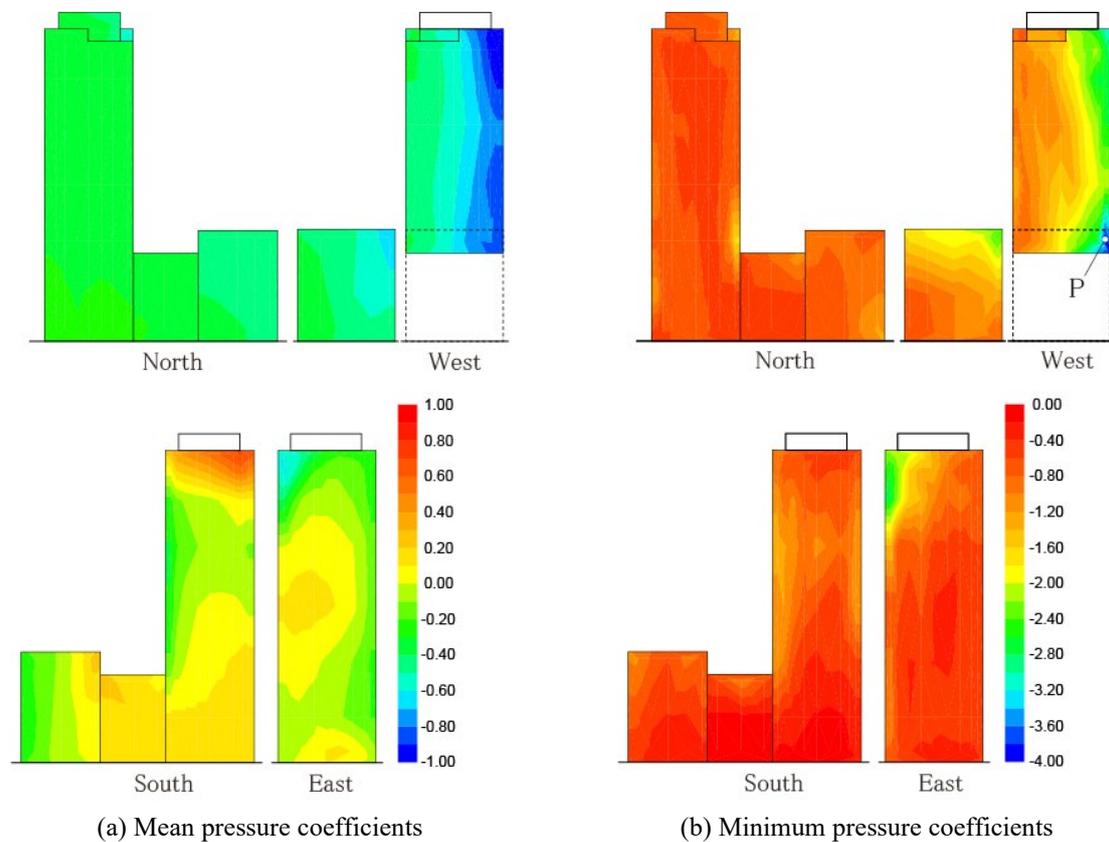
Figure 5: Distributions of surface pressure coefficients

3.2 Characteristics of pressure fluctuation

Figure 6 shows the trace of the pressure fluctuation at a point close to the windward corner on the west surface, which is marked as point P in the contour maps of Figure 5(b). Large suction peaks are intermittently observed and the pressure coefficient occasionally reaches under -3.
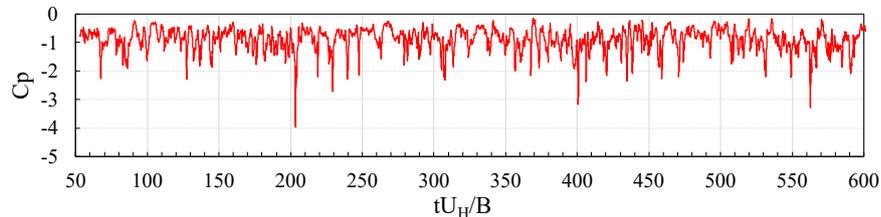
Figure 6: Trace of the pressure fluctuation at a point close to the windward corner on the west surface

3.3 Conical vortex at occurrence of peak suction

Figure 7 shows the contour surfaces of instantaneous negative pressures (C_p = -1.0, -2.0, -3.0) when the negative peak pressure appears at the windward corner on the west surface. An inverted conical vortex can be clearly observed at the windward corner on the west surface. This vortex structure may locally intensify the negative pressure field. As a result, the level of the negative pressure becomes large at the windward corner on the west surface. Another conical vortex is formed on the roof of the low-rise building.

Figure 8 shows the instantaneous streamlines. The flow that goes towards the west surface from the south surface of the target building rolls up forming inverted conical vortex at the corner on the west surface.
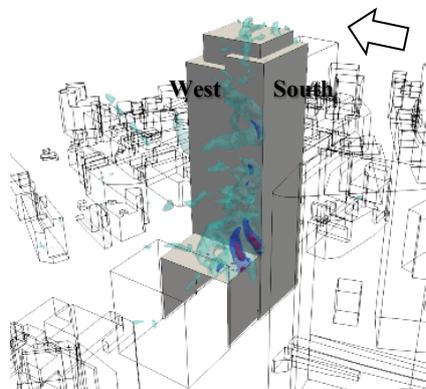
Figure 7: Contour surfaces of instantaneous negative pressures
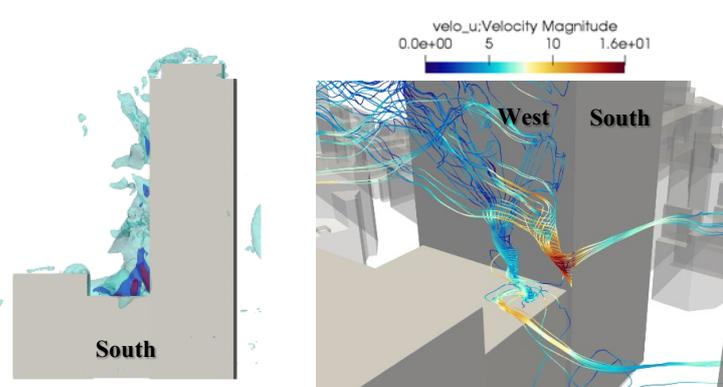
Figure 8: Instantaneous streamlines

Figure 9 shows the horizontal distribution of the instantaneous vertical vorticity at the height of 0.3H. It can be observed that the separated vortices from buildingB act around the corner of the target building. Figure 10 shows the instantaneous spanwise vorticity in the vertical x–z plane around the low-rise part of the target building. Separated flow can be observed above the roof of the low-rise building. These results imply that separated flow from buildingB and the low-rise part of the target building accelerate the rotation of conical vortex.
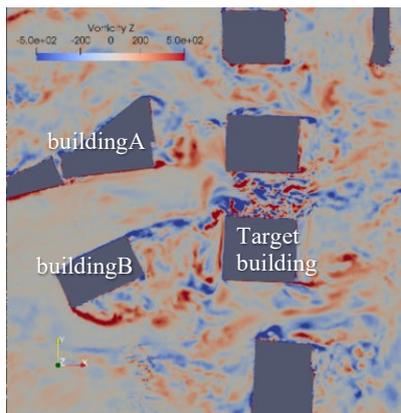
Figure 9: Horizontal distribution of the instantaneous vertical vorticity
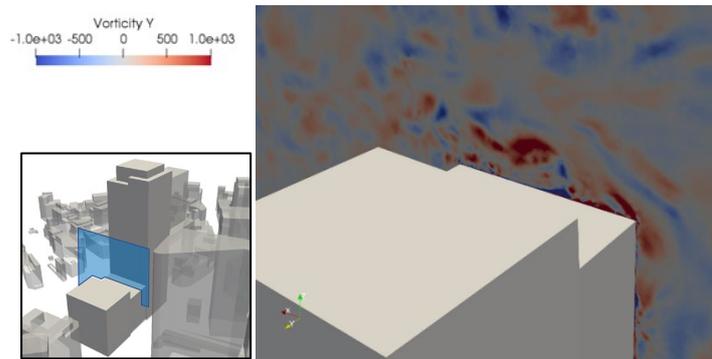
Figure 10: Vertical distribution of the instantaneous spanwise vorticity around the low-rise part of the target building

4 CONCLUSIONS

In this paper, the characteristics and cause of the local peak pressure observed on the surface of a super high-rise building with lower parts in an actual urban area are discussed through a relationship with the flow characteristics. The obtained results are summarized as follows:

- It is confirmed that the large peak suction near the windward corner of the target building is induced by the development of a strong conical vortex.
- The rotation of conical vortex is accelerated by the shear layer generated by the windward building and the flow over the roof of the lower part of the target building when negative peak pressure occurs. It is found that the local peak pressure observed in this study results from the flow influenced by the configuration of the windward building and the target building itself.

REFERENCES

[1] Okuda, Y. and Taniike, Y. Conical vortices over side face of a three-dimensional square prism. *J. Wind Eng. Ind. Aerodyn.* (1993) **50**: 163–172.

[2] Ono, Y. and Tamura, T. LES of local severe suction on side face of a three-dimensional square cylinder. *J. Struct. Constr. Eng. (Trans. AIJ).* (2013) **78**: 2065-2072. (In Japanese)

[3] Melbourne, W.H. Turbulence and the leading edge phenomenon, *J. Wind Eng. Ind. Aerodyn.* (1993) **49**: 45–63.

[4] Guidebook of Recommendations for Loads on Buildings 2 - Wind-induced response and load estimation/Practical guide of CFD for wind resistant design -, *Architectural Institute of Japan.* (2017) (In Japanese)

[5] Architectural Institute of Japan, AIJ Recommendations for Loads on Buildings (2015), *Architectural Institute of Japan.* (2015)