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Academic Article

The Influence of building shapes to the street wind
- Using wind tunnel experiment and numerical computation -

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ABSTRACT

In recent years, the shape of a building using a curved surface has increased from a quadrangular prism. One reason is to avoid the occurrence of strong winds caused by buildings. In this study, wind tunnel experiments and numerical computations are performed, and the influence on flow is evaluated by comparing the wind velocity distribution around the building model typified by a quadrangular prism and a circular cylinder. As a result, at the point behind a building, the change in the wind velocity with the height of the circular cylinder is smaller than that of the quadrangular prism. The effect of mitigating wind environments, which seems to have a cylindrical shape, is confirmed.

Key Words : Wind tunnel experiment, Numerical computation, Building shape, Urban canyon

1. Introduction

In recent years, the shape of a building using a curved surface has increased from a quadrangular prism. This seems to include the meaning of mitigating the strong wind. In London, the head office of Swiss Re is in the smooth form, is reported to have few strong wind caused by buildings than other square building.
In this research, the influence of flow by comparing the wind velocity distribution around the building model typified by a quadrangular prism and a circular cylinder using wind tunnel experiment and numerical computation is evaluated. The purpose of the research is to examine the mitigation effect of the wind environment which the cylindrical shape seems to have. The meaning of the mitigating wind environments are to reduce the large range of wind velocity. Here, the neutral atmospheric stability that approximates the natural wind of the outdoors in the flow field of a three-dimensional street is assumed, and the velocity at upper level is assumed about 3 m/s, which is generally considered to be common in Osaka, Japan.
In past studies, wind tunnel experiments and numerical computations were performed on single building model and simple building group model[1)]. However, in the study presented here, we discussed the wind velocity distribution inside street canyons in building groups of prism and cylinder as fundamental research using wind tunnel experiments and numerical computations.

2. Wind tunnel experiment

2.1 Method of wind tunnel experiment

In the experiments presented in the paper, an urban area with a characteristic street configuration is considered. The street and the back of the building are the main examination target position. As shown in Fig. 1, the wind tunnel used in the experiment has a total length of 300 cm, a working space of 30 cm × 45 cm, and the center of the working space at 175 cm from the inlet part of wind tunnel[2)]. The wind velocity at the upper of the boundary layer was fixed with a value of 3 m/s. As the characteristics of the street shape, the ratio of the prism case is l : h : w= 1 : 1 : 1 for the length between the building (l), the height (h) and the width (w) . The ratio of cylinder case is r : h : w = 1 : 1 : 1 for the diameter of cylinder (r). The width of the prism and the diameter of the circular cylinder are 3 cm.

As shown in Table 1, two kinds of experiments with prisms and cylinders in three dimensional street model are conducted. The wind velocity at the following 3 points under the regular arrangement is measured. ① in the street parallel to wind direction, ② in the center of the intersection, ③on the leeward side of the building. For the measurement of the wind velocity, CLIMOMASTER (KANOMAX, Model 6543-21)[3] is installed in the center of the working space. Measurement is carried out adjusting to the position of points ①②③ by slightly moving the block model horizontally. Measurement point intervals in the height direction for the lower part are 0.5 cm from the bottom to 3 cm. For the upper part from 3 cm to 6 cm, the intervals are 1 cm. The sampling rate of wind velocity is 1 Hz and a 3-min-averaging time is used for each run.

2.2 Results of wind tunnel experiment

The wind tunnel results of wind velocity with heights are shown in Fig. 2, 3. U/Ur is the wind velocity ratio, and Ur is the wind velocity at z/h = 2.0.

1) Comparison of ①, ② and ③ of prism (see Fig.2 left)

The wind profile of all points ①, ② and ③ are almost no difference at the height of z/h=1.3~2. Although the difference is small, point ② is weaker than ① at the height of z/h = 0.2~0.9. The wind velocity of point ③ is extremely weaker than ① and ②. Especially the wind velocity of ③ is weaker than ① and ② at z/h = 0.2.

2) Comparison of ①, ② and ③ of the cylinder (see Fig.2 right)

As the same as 1), the wind profile of all points ①, ② and ③ are almost no differences at the height of z/h=1.3~2.0. Although the difference is small, point ② is weaker than ① at the height of z/h = 0.2~1.8. The wind velocity of point ③ is extremely weaker than ① and ②.

3) Comparison of prism and cylinder in ① (see Fig.3 ① left)

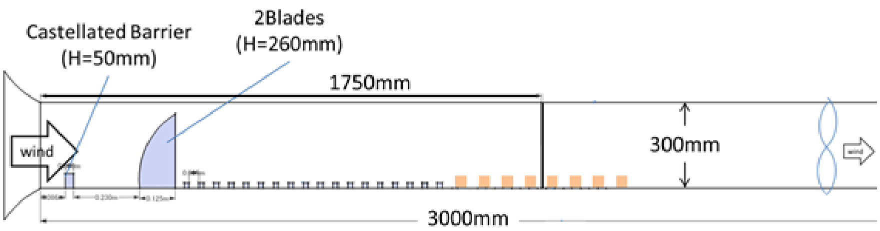
There is almost no difference between the prism and the cylinder, and the wind velocity increases monotonously with the height. However, the wind velocity of cylinder is slightly faster at the height of z/h = 0.6~1.6.

4) Comparison of prism and cylinder in ② (see Fig.3 ② left)

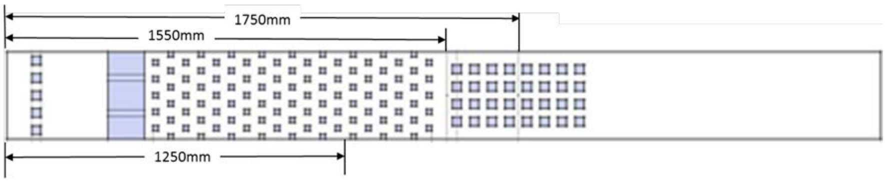
There is almost no difference between the prism and the cylinder, and the wind velocity increases monotonously with the height.

5) Comparison of prism and cylinder in ③ (see Fig.3 ③ left)

The wind velocity of prism is weaker a little than cylinder at the height of z/h = 0.2~0.8, and the wind velocity is greatly changed when exceeding the building height. The wind velocity with height of cylinder is almost same up to the building height.



Working section



Plan

Fig1. Wind tunnel

Table 1 Measurement points of wind tunnel experiments

Measurement points \ Building model	Quadrangular prism (3cm×3cm×3cm)	Circular cylinder (diameter:3cm×hight:3cm)
①The point in the street parallel to wind direction		
②The center of intersection		
③The point in the leeward side of the building		

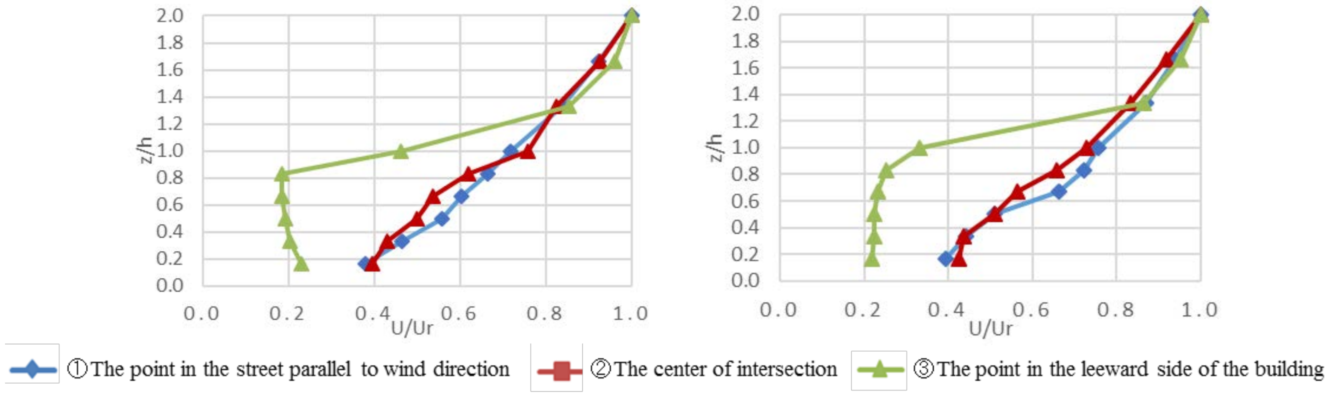
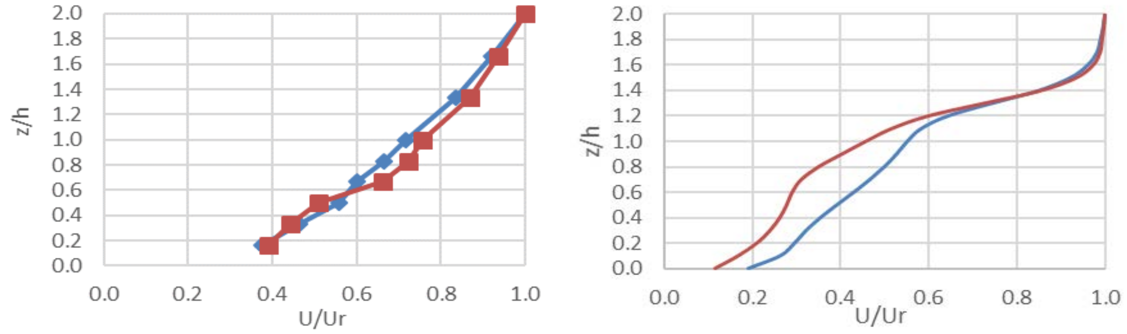
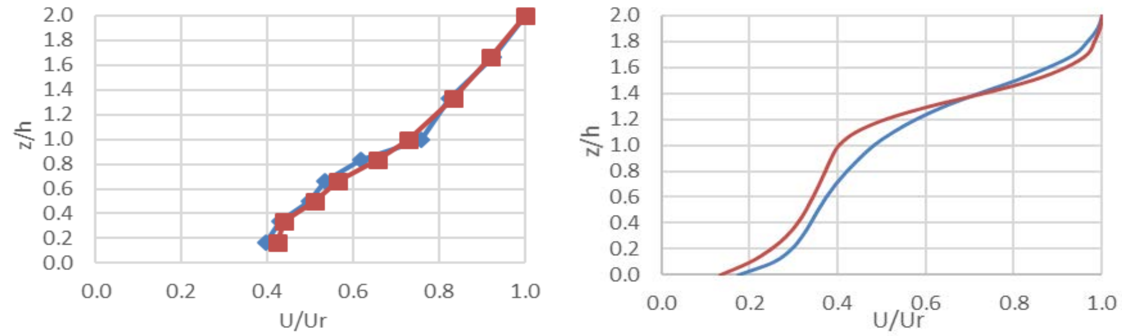


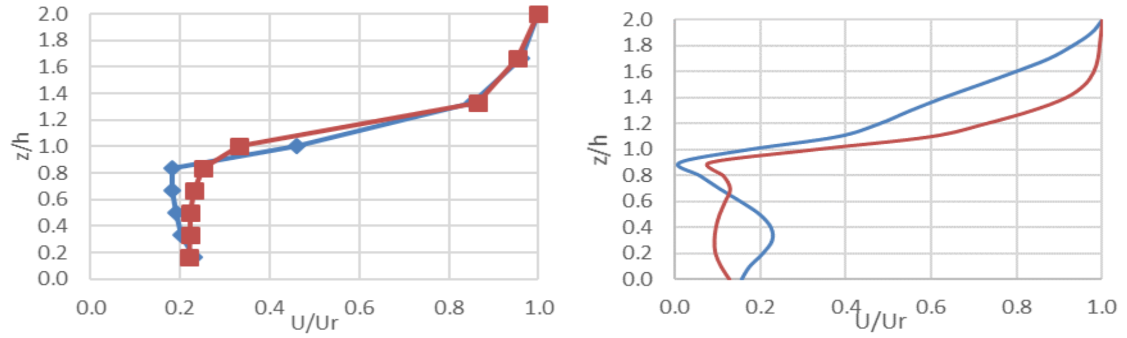
Fig.2 Wind tunnel results of wind velocity with height (Left : prism, Right : cylinder)



① The point in the street parallel to wind direction



② The center of intersection



③ The point in the leeward side of the building

prism cylinder

Fig.3 Comparison of wind tunnel experiment and numerical computation (Left : wind tunnel, Right : numerical computation)

3. Numerical computation

3.1 Outline of numerical computation

The simulation is carried out using CFD software (STREAM Ver. 12[4)]) with standard k-ε turbulence model. Boundary conditions are given in Table 2.

1) Computation area

The computation area is 200 cm in X direction, 30 cm in Y direction, 30 cm in Z direction. Because it is the simulation of the wind tunnel experiment, the Y direction and the Z direction are set to the actual same size as the wind tunnel. The grid spacing is 0.1 cm in the horizontal direction. It is 0.1 cm in the vertical direction from the bottom to the building height, and above the building height an expanded grid interval is used.

Table 2 Boundary conditions

Inlet	Power law Wind velocity: 3 m/s at height of z = 15cm Power exponent: 1/3.7
Outlet	Free slip
Upper surface	Free slip
Bottom surface	Logarithmic wind profile law over the smooth surface
Sides	Free slip
Building surfaces	Logarithmic wind profile law over the smooth surface

2) Computation case

The roughness of the same size as the wind tunnel case were arranged in the computation case.

Two cases are calculated : one is quadrangular prism (3 cm x 3 cm x 3 cm) and the other is circular cylinder (diameter 3 cm, height 3 cm).

3.2 Results of numerical computation

The numerical computation results of wind velocity with heights are shown in Fig. 3 and 4.

1) Comparison of ①, ② and ③ of prism (see Fig.4)

The wind profile of points ① and ② are making similar changes. However, point ② is weaker than ① at the height of z/h = 0.3~2.0. The wind velocity of point ③ is extremely weaker than ① and ②.

2) Comparison of ①, ② and ③ of the cylinder (see Fig.4)

The wind profile of points ① and ② are making similar changes. However, point ② is weaker than ① at the height of z/h = 0.8~2.0. The wind velocity of point ③ is extremely weaker than ① and ②.

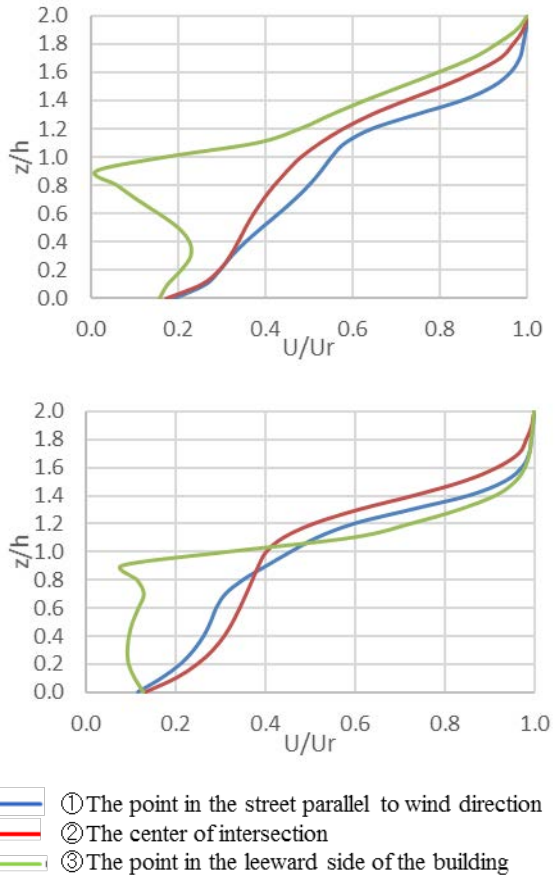


Fig.4 Culcuration results of wind velocity with height
(Upper : prism, Lower : cylinder)

3) Comparison of prism and cylinder in ① (see Fig.3 ①)

The wind velocity of the cylinder is weaker until the building height, and the prism and cylinder are the same if z / h = 1.2 is exceeded.

4) Comparison of prism and cylinder in ② (see Fig.3 ②)

The difference between prisms and cylinders is small, but slightly cylindr is weaker than the prism.

5) Comparison of prism and cylinder in ③ (see Fig.3 ③)

The prism changes largely in wind velocity to the height of z/h = 1.0. But the wind velocity of the cylinder does not change much in the height direction until the height of z/h = 1.0.

As shown in the upper part of Fig. 5, the horizontal vortexes behind the prism and cylinder do not significantly affect the flow between buildings in the X axis direction.

In comparison of prism and cylinder, the wind velocity is similar, as shown in the lower part of Fig.5, in the street parallell to the wind direction.

The results of the numerical computation here is not yet steadily. It seems that the further discussion about the behavior of the vortexes behind a building is needed.

4. Comparison between wind tunnel experiments and numerical computations

A comparison of the results of wind tunnel experiments and numerical computations are given in Fig. 3.
The results of the numerical computations are similar to the results of the wind tunnnel in vertical profile of wind velocity. However there are the different points as below.
The wind velocity of points ① and ② decrease monotonously to the ground level in wind tunnnel, but in the results of numerical computations, the change of the height direction are smaller than wind tunnnel at z/h=1.6～2.
In the point ③, the wind velocity of the wind tunnnel is almost constant in the vertical direction at z/h=0.2～1.6. Especially the wind velocity of the prism is almost zero at z/h=0.9. The reason seems the vortex of the vertical section caused by street canyons (see Fig. 5）.

5. Conclusions

The rusults of wind tunnel experiments and numerical computations are used to compare the wind velocity distribution around the building model typified by prisms and cylinders to evaluate the influence on flow.
As the results, the wind velocity of point ③(behind bldg.) is extremely weaker than ①(street) and ②(intersection). In addition, in the wind tunnel experiment of point ③, the wind velocity of prism is weaker a little than cylinder at the height of z/h = 0.3~0.8. In further, numerical computation of point ③, the change of the wind velocity at the prism is large, the wind velocity of the cylinders is almost constant with heigh.
From the above, with regard to the behind a building, the wind mitigation effect of the cylinder is confirmed by wind tunnel experiments and also numerical computations.

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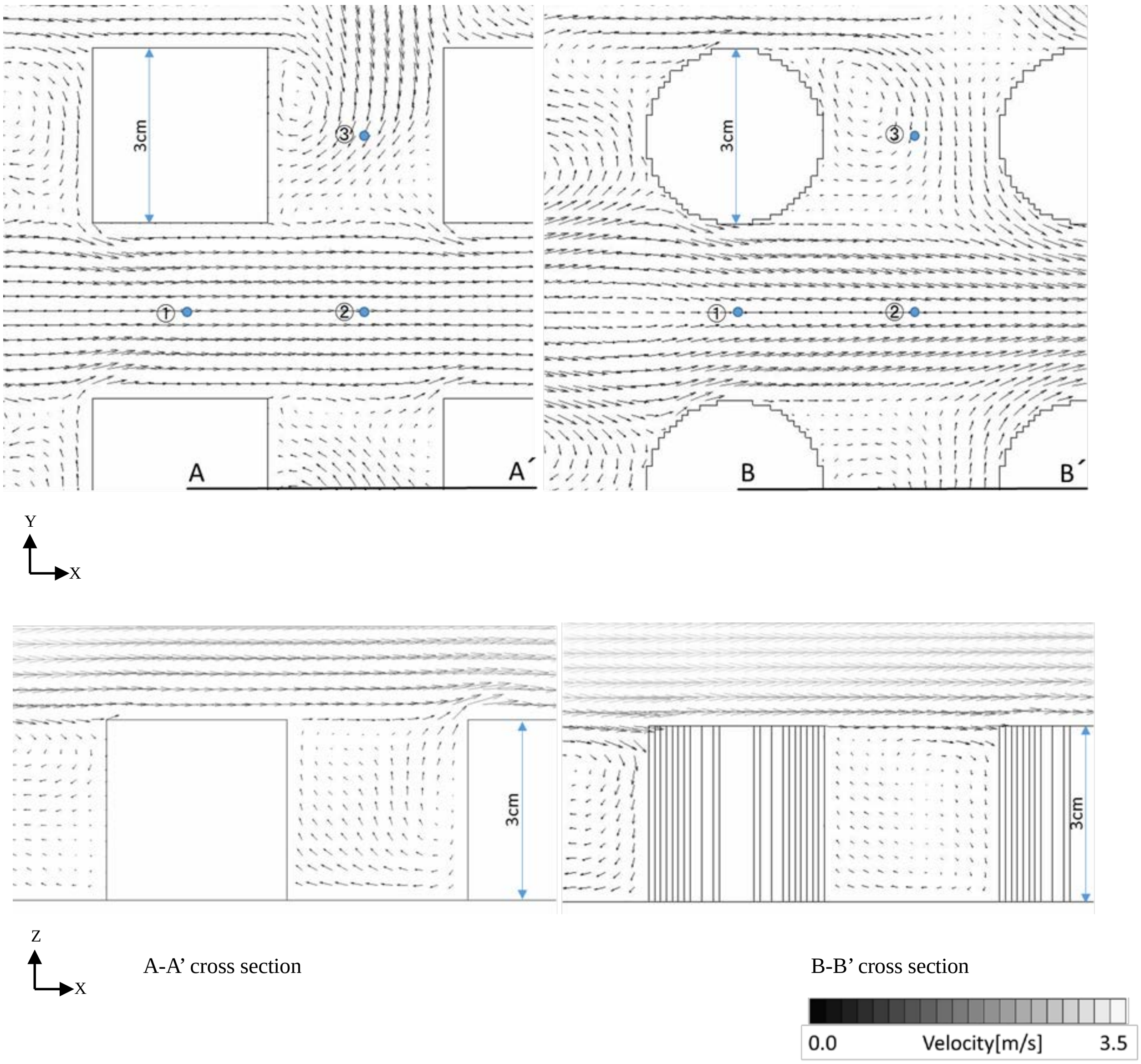

Fig.5 Wind vector of computation results
(Left : prism, Right : cylinder)
(Upper : X - Y axis cross section (z / h = 1/5), Lower : X - Z axis cross section)

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