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A Study on the Distribution of the Peak Wind Pressure Coefficient for the Wind Resistant Design of Rooftop Hoardings in High-rise Buildings

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ABSTRACT

Among outdoor advertisements, rooftop hoardings are larger and more affected by the wind. They suffer much damage due to strong winds every year. However, there is no accurate wind load for the design of wind-resistant rooftop hoardings. Wind pressure experiments were conducted to determine the peak wind pressure coefficient for the wind-resistant design of a two-sided rooftop hoardings installed on 10–20-storey buildings. The minimum peak wind pressure coefficient of the rooftop hoardings was -3 for the corners of the front and rear bottoms and -2 for the entire sides. As the height of the rooftop hoardings increased due to an increase in building height, the absolution peak value at the minimum peak wind pressure coefficient was larger. The distributions of the maximum/minimum peak wind pressure coefficients of outdoor rooftop signboards were affected by the signboard location and wind angle.

Keywords: Hoarding on roof, Outdoor Billboard, Outdoor Structure, Wind Pressure Coefficient, Wind Tunnel Experiment

I. INTRODUCTION

The importance of advertisements is increasing with the development of urban commerce. The installation of outdoor advertisements on downtown buildings has become an important factor, positively affecting sales.[1] In particular, many outdoor advertisements, including protruding signboards, pillar signboards, and rooftop hoardings, are being continuously installed. Because outdoor advertisements are installed on exteriors, walls, and rooftops, structural safety in the method of installation and the positioning of signboards is a critical issue.[2] Among outdoor advertisements, rooftop hoardings, which are installed on the rooftop rather than on the exterior or wall of a building, have a larger area than general outdoor signboards, and they are greatly affected by wind. Fig 1 shows outdoor advertisements destroyed by a typhoon and strong winds. Damaged rooftop hoardings can become debris, carrying the risk of damaging other buildings and injuring people. Currently, 4-m or higher rooftop hoardings must ensure wind safety for structures according to the building standard law. The building load guide[1] of the Architectural Institute of Japan specifies the wind force coefficient of fences built on the ground. However, there is no specific standard for wind force acting on hoardings on building rooftops. Furthermore, ASCE 7-12[2] defines the wind force coefficient as the difference between the parapet pressure and the negative pressure of the roof surface. The applicability of the wind force coefficient to the parapet is uncertain for rooftop hoardings because there are often spaces at the bottom. Therefore, wind resistance design data for rooftop hoardings is necessary to reduce wind damages. Masyama Yuka et al. investigated the wind pressure coefficient of rooftop hoardings and the wind pressure coefficients according to the size and position of signboards.[4] They examined the relationship between the installation shape and position to determine the peak force pressure coefficient of rooftop hoardings, and they proposed a peak force pressure coefficient for exterior materials of rooftop hoardings. The present study investigated the wind load distribution for the exterior material design of rooftop hoardings with no space at the bottom that are installed on 20-storey buildings.

Figure 1. Damage of rooftop hoardings

II. WIND TUNNEL EXPERIMENT

II.I Experiment Model

To analyze the wind pressure coefficient for the exterior material design of rooftop hoardings, building sizes were specified as 18 m (B) × 7.5 m (D) × 20 m (H) (Case 1) and 18 m (B) × 7.5 m (D) × 60 m (H) (Case 2). The sizes of the rooftop hoardings were specified as 10 m (B) × 3.5 m (D) × 10 m (H) for Case 1 and 10 m (B) × 3.5 m (D) × 15 m (H) for Case 2. The heights of the rooftop hoardings were designed to increase as the building height increases. The hoardings were installed at the center of the building front, which is currently the most popular position. The wind pressure model scale was set at 1/100. Fig 2 shows the position of the rooftop hoarding and wind angle for each case. A wind pressure model was produced using acrylic to measure the peak external pressure coefficient of the rooftop hoardings. To measure the distribution of the peak external pressure coefficient acting on each side of the rooftop hoardings, for Case 1, 80 wind pressure holes in total were installed, including 25 each on the front and rear and 15 each on the left and right sides. For Case 2, 106 wind pressure holes in total were installed, including 35 each on the front and rear and 18 each on the left and right sides. Fig 3 and 4 show the layout of the wind pressure holes in Cases 1 and 2. Fig 5 shows the experimental model installed inside the wind tunnel.

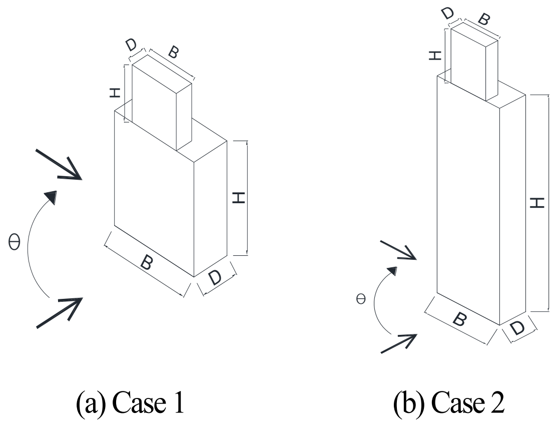


Figure 2. Size of prototype

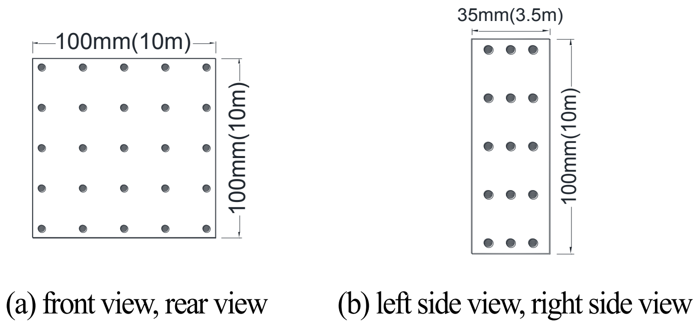
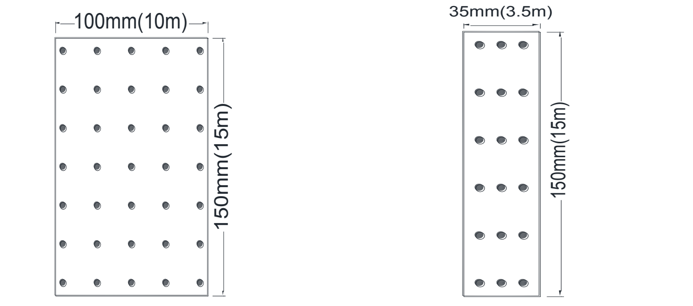
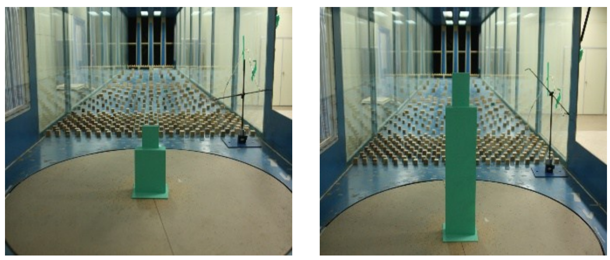


Figure 3. Layout of pressure tap (Case 1)



(a) front view, rear view (b) left side view, right side view

Figure 4. Layout of pressure tap (Case 2)



(a) Case 1 (a) Case 2

Figure 5. Experiment model installed within the wind tunnel

II.II Wind Tunnel Experiment

A wind tunnel experiment was carried out to determine the distribution of the peak wind pressure coefficient on each side of the rooftop hoardings. The dimensions of the wind tunnel measuring unit were 18 m in length, 2.1 m in width, and 1.8 m in height, and the wind velocity range is 0.3–12 m/s. For the turbulent boundary layer applied to the wind tunnel experiment, the surface roughness classification B (α = 0.22) was used, which corresponds to the mid–low floors in downtown area. The meanaverage wind velocitiesy inside the wind tunnel and the vertical distribution of the turbulence intensitiesy are shown in Fig 5. The solid line indicates the theoretical equation, and ● and ■ indicate the wind velocity and turbulence intensity, respectively, as measured at each height. The equations for the maximum/minimum peak wind pressure coefficients for each wind pressure value measured in the wind pressure experiment are shown in equation 1.

Maximum peak wind pressure coefficient (positive pressure): $C_{Pmax} = P_{max}/q_H$

Minimum peak wind pressure coefficient (negative pressure): $C_{Pmin} = P_{min}/q_H$ (1)

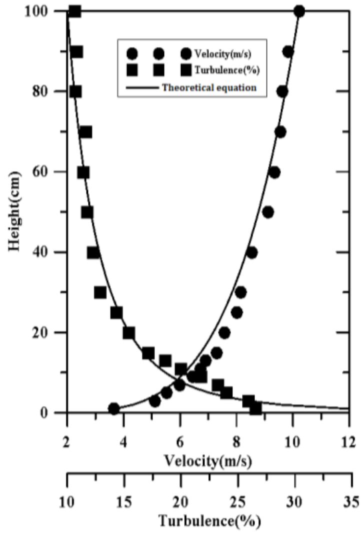


Figure 5. Distribution of mean wind velocities and turbulence intensities

The wind pressure experiment was based on Seoul, where many rooftop hoardings are used. The design wind velocity of the rooftop hoarding used in this experiment was determined using equation 2. Table 1 shows the law of similarity used in the wind tunnel experiment. The airflow in the wind tunnel was measured using a hot-wire anemometer (IFA-300). The wind pressure experiments for the rooftop hoardings were carried out for 36 directions in 10° intervals. Fig 6 shows the angles used in these experiments.

$$V_z = V_0 \times K_{zr} \times K_{zt} \times I_w \qquad (2)$$

where V_0= basic wind velocity (26m/s)

K_{zr}=1.0, K_{zt}=1.0, I_w=0.9

Table 1. The similarity law of the wind tunnel experiment

Velocity scale		**Design Velocity**	**Experiment velocity**	**Velocity Scale**
	Case 1	17.58m/s	5m/s	1/3.5
	Case 2	21.56m/s	5m/s	1/4.3
Model scale	1/100			
Time scale	Case 1	1/28.44		
	Case 2	1/23.19		
Ensemble average	10time			
Sampling Frequency	100HZ			
Wind direction	36 direction (0° - 350°)			
Roughness division	Roughness B			

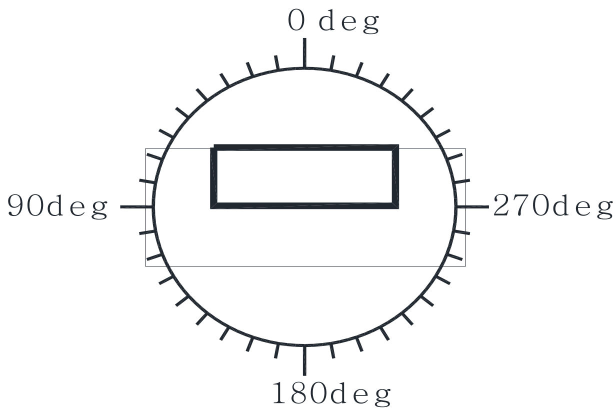


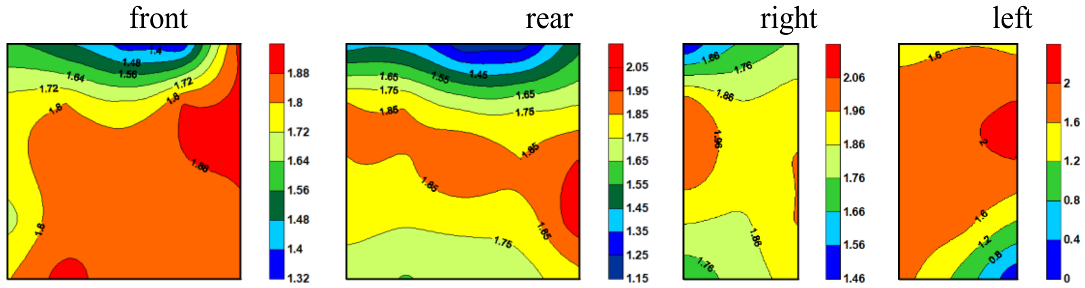
Figure 6. Wind direction

III. EXPERIMENT RESULTS

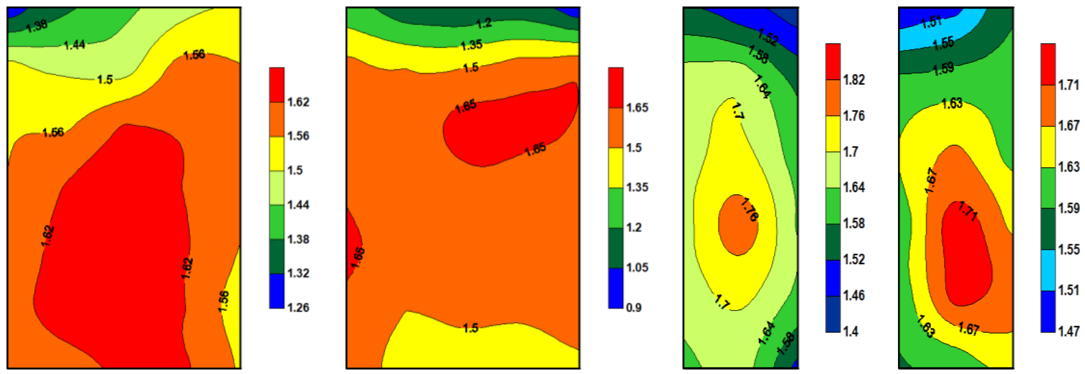
III.I Maximum/Minimum Peak Wind Pressure Coefficient

Fig 7 and 8 show the maximum/minimum peak wind pressure coefficients of the rooftop hoardings. At each position on the front and rear in Cases 1 and 2 of the rooftop hoardings, the maximum peak wind pressure coefficient (positive pressure) of the bottom part of the rooftop hoarding was greater by at least 25% than that of the top part. In Case 2, with an increase in the height of the rooftop hoarding 30% greater than that of Case 1, the maximum peak wind pressure coefficients (positive pressure) of the front and rear were lower by 10–20% than those of Case 1. Furthermore, the maximum peak wind pressure coefficient (positive pressure) on the left and right sides appeared at the center of the side of the rooftop hoarding. Furthermore, when the maximum peak wind pressure coefficient (positive pressure) was compared between the front and rear, it was at least 10% larger on the front. The minimum peak wind pressure coefficient (negative pressure) according to the height of the rooftop hoarding on the front and rear of Case 1 were at least 20% larger than those of Case 2. The minimum peak wind pressure coefficient (negative pressure) was at the front and rear corners of the rooftop hoarding.

In Case 2 with a greater height of the rooftop hoarding, the coefficient ranged from -1.8 to -2.8, which was at least 30% greater than the coefficient range of -1.62 to -1.92 in Case 1. The distribution pattern of the minimum peak wind pressure coefficient (negative pressure) was that the minimum value at the top and bottom corners decreased toward the center of the hoarding. The difference in the minimum peak wind pressure coefficient (negative pressure) between the sides was smaller than -2.0 and the difference according to the height of the rooftop hoarding was not large. When compared with the maximum peak wind pressure coefficient (positive pressure), the minimum peak wind pressure coefficient (negative pressure) appeared at the bottom corner of the hoarding rather than at the center.

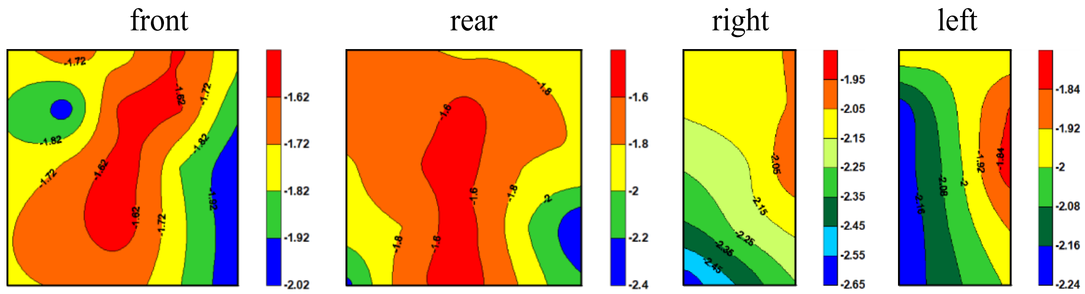


(a) Case 1

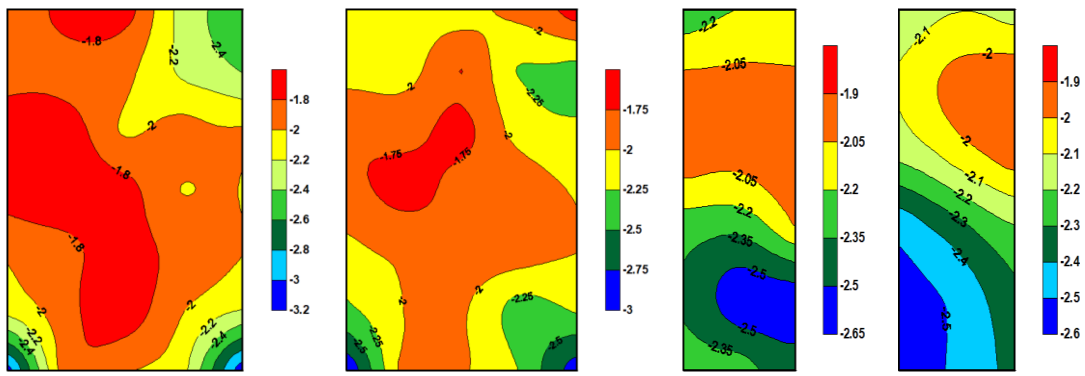


(b) Case 2

Figure 7. Maximum peak pressure coefficients



(a) Case 1



(b) Case 2

Figure 8. Minimum peak pressure coefficients

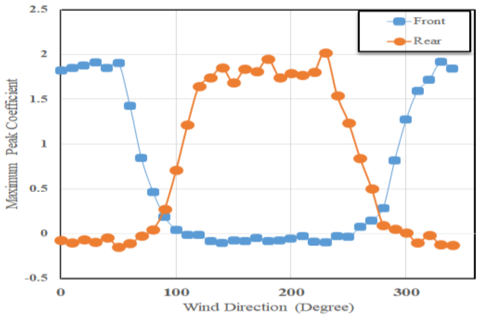
III.II Maximum/Minimum Peak Wind Pressure Coefficient According to Wind Angle

Fig 9 and 10 show the distribution of the maximum/minimum peak wind pressure coefficient according to the wind angle change. The maximum/minimum peak wind pressure coefficients according to the angle of the wind pressure holes installed on each side of the rooftop hoarding were analyzed separately. The maximum peak wind pressure coefficients (positive pressure) on the front and rear appeared in the angle 0°

The maximum value appeared between 330 and 350° on the front and between 120 and 230° on the rear. At other angles, a constant minimum value appeared. The difference between the maximum value and the minimum value of the maximum peak wind pressure (positive pressure) at the front and rear was about 2 times.. Furthermore, the minimum peak wind pressure coefficient (negative pressure) appeared at 80° on the front and at 260° on the rear. This difference is exactly 180°.

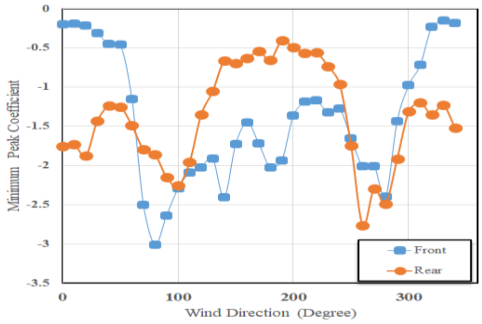
The maximum peak wind pressure coefficient (positive pressure) appeared between 0 and 180° on the left side of the rooftop hoarding and between 180 and 340° on the right side. It was found that they distributed symmetrically. The angles at which the minimum peak wind pressure coefficient (negative pressure) appeared on the left and right sides were the same as those of the maximum peak wind pressure coefficient (positive pressure). However, the minimum peak wind pressure coefficients (negative pressure) on the left and right sides appeared at 0° and 270° based on the size of the coefficient value, respectively. The difference between the maximum and minimum values of the maximum peak wind pressure coefficient (positive pressure) at the left and right sides was at least twice. However, the difference between the maximum and minimum values of the minimum peak wind pressure coefficient (negative pressure) was 2.5 times larger based on the size of the coefficient value, and it was distributed over a wider range of angles.

For the distribution of the maximum/minimum peak wind pressure coefficients by angle in Case 1 and 2 according to the height of the rooftop hoarding, the maximum peak wind pressure coefficient (positive pressure) was approximately 20% greater in Case 1 than in Case 2. However, the minimum peak wind pressure coefficient (negative pressure) was approximately 22% greater in Case 2 than in Case 1. The maximum and minimum values of the maximum/minimum peak wind pressure coefficients of the rooftop hoarding appeared differently according to the angle and position on every one of the four sides.



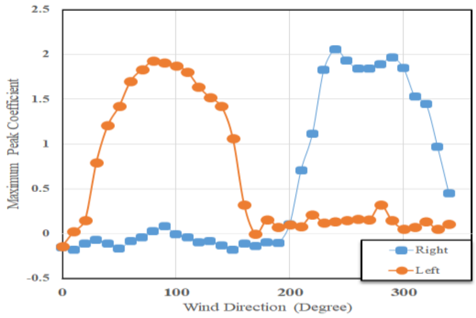
(a) maximum peak pressure coefficient

(front and rear)



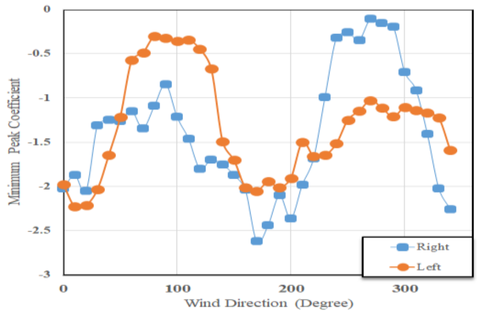
(b) minimum peak pressure coefficient

(front and rear)



(c) maximum peak pressure coefficient

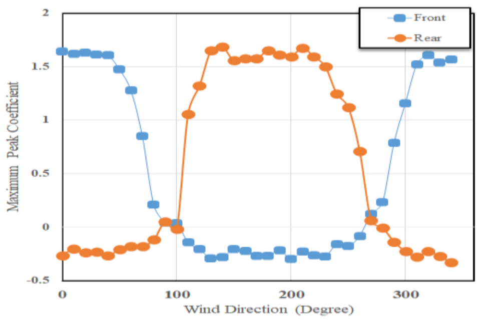
(right and left)



(d) minimum peak pressure coefficient

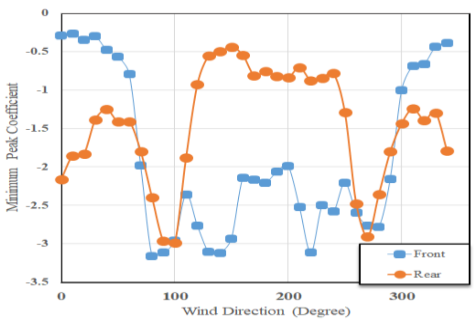
(right and left)

Figure 9. Peak pressure coefficients (Case 1)



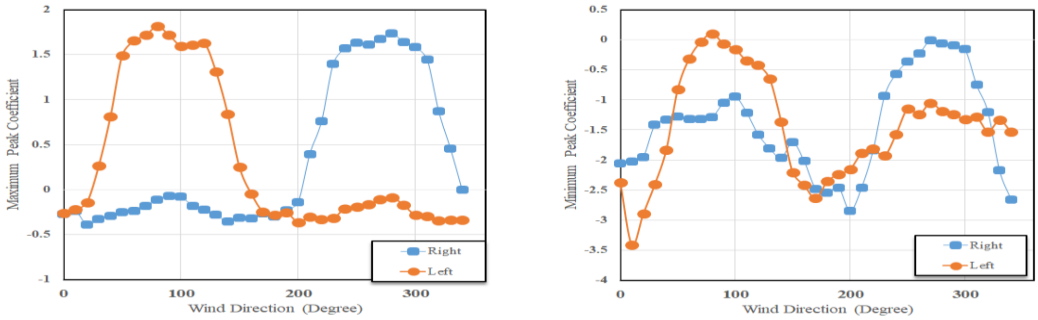
(a) Maximum Peak Pressure coefficient

(Front and Rear)



(b) Minimum Peak Pressure coefficient

(Front and Rear)



(c) maximum peak pressure coefficient (right and left) (d) minimum peak pressure coefficient (right and left)

Figure 10. Peak pressure coefficients (Case 2)

IV. CONCLUSION

Wind tunnel experiments were conducted for the distribution of peak wind pressure coefficients for rooftop hoardings, and the following conclusions were obtained.

1) The maximum and minimum peak wind pressure coefficients on the front and rear of the rooftop hoarding were localized at the bottom corners. The minimum peak wind pressure coefficient at the bottom corners on the front and rear was larger by at least -3. However, the minimum peak wind pressure coefficient on the side of the rooftop hoarding was -2 and was distributed widely over the entire side rather than over a localized region. Because the height of the rooftop hoarding increased with an increase in building height, the minimum peak wind pressure coefficient (negative pressure) was larger based on the size of the coefficient value.
2) The maximum/minimum peak wind pressure coefficients of the rooftop hoarding according to the wind angle varied depending on the hoarding position and the wind angle. Both the maximum/minimum peak wind pressure coefficients for an exterior material design appeared symmetrically in the range of 100°–300°. On every side of the rooftop hoarding, the peak wind pressure coefficient was affected by the angle.

ACKNOWLEDGEMENTS

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