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Characteristics of peak wind pressure acting on tall buildings with step on wall surface

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Abstract

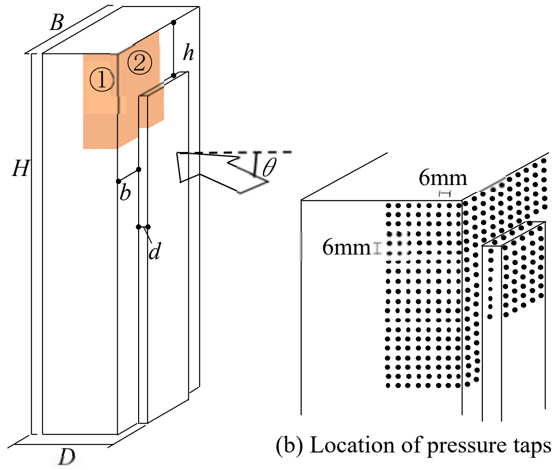
Not only for the design of tall buildings but also for the reduction of response, corner cut, corner chamfered or a case of changing the shape of buildings are adopted for the point of view of aerodynamic superiority. Kikuchi et.al pointed out that large negative peak external pressure is possible to appear near the inside corner of set-back low rise buildings. It is necessary to take attention for facade design around the steps on building surface. Peak wind pressures of corner cut or corner chamfered are given in the AIJ code, however, it cannot be applied for many variations of vertical and horizontal steps of building surface. Systematic researches for the peak wind pressures of steps for building surface have not seen in the previous. In this study, detail phenomenon of peak wind pressures on steps of buildings are investigated focusing on the vertical and horizontal distance from building corner.

Introduction

Nowadays, the corners of buildings are chamfered or cut off in many cases, for improving not only design, but also aerodynamic advantages. Tanaka et al.[1] indicated that it is possible to increase the aerodynamic advantages of buildings by modifying the shapes of their corners or altering them vertically. On the other hand, Kikuchi et al.[2] pointed out that buildings with setbacks force air flow to contract around the recessed areas and cause the absolute value of peak external pressure to augment locally. Since the peak external pressure acting on the horizontally and vertically chamfered edges of buildings is different from that on the buildings whose corners have not been chamfered, it is necessary to pay careful attention to this fact when designing a building. AIJ-RLB[3] indicate the peak external pressure coefficients for relatively simple chamfered or cut corners, but these cannot be applied to complex steps on walls. In addition, there have been no systematic research regarding the steps on building walls and peak external pressure coefficients, and so it is difficult to reasonably estimate the wind loads on exteriors around steps on walls. In this study, the authors change the horizontal and vertical distances of steps on walls for two kinds of building shapes, and research the trend of peak external pressure coefficients while focusing on the parts susceptible to the steps on walls. In this paper, the vertical and horizontal chamfered corners are all called "steps."

Outline of experiment and analysis methods

A step-mounted building model shown in Figure 1 was used for air tunnel experiment. The scale of the model was 1/350, and as shown in Figure 1(b), wind pressure measurement points were concentrated around the corners of the top of the model (represented by the shade in Figure 1(a)), and wind pressure was measured at a total of 357 points concurrently. Table 1 shows the dimensions of the experimental model. Two kinds of planar shapes were adopted. The ratio of the width to the depth (side ratio) was 1 and 2. For the planar shape with a side ratio equal to 1, there were



(a)Experimental model

(b) Location of pressure taps

Figure 1 Outline of experimental model

Table 1 Dimensions of the experimental models

	Side ratio B/D = 1	Side ratio B/D = 2
Height H	480 mm	
Depth D	120 mm	
Width B	120 mm	240 mm
Step thickness d	12 mm	
Horizontal distance b	0 – 30mm @6mm	0 - 24mm @6mm
Vertical distance h	0 – 60mm @6mm	0 – 60mm @6mm

29 combinations of vertical distance h and horizontal distance b. For the planar shape with a side ratio equal to 2, there were 39 combinations of vertical distance h and horizontal distance b. Here, h represents vertical distance between the top of the building and the top of the step, while b denotes horizontal distance between the corner of the building and the step. For experimental air flow, the power index of the vertical gradient of average wind velocity α was set at 0.2 (corresponding to terrain roughness category III in AIJ-RLB). Experimental wind direction was altered at intervals of 5° from 0° to 180° to focus on the negative peak, and measurement was conducted for 37 wind directions. When basic wind speed was set at 36 m/s assuming the urban center of Tokyo, design wind speed in a 100-year simulation period was approximately 50 m/s. The scale of wind speed was 1/5, while that of time was 1/70. Sampling frequency was 800Hz, and measurement duration was 10 minutes in actual time for one sample. The variation in wind pressure was measured for 10 samples. The minimum peak external pressure coefficient (the minimum C_p) was defined by

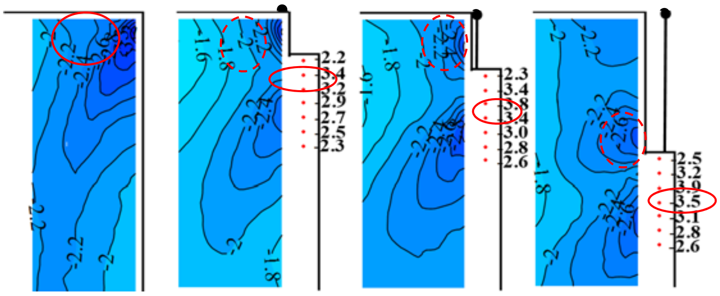
Equation (1). Assuming the comparison between AIJ-RLB and the results of the experiment, the moving-average method was used for a period equivalent to 1.0 seconds in actual time[4], the ensemble average of the minimum Cps of 10 samples was obtained, and peak values were evaluated. When moving average is 0.2 seconds, the absolute value becomes about 20% larger.

$$\breve{C}_P = \frac{\breve{P}}{\bar{q}_H} \qquad (1)$$

$\breve{C}_P$: Minimum peak external pressure coefficient, $\breve{P}$: Minimum peak external pressure with averaging time as 1.0 second, $\bar{q}_H$: Mean velocity pressure at the top of the building

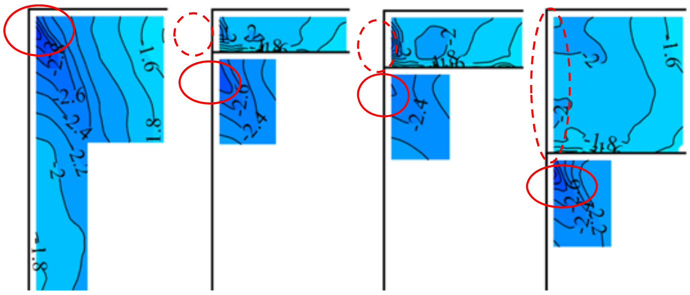
Distribution of minimum peak external pressure coefficients

Figure 2 shows the distributions of minimum peak external pressure coefficients under the condition that horizontal distance b = 0 and vertical distance h is changed, while focusing on the case where wind direction angle θ = 15°, which had the minimum C_p on the step-free side (1) of a rectangular prism with a side ratio of 1. From now on, vertical distance h and horizontal distance b will be made dimensionless with step thickness d. On the rectangular prism with a side ratio of 1 (Figure 2 (a)), there is a minimum peak external pressure coefficient with the largest absolute value around the top of the building (circled by the solid line). The minimum C_p emerged in the area circled by the solid line below the top of the step, in the case where vertical distance h = 1.5 d (Figure 2 (b)). In the cases where vertical distance h = 2d and 5d (Figures 2 (c) and (d)), the location of the minimum C_p circled by the solid line varied with vertical distance h. The local minimum peak external pressure coefficient, which emerged at the step, was continuous from the lateral side of the step to the building side, and is considered due to the vortex originating from the corner of the step. When we focus on the areas circled by the dashed lines in Figures 2 (b) to (d), it can be understood that a relatively large minimum peak external pressure coefficient emerges and varies according to vertical distance h like the above mentioned case, and this phenomenon can be considered as the same as the peak external pressure coefficient emerging locally at the upper part of the corner of the step when a step exists on a low-rise building, as indicated in the study of Kikuchi et al. Figure 3 shows the distributions of minimum peak external pressure coefficients under the condition that horizontal distance b = 0 and vertical distance h is changed, while focusing on the case where wind direction angle θ = 75°, which had the minimum C_p on the step-free side (2) of a rectangular prism with a side ratio of 1. On the rectangular prism with the side ratio equal to 1 in Figure 3 (a), a three-dimensional vortex was generated obliquely downward from the top of the building5), and a minimum peak external pressure coefficient with a large absolute value emerged. The distributions of minimum peak external pressure coefficients circled by the solid lines around the top of the step shown in Figures 3 (b) to (d) show the same tendency as that of (a). This is considered due to the three-dimensional vortex, although it is weak. Also in the area between the top of the building and the step circled by the dashed line, a minimum peak external pressure coefficient with a relatively large absolute value emerged, but a vortex like that on the rectangular prism of (a) was not generated. This is considered due to the peeling-off from the lateral side. Figure 4 shows the distributions of minimum peak external pressure coefficients under the condition that vertical distance h = 0 and horizontal distance b is changed, while focusing on the case where wind direction angle θ = 15°, which had the minimum C_p on the step-free side (1) of the rectangular prism with a side ratio of 1. When horizontal distance b = d as shown in Figure 4 (b), minimum peak external pressure coefficients emerged homogeneously in the vertical direction on the lateral side of the step (circled by the dashed line), and there



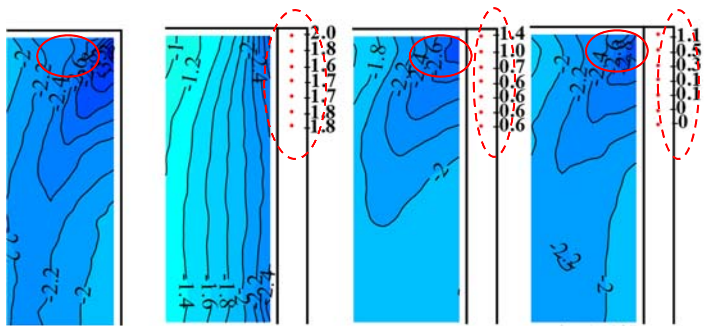
(a) Square (b) h=1.5d (c) h=2d (d) h=5d

Figure 2 Minimum peak external pressure distributions with different vertical distance (B/D=1, Surface①, Wind direction θ=15° , Horizontal distance b=0)



(a) Square (b) h=1.5d (c) h=2d (d) h=5d

Figure 3 Minimum peak external pressure distributions with different vertical distance (B/D=1, Surface②, Wind direction θ=15° , Horizontal distance b=0)



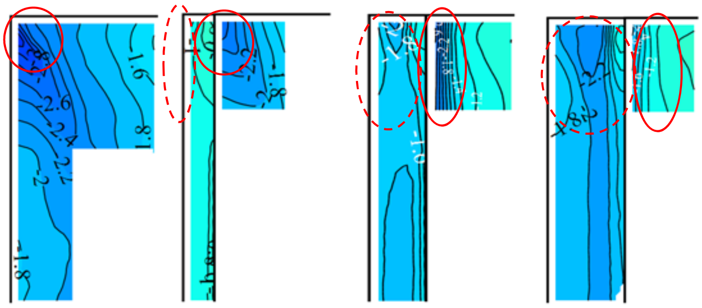
(a) Square (b) b=d (c) b=1.5d (d) b=2.5d

Figure 4 Minimum peak external pressure distributions with different horizontal distance (B/D=1, Surface①, Wind direction θ=15° , Vertical distance h=0)

was a two-dimensional distribution in the vertical direction on the lateral side of the building.4) As shown in Figures 4 (c) and (d), when horizontal distance b = 1.5d or over, a three-dimensional vortex was generated on the lateral side of the building like the case of the rectangular prism with a side ratio of 1. Figure 5 focuses on the side (2) with θ = 75° axially opposite to Figure 4 with respect to the wind direction angle 45°. Figure 5 (b), in which horizontal distance b = d, shows the vertically homogeneous minimum peak external pressure coefficient around the recessed part of the building. Around the top of the step circled by the solid line, the area of wind pressure measurement points is so small that a minimum peak external pressure coefficient with a large absolute value apparently emerged locally, but this is considered to be the same as that shown in Figure 4 (b). As shown in Figures 5 (c) and (d), the recessed part and step of the building have two-dimensional distributions in the vertical direction. It can be understood that a step makes it difficult to generate a three-dimensional vortex, which emerged on the lateral side of the under the condition that vertical distance h is changed, while focusing on the case where wind direction angle θ = 15°, which had the minimum C_p on the step-free side (1) of the rectangular prism with a side ratio of 1. Let us focus on the case where horizontal distance b = 1.5d, at which the influence of vertical distance h was the most significant. When vertical distance h = 0.5d, the absolute value of the minimum C_p at the top of the step is as large as 1.5, and as vertical distance increases, the absolute value gets closer to 1. The minimum C_p at the top of the building circled by the solid line is −2.6, indicating the minimum absolute value, when h = 0.5d, and gets closer to −3.6 when vertical distance is 2d or over, that is, it becomes more similar to the case of a rectangular prism with a side ratio of 2. Since horizontal distance is 1.5d, a local minimum peak external pressure coefficient, which emerges around the recessed part of the step as shown in Figure 2, did not emerge. Figure 7 shows the distributions of minimum peak external pressure coefficients on the Surface① under the condition that horizontal distance b is changed, while focusing on the case where vertical distance h = 3d, at which the influence of horizontal distance b is significant. The wind direction angle θ at which a minimum peak external pressure coefficient with the largest absolute value emerged on the side (1) was 10° in Figure 7 (a), 0° in Figure 7 (b), and 15° in Figures 7 (c) and (d). When horizontal distance b = 0.5d and d, the absolute value of the minimum C_p at the step is large, and it emerges at the lateral side of the building around the top of the step circled by the solid line. When horizontal distance b = 1.5d and 2d, the absolute value of the minimum C_p at the step is small, and the minimum C_p emerges due to the three-dimensional vortex around the top of the building. The formation of a three-dimensional vortex on a building is closely related to the horizontal and vertical distances of a step.

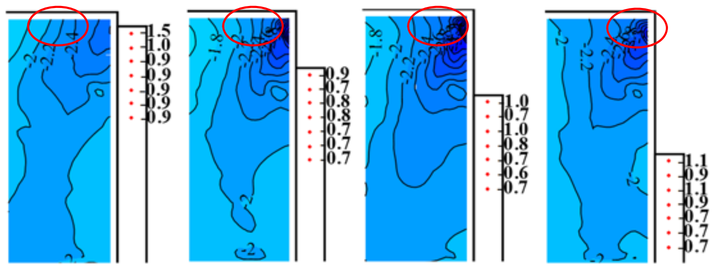
Minimum peak external pressure coefficient in each region

In this section, the minimum C_p of each categorized region with a large absolute value are discussed. Based on the results, the minimum C_p with the largest absolute value for the experimental wind direction in each region and every measurement point is summarized. Figure 8 shows the variation in the region A with a side ratio of 2. The figure also shows the minimum C_p obtained through the experiment on a rectangular prism with the same side ratio. When horizontal distance b = 0.5d and d, the absolute value is smaller than that of a rectangular prism regardless of vertical distance h. In the case where horizontal distance b = 1.5d and 2d, the absolute value exceeds that of a rectangular prism, as vertical distance h is 2d or over. When horizontal distance b = 2d and vertical distance h = 3d, there may emerge a negative pressure (− 4.2) that has the largest absolute value. Figure 9 shows the variation in the region B with a side ratio of 2. In the cases where horizontal distance b = 0.5d and d, the absolute value increases as vertical distance h gets longer. In the cases where horizontal distance b = 1.5d and 2d, the absolute value decreases. In all of the cases, the absolute value of the minimum C_p is larger than that of a rectangular prism. In the region B with a side ratio of 2, the minimum C_p increases due to the existence of a step, compared with that with a side ratio of 1. Figure 10 shows the variations in wind directions at the measurement points where the minimum C_p with the largest absolute value emerged in the region B with a side ratio 2. In the case where horizontal distance b is short, the minimum C_p with a large absolute value emerges when the wind direction angle θ is around 10°, and when horizontal distance b is long, the coefficient emerges when θ is around 90°. When horizontal distance b = 0.5d, the absolute value does not vary significantly according to vertical distance h. However, when horizontal distance b = 2d, the absolute value of the minimum C_p increases as vertical distance h gets shorter. Namely, the factor in the emergence of the minimum C_p with the largest absolute value in the region B is the negative pressure around the recessed part of



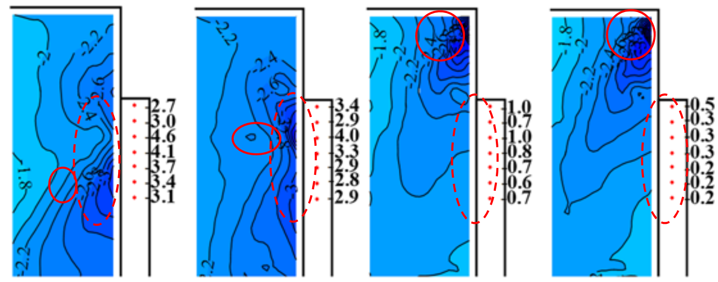
(a) Square (b) b=d (c) b=1.5d (d) b=2.5d

Figure 5 Minimum peak external pressure distributions with different horizontal distance (B/D=1, Surface②, Wind direction θ=75°, Vertical distance h=0)



(a) h=0.5d (b) h=2d (c) h=3d (d) h=5d

Figure 6 Minimum peak external pressure distributions with different vertical distance (B/D=2, Surface①, Wind direction θ=15°, Horizontal distance b=1.5d)



(a) h=0.5d θ=10° (b) h=2d θ=0° (c) h=3d θ=15° (d) h=5d θ=15°

Figure 7 Minimum peak external pressure distributions with different horizontal distance (B/D=2, Surface①, Wind direction θ=15°, Horizontal distance h=1.5b)

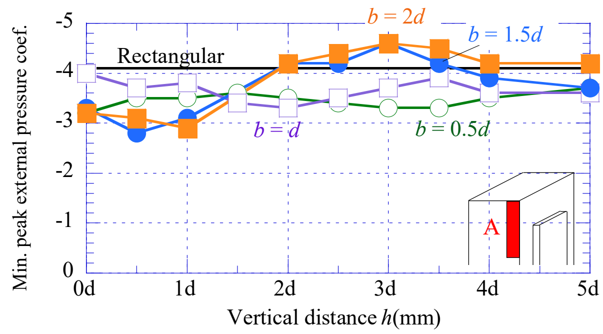


Figure8 The variations of the minimum external pressure coefficient of region A in all measured wind directions with various step locations (B/D = 2, Region A)

the step when horizontal distance b is short, and the peeling-off from the upstream when horizontal distance b is long. Figure 11 shows the variation in the region C with a side ratio of 2. When horizontal distance b = 0.5d and d, the absolute value of the minimum C_p increases as vertical distance h gets longer. When horizontal distance b = 1.5d and 2d, the absolute value does not vary significantly according to vertical distance h. In the case of the region C, the absolute value of the minimum C_p increases as horizontal distance b gets shorter, no matter whether the side ratio is 1 or 2. Figure 13 shows the variation in the minimum C_p at the measurement point P, where the absolute value is the largest in the region C, with respect to wind direction angle. In the case where horizontal distance b = 0.5d, the absolute value of the minimum C_p is the largest when wind direction angle θ is around 10°. This indicates that the absolute value of the minimum C_p increases as vertical distance h gets longer. In the case where horizontal distance b = 2d, the absolute value of the minimum C_p is the largest when wind direction angle θ is around 90°, and the minimum C_p does not vary significantly according to vertical distance h. The variation in the minimum C_p with respect to wind direction angle at the measurement point P is similar to that in the region B. The minimum C_p in the region C is considered due to the vortex around the recessed part of the step when horizontal distance b is short, and due to the peeling-off from the lateral side when b is long.

Conclusions

The minimum C_p of a building that has a step in the horizontal and vertical directions with a side ratio of 1 or 2 were examined. The wall surface was classified into some regions according to the characteristics of the wind pressure distribution of the minimum C_p, and the authors summarized the minimum C_p that varies according to the horizontal and vertical distances of the step in the experimental wind. There was no significant variation in the wind pressure distribution due to the step when side ratio was 1 or 2. It was found that a three-dimensional vortex is generated at a building according to the location of a step, and the authors were able to identify the wind direction angles at which the absolute value of the minimum C_p is a local maximum. The authors clarified the region where the minimum C_p with a large absolute value emerges due to a step, compared with the case of a step-less rectangular prism. There are an enormous number of combinations of the position of a step, and this study cannot be said to be sufficient. The authors will keep studying the combinations of building shapes and steps, and discuss the phenomenon of vortex formation through experiments, such as PIV.

Acknowledgments

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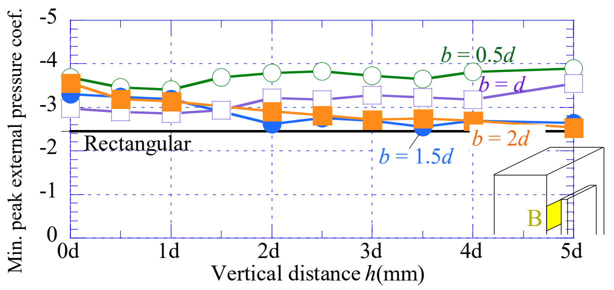

Figure 9 The variations of the minimum external pressure coefficient of region B in all measured wind directions with various step locations (B/D = 2, Region B)

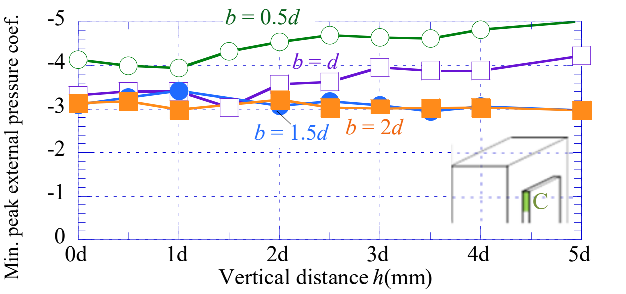

Figure 11 The variations of the minimum external pressure coefficient of region B in all measured wind directions with various step locations (B/D = 2, Region B)

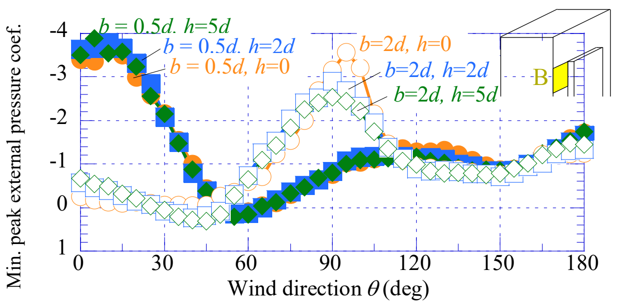

Figure 10 Variations of minimum peak external pressure in region B with different wind directions (B/D=2, Region B)

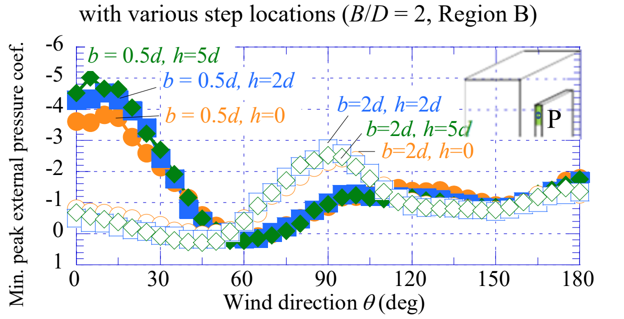

Figure 12 Variations of minimum peak external pressure at Point P in region C with different wind directions (B/D=2, Region C)