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WIND-TUNNEL STUDY ON EFFECTS OF SMALL-SCALE TURBULENCE ON FLOW PATTERNS AROUND RECTANGULAR CYLINDER

Hitoshi Yamada*and Hiroshi Katsuchi†

*Department of Civil Engineering
Yokohama National University, Yokohama, 240-8501, Japan
e-mail: y-yamada@ynu.ac.jp

† Department of Civil Engineering
Yokohama National University, Yokohama, 240-8501, Japan
e-mails: katsuchi@ynu.ac.jp

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1 INTRODUCTION

Aerodynamics of a bluff-body structure such as a bridge deck is governed by the state of flow separation around it. Its separation state is strongly affected by turbulence of an incoming flow, and therefore turbulence characteristics should be properly simulated when conducting a wind-tunnel test to evaluate its aerodynamics. However, the effects of turbulence on bluff-body aerodynamics have not been fully understood. In addition, it is very difficult to simulate perfectly turbulence characteristics in a wind tunnel. Considering such situations, turbulence intensity is primarily simulated in a wind-tunnel test.

Shear layers around a bluff body are affected mainly by a small-scale turbulence component. Since large-scale turbulence (large turbulence scale) cannot be easily simulated in a wind tunnel and the disregard of large-scale turbulence will be practically conservative, one can suggest that partially simulated turbulence in a high-frequency part can be used in a wind tunnel to investigate wind-induced responses of a structure. In fact, Irwin [1,2] suggested that the partial simulation condition could give a better explanation for bridge deck vortex-induced vibration response between full scale and wind-tunnel test [3].

In this study, a wind-tunnel investigation for this partial simulation idea was conducted. Using rectangular cylinders with various slenderness ratios, the base pressure was compared to investigate the small-scale turbulence effect (partial simulation idea) on bluff-body aerodynamics.

2 PARTIAL SIMULATION OF TURBULENCE

Turbulence flows can be perfectly simulated in a wind tunnel if its power spectral density is simulated over all frequency range. However, due particularly to the wind-tunnel size, the turbulence scale generated in a wind tunnel is usually much smaller than that of full-scale turbulence. Therefore, it is very difficult to simulate the low-frequency part of that (large-scale turbulence) in a wind tunnel.

Small-scale turbulence affects the flow patterns around a bluff body and therefore it governs characteristics of cross-sectional aerodynamics. On the other hand, large-scale turbulence will decrease span-wise correlation and change mean wind speed, which will decrease the amplitude and occurrence of wind-induced vibration. The disregard of the large-scale turbulence effects will be practically conservative. Considering these, one can suggest that the simulation of the power spectral density in a high-frequency part might give a good explanation of the full-scale behavior in a wind-tunnel test.

Having the Karman-type power spectral density function and considering to simulate the high-frequency part of it, the similarity requirement will be obtained in Eq.(1). For example, if a turbulence scale ratio to the structural dimension in a wind tunnel $(L_u^x/D)_m$ is by one order smaller than that in the full scale, the similarity requirement for the turbulence intensity in the wind tunnel will be about half of that in the full scale. This turbulence similarity requirement (referred to partial simulation) was suggested by Irwin [1,2] and pointed out that the full-scale measurement by Macdonald et al. [3] might prove this.

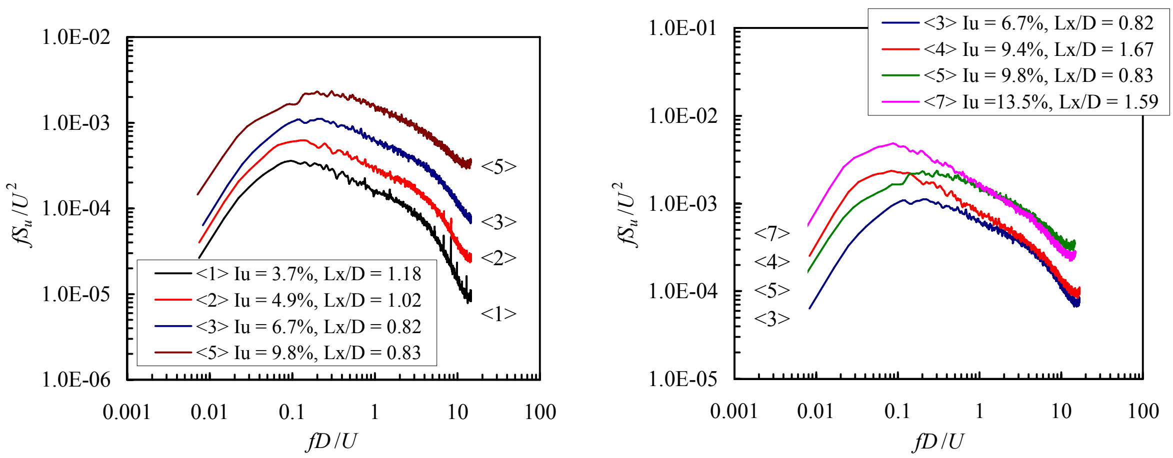
In order to investigate this similarity requirement for turbulence, base pressure rather than wind-induced response was compared under various combinations of turbulence properties (intensity and scale) in this study. Because the wind-induced response of a bluff body is governed by the flow-separation state around it and it was thought that base pressure rather than the response would be sensitive to the change of the flow-separation state and that base pressure would be a good indicator to judge if the partial simulation is satisfied or not.

$$\frac{(I_u)_m}{(I_u)_p} = \left(\frac{(L_u^x/D)_m}{(L_u^x/D)_p} \right)^{1/3} \quad (1)$$

3 BASE PRESSURE MEASUREMENT

3.1 Turbulences partially simulated

The study was conducted in the open circuit wind tunnel of Yokohama National University. Its working section is 1.3m wide and 1.8m high. Turbulence flows in the wind tunnel were generated by different-size and -distant grids. Fig. 1 shows their power spectral density. In



(a) Different turbulence intensity series (b) Small-scale turbulence simulation series

Figure1: Power spectral density of wind-tunnel turbulence

order to investigate the small-scale turbulence effects, two series of turbulence combinations were chosen. First series are different turbulence-intensity flows, power spectral densities of which do not coincide with each other as shown in Fig.1(a). Second series are turbulence flows with the same power spectral density in a high-frequency part as shown in Fig.1 (b).

3.2 Measurement of base pressure

Base pressure was measured for rectangular cylinders with various slenderness ratio (B/D = 0.26 – 0.98) and different model height (D). The model height was chosen as 3, 6 and 9cm so that large variety of the turbulence-scale ratio to the model size can be obtained. The value of B/D was changed by changing the model width B. In this study, the base pressure at the span center of the model was used. The Reynolds number at the measurement was approximately 3.7×10^4 with respect to the model height (D = 9cm). In order to correct the wind-tunnel blockage effect, correction factors were obtained from the base-pressure measurement results of the different model size at each B/D ratio based on Ref. [4].

Fig.2 shows the comparisons of the base pressure C_{pb} in the smooth flow between the present study and past studies [5, 6]. The present study fairly agrees with the past studies. The critical ratio of B/D was also confirmed at around 0.6 which is nearly identical to the past studies.

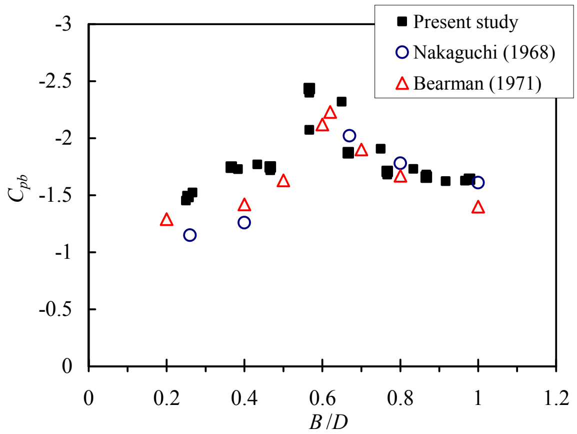


Figure 2: Comparison of C_{pb} in smooth flow

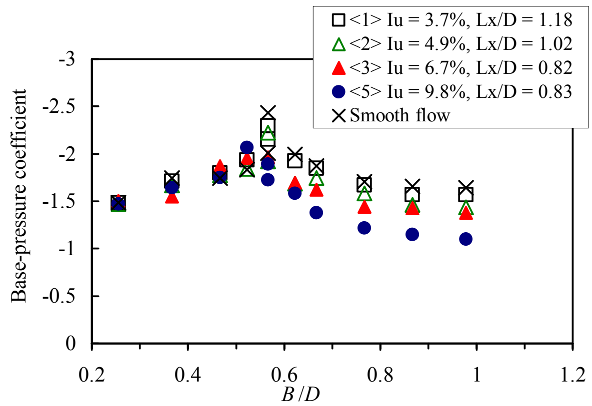


Figure 3: Comparison of C_{pb} in different turbulence intensity

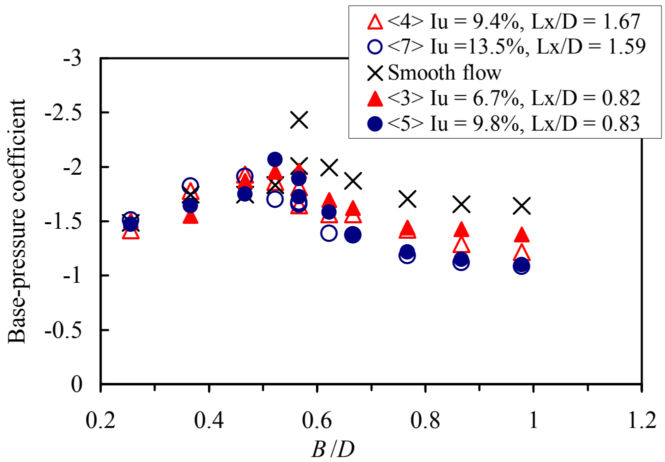


Figure 4: Comparison of C_{pb} in partially-simulated turbulence

Fig. 3 shows the comparisons of C_{pb} in turbulence flows with different intensities but close turbulence scale. It can be seen that C_{pb} for B/D less than the critical is not so much different but that C_{pb} at and larger than the critical becomes large (to positive value) as the turbulence intensity becomes large. This may result from the enhancement of interaction of shear layer with small eddies around the cylinder by the increase of turbulence intensity. In addition, the critical B/D moves to a lower value as the turbulence intensity increases.

Fig. 4 shows the comparisons of C_{pb} for partially simulated turbulences. As shown in Fig.1 (b), turbulences <3> and <4>, and <5> and <7> are pairs of turbulences with PSD simulated at a high-frequency part. These two pairs hold the relationship of Eq. (1). From this figure, C_{pb} at and larger than the critical B/D fairly agrees for the partially simulated turbulence conditions. This fact proves that flow patterns around a rectangular cylinder can be simulated if turbulence is simulated at the high-frequency part, in other word, the partial simulation of turbulence can be achieved. However C_{pb} in Figs.2-4 covers B/D ranging from 0.26 to 0.98 which is much smaller than a typical value of bridge decks. Therefore, it cannot be judged from this study that the partial simulation can hold even for bridge decks.

4 CONCLUSIONS

Small-scale turbulence simulation (partial simulation) idea in a wind tunnel was experimentally investigated. Base pressure of rectangular cylinders with various slenderness ratios (B/D = 0.26 – 0.98) was compared for the partially simulated turbulences. The results showed that the base pressure of a rectangular cylinder at and larger than the critical slenderness ratio fairly agrees for the partially-simulated turbulence. This fact proves that flow patterns around a rectangular cylinder can be simulated if turbulence is simulated at the high-frequency part. In future, base pressure for larger slenderness ratio such as a bridge deck is measured and applicability of the partial simulation idea should further be clarified.

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