

FLUCTUATING WIND VELOCITY CHARACTERISTICS OF THE WAKE OF A CONICAL HILL THAT CAUSE LARGE HORIZONTAL RESPONSE OF A CANTILEVER MODEL

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Abstract *The flow structure in the wake of a conical hill that causes large horizontal response of a horizontally supported cantilever model was studied. Fluctuating wind velocities of u -, v -, w -components were measured with split film probes, and they were conditionally sampled based on the large response of the cantilever model. A clear flow structure with velocity toward slightly downward and inward that acted around the tip location of the cantilever model was observed and it was thought to cause the large response.*

1 INTRODUCTION

Effects of complex terrain have to be carefully considered for the wind resistant design of long span bridges. In some cases, large along-wind responses were observed when the bridge is located in the wake of a hill, which cannot be explained by the conventional buffeting theory. As a step to clarify the cause of such large responses, fluctuating wind velocity characteristics acting on a simplified bridge model were studied. Similar study has been presented by the authors [1] before, but the data presented in this paper were taken after the study for Ref. [1], and somewhat different characteristics were found and they are mainly discussed here.

2 EXPERIMENTAL SETUP

A simplified conical hill model with height H of 30cm and diameter $2R$ of 135cm was used. The bridge model was a rigid square cylinder made of wood with width and height of 2.0cm and length L of 30cm. It was cantilever-supported horizontally at the height of 3.7cm with a steel plate to be allowed 1DOF along-wind response. The natural frequency and damping ratio of the model were 7.5Hz and 4.0%.

An Eiffel type boundary layer wind tunnel with width, height and length of 2.4m, 1.8m and 20m was used. No turbulence generating device was used but the boundary layer that can be approximated with power law coefficient of 0.16 and thickness of 60cm was generated at the hill model location.

The bridge model free end was set at the location of $x/R=1.48$ and $y/R=-0.15$, where the origin of the coordinate was taken at the center of the hill model and the height of the bridge

model axis with x -coordinate defined toward leeward, z upward and y with the right-handed coordinate system. The wind yaw angle β of the model was set as 40° from normal to the model axis, so that the bridge model free end pointed toward windward and center of the hill model direction (Fig. (1)). Those conditions were set based on the previous measurements that caused large bridge model responses.

The bridge model response amplitude and fluctuating wind velocities were simultaneously measured and stored with sampling frequency and time of 1000Hz and 10minutes, respectively, with the approaching gradient wind speed U of 4.0, 6.0 and 8.0 m/s. The fluctuating wind velocities were measured by split film probes and hot wire anemometry. The measurements were taken at 4cm windward of the model windward surface at the locations as shown in Fig. (2) for $U=6.0$ m/s. For the cases with $U=4.0$ and 8.0 m/s, measurements were taken at less location heights. In order to clarify the fluctuating wind velocity characteristics that cause large horizontal responses, the fluctuating wind velocity components were conditionally sampled based on the occurrence of the large response peak. The large response peak was defined in this study as that with the leeward amplitude of more than 2.5 times of the standard deviation.

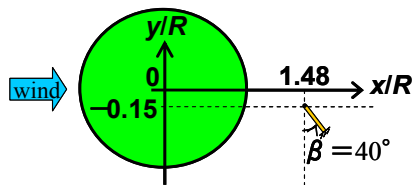


Figure 1: Definition of axes and plan view of model location.

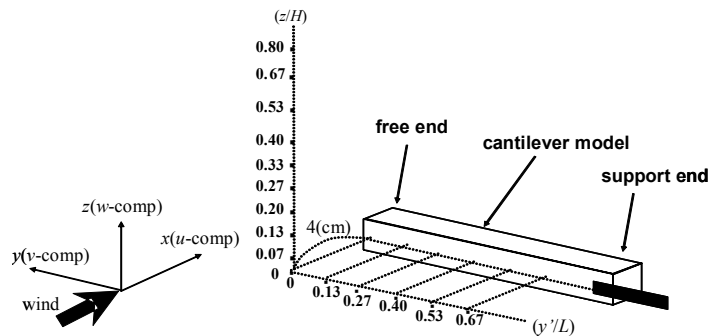


Figure 2: Wind velocity measurement location.

3 EXPERIMENTAL RESULTS

The characteristics of fluctuating wind velocities after conditional sampling are shown in the following. In all the figures, the origin of the horizontal coordinate corresponds to the instant when the large leeward response peak occurred.

3.1 Time history of the fluctuating wind velocities

In most of the cases, large wind velocity fluctuations were observed at a short time (0.05-0.15sec) before the response peak occurrence ($t=0$). These fluctuations are thought to cause the large response of the bridge model. In the cases with $U=6.0$ and 8.0 m/s, the velocity fluctuation peaks occurred almost simultaneously at different y'/L locations along the bridge model axis at the bridge model height ($z=0$), as shown in Fig. (3a) as an example. Because the model was located with wind yaw angle $\beta=40^\circ$, this means that the front line of the flow structure that caused the large response had the same skew angle at the model height. The similar observations were obtained in previous studies by the authors [1].

At higher locations (Fig. (3b) as an example), on the other hand, the velocity fluctuation peaks occurred from the model tip location ($y'/L=0.00$) to the support ($y'/L=0.67$). This

means that the flow structure was less skewed at higher locations, and it can be understood because the flow is less affected by the hill at higher locations.

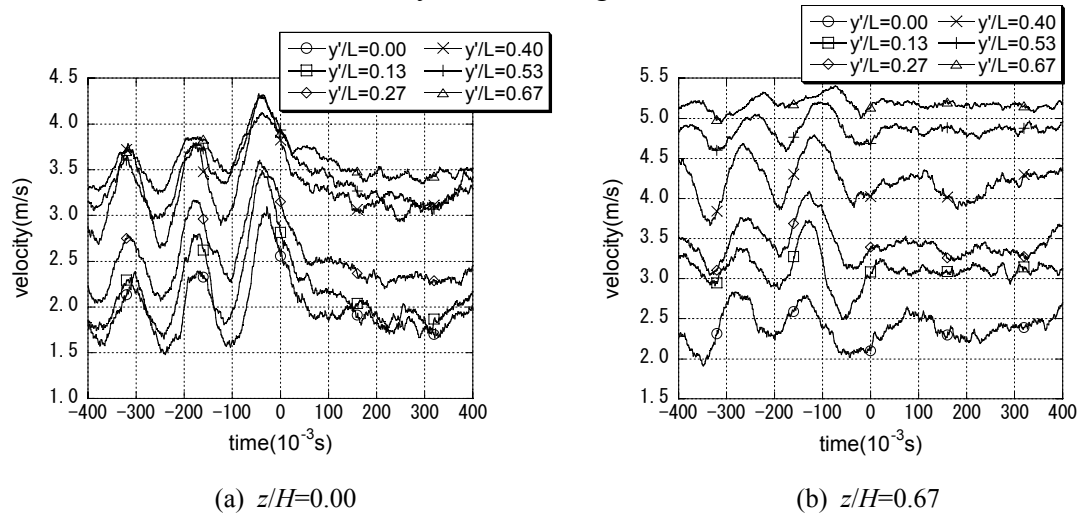


Figure 3: Time history of fluctuating wind velocity ($(u+U)$ -component, $U=6.0\text{m/s}$).

3.2 Possible flow structure causing large horizontal response

A trial was made to visualize the flow structure that causes the large horizontal responses by drawing the fluctuating velocity vectors (Figs. (4)), where the horizontal coordinate is “reduced x -coordinate”. Reduced x -coordinate is defined as the length that can be calculated by multiplying the time, U at the measurement location, and -1 . This procedure is similar to the Taylor’s frozen turbulence approximation. However, because the flow in the wake of the hill model is not stationary, the approximation cannot be applied. Instead, it has to be understood that Figs. (4) expresses the flow structure when it passed the measurement location and it is placed side by side to catch the overall tendency.

At $y^*/L=0$ location near the bridge model free end, a clear flow structure can be seen with much larger magnitude that acted on the model just before the occurrence of large response (Figs. (4)). The structure had the slightly downward (minus z -direction) and inward (plus y -direction in Fig. (1)) components. This structure seems to be generated by the downward flow with less u -component observed at 0 reduced x -coordinate. At higher locations ($z/H>0.40$), downward flow structure seems to have started from higher location and moved downward. This probably shows that this flow structure was acting from upward to downward.

At other y^*/L locations, similar structure was seen, but its magnitude became smaller. Therefore, this flow structure which mainly acted around the free end of the model seems to effectively generate large response of the cantilever model.

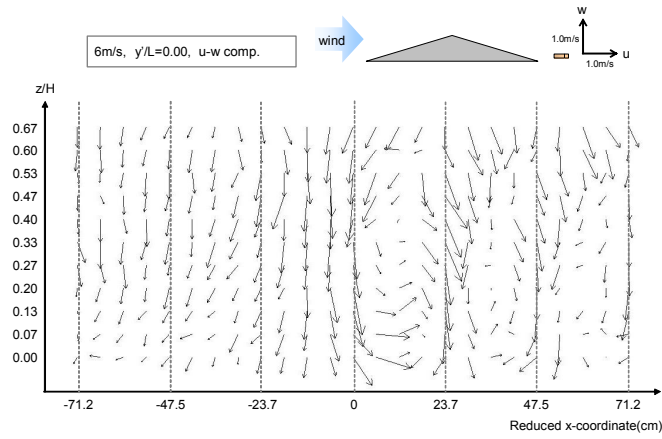
4 CONCLUDING REMARKS

As a step to understand the effects of complex terrain to the wind-induced response of long-span structures, wind tunnel studies were conducted. Fluctuating wind velocities in the wake of a conical hill were measured and conditionally sampled based on the large response of a cantilever model. Conditionally sampled wind velocity components were analyzed and a possible flow structure to cause large response was clarified.

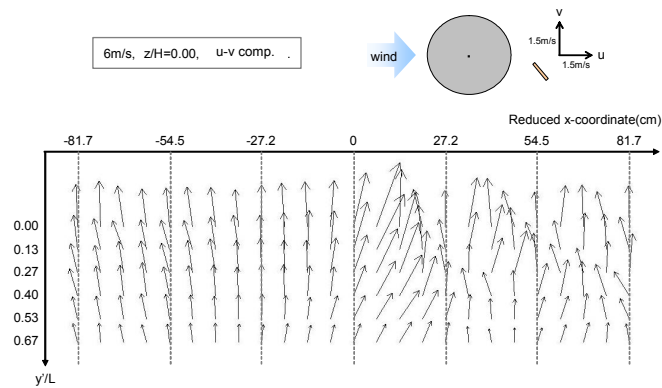
Further studies are planned where fluctuating pressures on the cantilever model will be also simultaneously measured and the flow structure to cause the large response is to be identified based on the pressure characteristics and response analysis.

REFERENCES

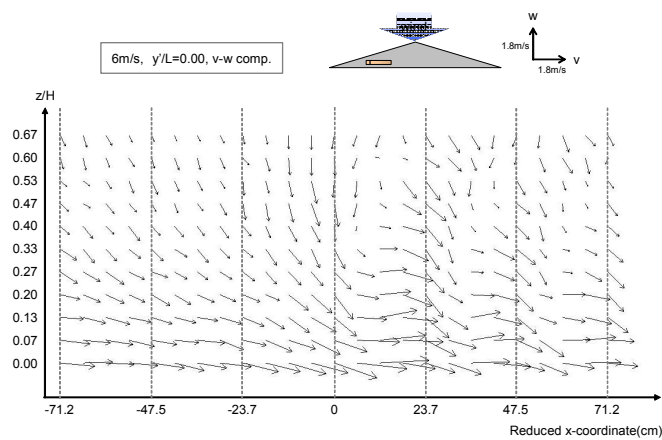
- [1] K. Kimura, E. Harada, K. Takakura, Y. Kubo and K. Kato. Fluctuating wind velocity and pressure characteristics of the flow in the wake of a conical hill causing large horizontal response of a bridge model. Proceedings of the CWE2006, Tokyo, pp. 319-322, 2006.



(a) u - w -component, $y'/L=0.00$, $U=6.0\text{m/s}$



(b) u - v -component, $y'/L=0.00$, $U=6.0\text{m/s}$



(c) v - w -component, $y'/L=0.00$, $U=6.0\text{m/s}$

Figure 4: Possible flow structure drawings using fluctuating wind velocity vectors after conditional sampling.