PROPERTIES OF UNSTEADY PRESSURE ACTING ON A CIRCULAR CYLINDER OSCILLATING IN A WAKE OF A PRISM

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1   INTRODUCTION

The wake excitation of tandem or staggered cylinders, such as cables of cable-stayed bridge, chimney and so on, is a serious problem. Many researchers have investigated this phenomenon to clarify the mechanism of this oscillation [1-5]. It has been pointed out that the characteristics of the wake excitation of a tandem or staggered cylinders depend on the arrangement of the circular cylinders and Reynolds number.

To clarify the mechanism of the wake excitation, it is necessary to separate the influence of the arrangement of the circular cylinders, and that of Reynolds number from the experimental results. However, it is difficult to separate those influences while the circular cylinder was used as the windward cylinder. Therefore, to reduce the effects of Reynolds number on the wake excitation, the windward circular cylinder was replaced by a square prism.

In this study, the wake excitation of a circular cylinder in the wake of a prism was investigated by following wind tunnel tests; 1) free vibration tests for 1DOF and 2DOF, 2) unsteady pressure measurements in forced vibration, 3) visualization tests using a high speed camera.

2   EXPERIMENTAL CONDITION

All tests were carried out in a wind tunnel test, whose test section was 1.0m wide, 1.5m high and 4m long. Fig.1 shows the arrangement of a windward square cylinder and a leeward circular cylinder. In the free vibration test, the circular cylinder, whose diameter, D, and length, L, were 40 mm and 900 mm respectively, was supported by 8 coil springs as longitudinal 1 DOF, lateral 1 DOF and 2DOF. The width of the windward square prism, d, was changed from $1/8D$ to $3/4D$ to investigate the effects of the width of the wake on the

aerodynamic response of the circular cylinder. The leading edge of the upstream prism was set at the point of 3D or 9/4D upstream from the center of the circular cylinder. The distance between the centers of the windward prism and of the circular cylinder normal to flow direction, e, was changed from 0 to 6/5D to examine the response of the circular cylinder under the staggered arrangement.

In the unsteady pressure measurement tests, the leeward circular cylinder, whose diameter, D, and length, L, were 70 mm and 900 mm respectively, was vibrated forcedly by 2DOF forced oscillator composed of two linear actuators. This oscillator can reproduce the time record of the response measured in the free vibration tests. 72 pressure holes, whose diameter was 1 mm, were installed on the surface of the center span of the circular cylinder. The unsteady pressure on the leeward circular cylinder was measured in 2DOF, 1DOF for transverse or longitudinal direction. The measured pressure was ensemble averaged during one period. The flows around the model for the same motions were also observed by a high-speed camera.

In this paper, the results for changing e/D with the constant d/D=1/2 and the constant c/D=9/4, are shown by the convenience of place.
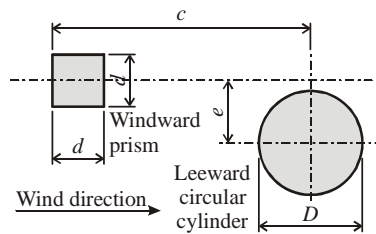

Figure 1: Arrangement properties of test model

3 RESULTS AND DISCUSSION

3.1 Effects of *e*/*D* on the response

Fig. 2 shows the effects of e/D on the response of the leeward circular cylinder in 2DOF and transverse 1DOF. The relation between the velocity and the response amplitude was changed by e/D. The on-set velocity increased in proportion to e/D, and prevailing response direction changed from transverse to longitudinal by increase of e/D. When e/D was less than 3/5, an unstable limit cycle appeared near the on-set velocity like a hard flutter. The response pattern changed from a hard flutter type to a soft flutter type with increase of e/D. In the case of 1DOF for transverse direction, the response amplitude increased, and the on-set velocity decreased in comparison with that in 2DOF.
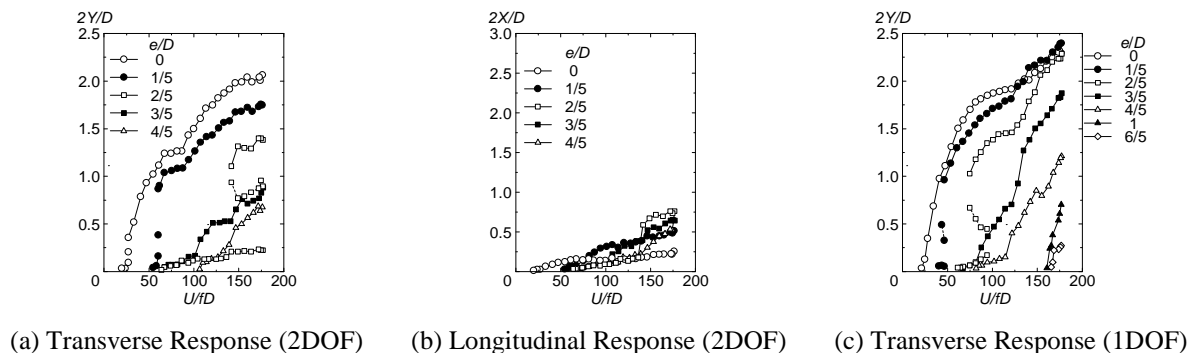

(a) Transverse Response (2DOF)   (b) Longitudinal Response (2DOF)   (c) Transverse Response (1DOF)

Figure 2: Response of leeward circular cylinder in 2DOF, transverse 1DOF (*d*/*D*=1/2, *c*/*D*=9/4)

3.2 Unsteady pressure distributions

Fig.3 and 4 indicate (a) time-record of displacement, (b) the ensemble averaged instant pressure distribution, C_p, (c) the fluctuating pressure distribution, C_p', (d) the distribution of transverse work of C_p', $W_{PY}*$, and (e) the transverse work of C_L', W_L*, in the cases of e/D=0 and 3/5. In these figures, $W_{PY}*$ and W_L* are defined as follows.

$$W_L{}^* = \int_0^1 W_L{}^*(t^*)dt^* = \int_0^1 \int_0^{2\pi} W_{PY}{}^*(\beta,t^*)d\beta \cdot dt^* = \int_0^T \int_0^{2\pi} -C_p{}'(\beta,t)\cdot\sin\beta\cdot\dot{Y}(t)T/Y\,d\beta\cdot dt \quad (1)$$

where, β is the angle from the upstream stagnation point, Y is the transverse amplitude, T is the oscillation period. Fig. 3 (b) shows that the positive high pressure area moved between β= +10 degrees and β= -10 degrees. This means that the leeward circular cylinder is outside of the wake of the windward prism during appearing the positive pressure on the upstream surface of the circular cylinder. In this case, the circular cylinder goes outside the wake of the windward prism twice a period. Fig. 3 (c) indicates that the negative fluctuating pressure area moved synchronizing with the movement of the circular cylinder. In Fig. 3 (d), the positive work area around β= +60~+90 degrees and β=-30~-90 degrees existed around t^*=0~0.3 and t^*=0.5~0.8. Fig. 3(e) indicates that the total positive work was generated by the time lag of change from the positive work to the negative work around t^*=0.25~0.3 or t^*=0.75~0.8 in Fig. 3(d).

Fig. 4 shows the results in the case of e/D=3/5. In Fig. 4 (b), the positive high instant pressure area appeared once a period around β= -30 ~ +20 degrees. Therefore, the leeward circular cylinder goes outside the wake of the windward prism once a period. Fig. 4 (d) indicates that the work of C_L' was controlled by the work of C_p' around β=+30 ~ +120 degrees where faces the wake side of the windward prism. In particular, the positive work of C_L' was generated by keeping the fluctuating pressure around this area positive after t^*=0.25 in Fig. 4 (c). Therefore, it is clarified that the source of the positive work of C_L' is the time lag of changing pressure sign when the circular cylinder goes inside the wake of the prism.

3.3 Flow around cylinders

Photo 1 shows the flows at t^*=0.245 ~ 0.330 in the case of e/D=0 visualized by smoke wires and a high speed camera. Photo 1 (a) indicates that the vortexes from the windward prism streams below the leeward circular cylinder at t^*=0.245. After this, the circular cylinder goes across the wake of the prism. Photo 1 (d) indicates that the wake crossing of the circular cylinder finished at t^*=0.330. Therefore, the excitation force is generated by the time lag of wake crossing of the circular cylinder, and it can be said that it is important to clarify the cause of this time lag in order to understand the mechanism of the wake excitation.

4 CONCLUSION

Through the free vibration tests, pressure measurement tests, visualization tests, it is clarified that the time lag of the wake crossing of the circular cylinder plays an important role of the mechanism of the wake excitation.

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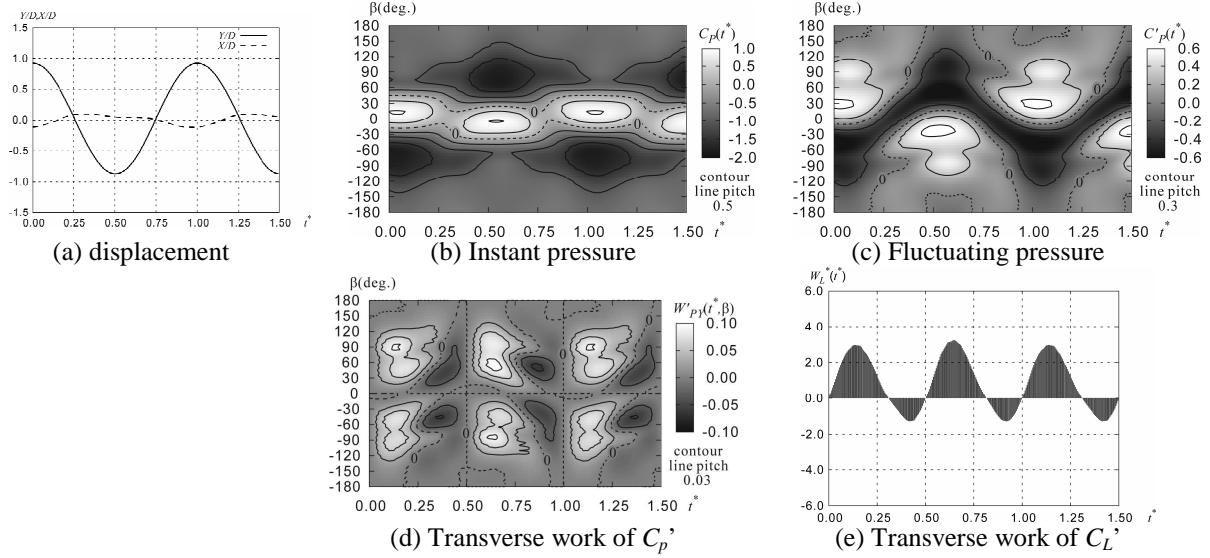[5] F. Nagao, H. Utsunomiya, M. Noda, M. Imoto and R. Sato, J. Wind Eng. Ind. Aerodyn., 91, pp.75-82, 2003.

(a) displacement (b) Instant pressure (c) Fluctuating pressure

(d) Transverse work of C_p' (e) Transverse work of C_L'

Figure 3 Ensemble averaged unsteady pressure and its work (2DOF, d/D=1/2, c/D=9/4, e/D=0, U/fD=145)

(a) displacement (b) Instant pressure (c) Fluctuating pressure

(d) Transverse work of C_p' (e) Transverse work of C_L'
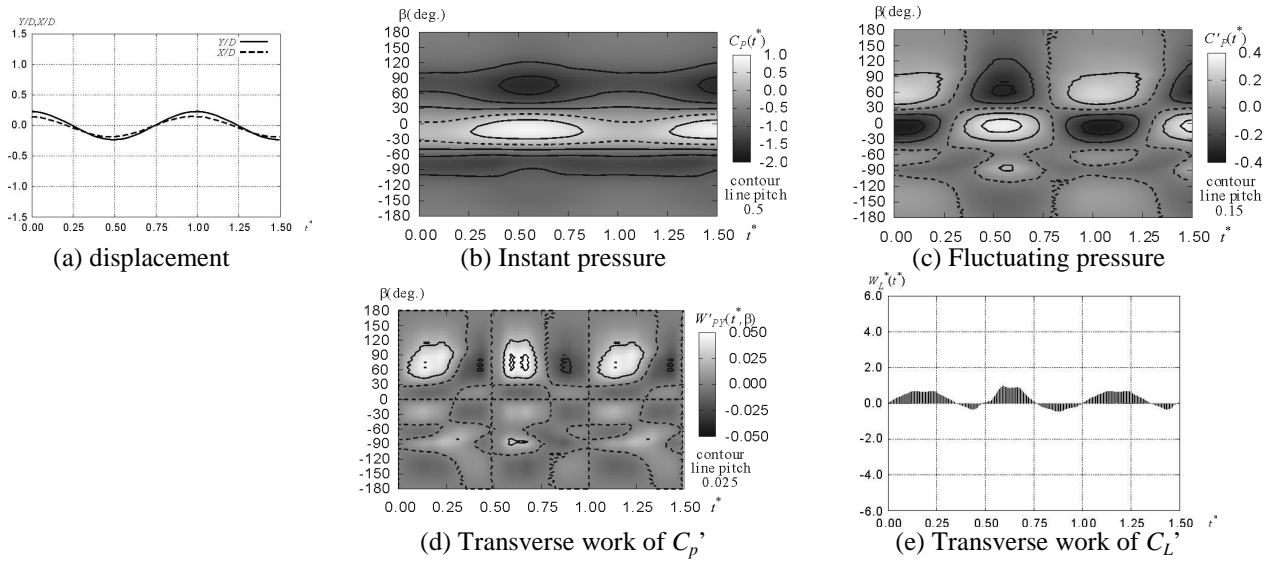
Figure 4 Ensemble averaged unsteady pressure and its work (2DOF, d/D=1/2, c/D=9/4, e/D=3/5, U/fD=145)

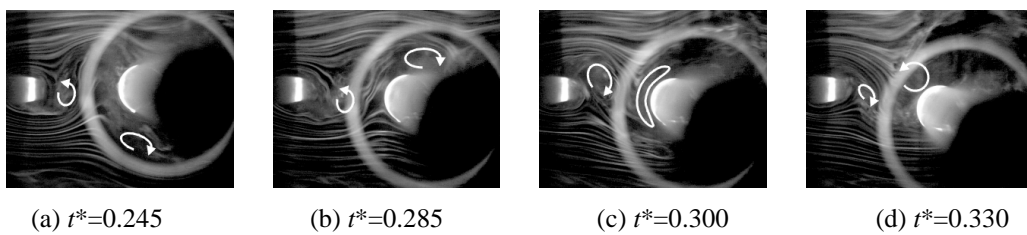(a) t^*=0.245 (b) t^*=0.285 (c) t^*=0.300 (d) t^*=0.330

Photo 1 Flow between the prism and the circular cylinder (2DOF, d/D=1/2, c/D=9/4, e/D=0, U/fD=145)