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Measurement of unsteady pressure distribution on an inclined circular cylinder during dry galloping

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SUMMARY:
A wind tunnel test was conducted to measure the pressure distribution around a cross-section of an inclined circular cylinder while the model was vibrating with dry galloping. The model was inclined by 30 deg. from vertical in the wind direction vertical plane, and it allowed transverse vibration. The pressure measurement devices were installed inside the model to avoid unnecessary interference caused by the sensor chords, and pressures at 32 points at equal intervals on a cross-section were measured. Results at a wind speed of 9 m/s (Re = 1.6×10^5) with standard deviation response amplitude A/D=0.34 are presented. Phase-averaged wind force in the transverse direction contributed to the excitation of the model generally through the cycle. Phase-averaged fluctuating pressure distribution showed that the excitation force seemed to act on the windward side of the model.

Keywords: dry galloping, pressure distribution, excitation force

1. INTRODUCTION

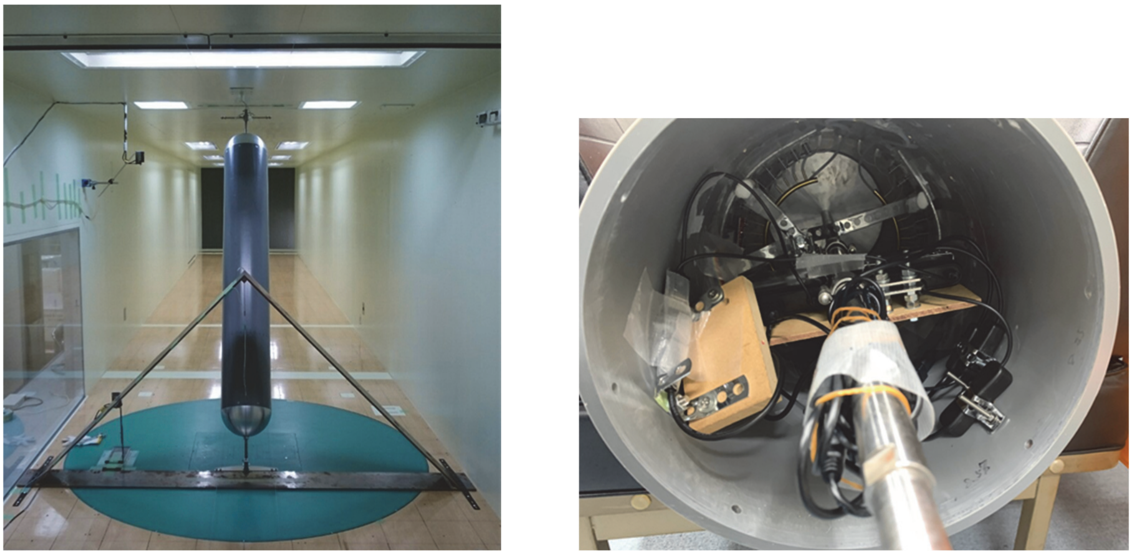
Dry galloping (or dry inclined cable galloping) is a wind-induced cable vibration under dry conditions, initially named for which occurred due to the difference of the aerodynamic forces around the drag crisis during a vibration cycle (Tanaka and Yagi, 2012; Macdonald and Larose, 2008). However, this mechanism cannot explain the purely transverse vibration, as observed by one of the authors (Kimura et al., 2012). Another explanation is the contribution of the transition in the critical flow regime (Benidir et al., 2015). But the mechanism can be understood more clearly if the wind force characteristics are measured during dry galloping. In this study, dry galloping was tried to be tested with a relatively low aspect ratio model due to the limitation of the wind tunnel size, and the wind pressures were measured during the response.

2. WIND TUNNEL TEST

A closed-circuit wind tunnel was used at National Institute of Occupational Safety and Health, Japan, with a test section of 2 m high, 2.3 m wide, and 17 m long. No turbulence-generating device was used, and the turbulence intensity was less than 1 %.

A circular cylinder of a standardized polyvinyl chloride pipe with a diameter D of 267 mm and length of 1583 mm, both sides of which were capped by aluminum hemisphere, was used. It was suspended by two wires that allowed basically across-wind vibration. The angle of the model axis was 30 deg. from vertical. Along-wind and torsional displacements were suppressed by long wires attached to both sides of the model and extended in the wind direction (Fig. 1(a)). The blockage ratio was around 9 %, and the aspect ratio of the model was as small as 5.9. This choice was made to have a high Reynolds number that could be essential for dry galloping. The natural frequency of the model was 0.478 Hz, the mass was 36 kg, and the structural damping ratio was 0.0012.

Pressures on a cross-section 400 mm from the bottom were measured at 32 points at equal intervals, with a sampling frequency of 200 Hz. However, one pressure sensor at ch.18 was not working, and its output was disregarded. The pressure measurement devices were installed inside the model to avoid unnecessary interference caused by the sensor chords. The pressure sensors were controlled, and the data were acquired by M5stack, connected from a PC via Wi-Fi. The transverse model response was measured by laser displacement sensors at the same time. The test was conducted in the wind speed range from 8.0 m/s to 17.0 m/s.



(a) Inside of the test section (from leeward side) (b) Measurement instruments installed inside the model

Figure 1. Experimental set-up and inside of the circular cylinder model.

3. RESULTS

Measured pressures were non-dimensionalized as pressure coefficients, and presented in the following. Test result at a wind speed of 9.0 m/s ($Re = 1.6\times10^5$) where a relatively large response was observed as 90.5 mm (standard deviation, A/D=0.34) is presented.

3.1. Mean pressure distribution

The mean pressure coefficient distribution is shown in Fig. 2. The wind was blowing from the left, and the distribution is more or less symmetric.

3.2. Phase-averaged wind forces and pressure distribution

Wind force in the transverse direction (orange line) was calculated from the pressures and was phase-averaged over 103 cycles based on the model displacement (blue line), and they are shown in Fig. 3(a). For the phase average, only the data were used without much rolling, a rotating motion around the axis through the model center in wind direction. Fig. 3(b) shows the phase-averaged power done by the wind force (red line) and the displacement. From Fig. 3(b), it can be seen that the excitation force was acting on the model generally through the cycle.

3.3. Phase-averaged unsteady pressure distribution

Fluctuating pressure components were calculated, and they were phase averaged. Their distributions at each 16th phase are shown in Fig. 4. Characteristic pressure patterns can be seen at the windward side that generates excitation force at 0 to $3\pi/8$, $6\pi/8$ to $11\pi/8$, and $14\pi/8$ to $15\pi/8$.

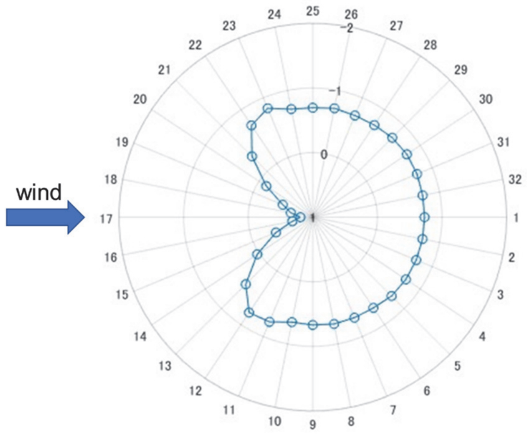
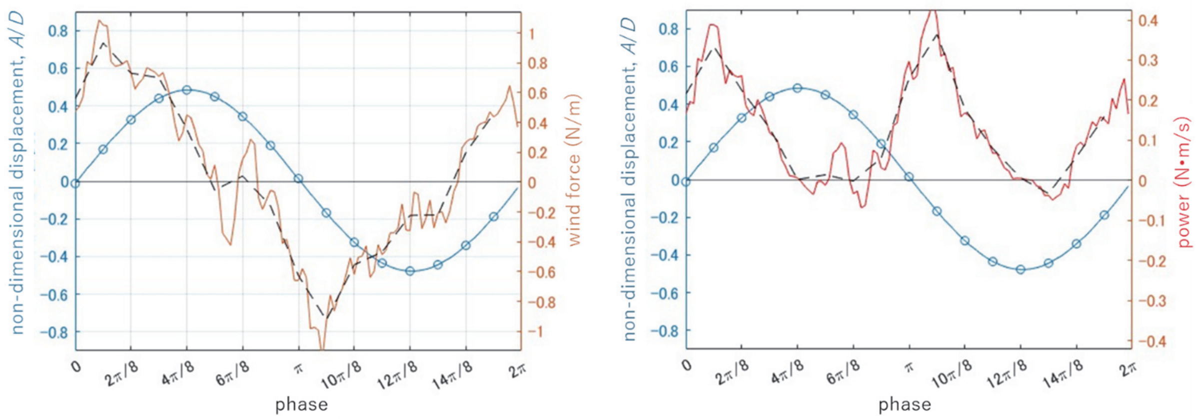


Figure 2. Distribution of mean pressure coefficients.



(a) Wind force (b) power

Figure 3. Phase averaged wind force and power (dashed line: moving averaged data).

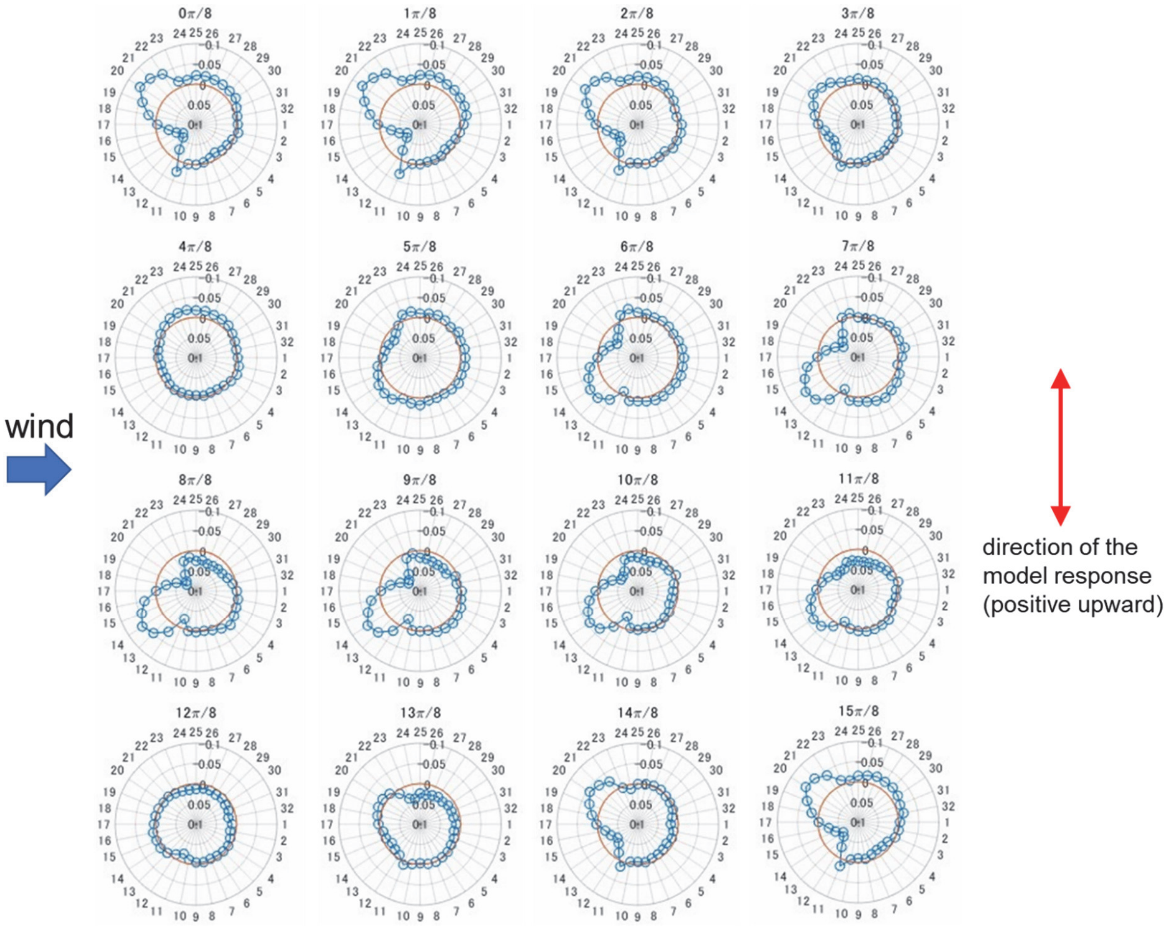


Figure 4. Phase-averaged distribution of fluctuating pressure coefficients.

4. CONCLUSIONS

Unsteady pressure distributions on a cross-section of an inclined circular cylinder model during dry galloping were measured. The results at 9 m/s wind speed where relatively large response occurred are presented. Characteristic pressure distribution patterns that generated excitation force were seen.

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