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FLow pattern around cable and its aerodynamic characteristics in critical Reynolds number range

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ABSTRACT

Reynolds number is a key parameter in the study of fluid mechanics particularly for the structures with smooth surface, such as stay-cables, since flow fields around such structures vary with Reynolds number. In this research, pressure of cable surface, wind force and cable vibration were measured, the changes of flow field around cable with variation of Reynolds number were analyzed. Results show that in critical Reynolds number range, with the decreasing of drag force coefficient, lift force appears and cable show large amplitude vibration. When Reynolds number is in sub-critical range, the pressure coefficient is symmetric. Correspondingly, the mean lift force coefficient is around 0; When Reynolds number increases to critical range, the pressure coefficient becomes asymmetric and mean lift force appears. There is the possibility that the lift force and particular flow in critical Reynolds number can induce cable vibration.

1. INTRODUCTION

Flow around a circular cylinder is known as a classical problem in the research of bluff body aerodynamics, as it is widely used in structures, such as cables and hangers. In natural wind speed, Reynolds numbers of these members are over a wide range, and flow phenomena are quite complicated and vary significantly with Reynolds number. Some researchers have paid effort to make clear the relevant problems (Bearman 1969, Roshko 1993, Schewe 1983, Zdravkovich 1997). In this research, by wind tunnel test, wind force, cable vibration and flow field around cable were measured, the Reynolds number effect on wind force and vibration are analyzed.

2. WIND TUNNEL TESTS

The wind tunnel used in this study is a closed/open circuit type with two sections. The small section is 2.2m in width, 2.0m in height and can reach a wind velocity of up

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[2)] Lecture

to 80m/s. The background turbulence of the small section is 0.2%.The big section is 4.4m in width, 3.0m in height and can reach a wind velocity of up to 30m/s. The background turbulence is 0.4% of the big section and 0.2% of the small section. The plane of wind tunnel is shown in Fig. 1.

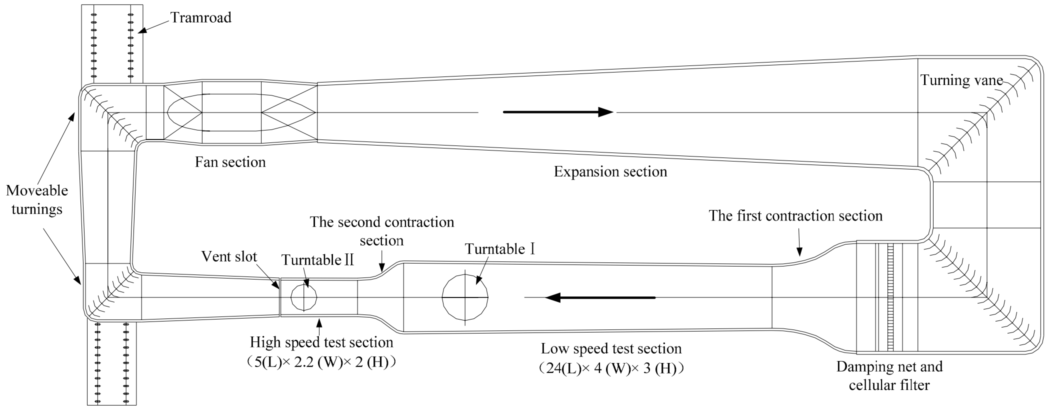


Fig. 1 Plane of wind tunnel

The cable model for surface pressure measurement has smooth surface. The diameter and length are 300mm and 2000mm respectively. To ensure the flow around model is in 2-dimension, two thin plates (Diameter is 1200m) were installed at the two ends of cable model. 180 pressure holes were arranged averagely around model surface. The diameter of pressure hole is 1mm. The cable model is shown in Fig. 2, the pressure hole arrangement on cable surface is shown in Fig.3, the test was carried out in the big working section in wind tunnel, the pressure was measured by Pressure Scanner. Wind force and vibration measurement model is shown in Fig.4, which was carried out in the small working section. Wind force was measured by 6-component balance when cable model was fix-supported, and vibration was recorded by Laser displacement meter for spring supported model. The testing Reynolds number is changing from about 100000 to 500000 with variation of incoming wind speed. There are 22 wind speeds in the test.

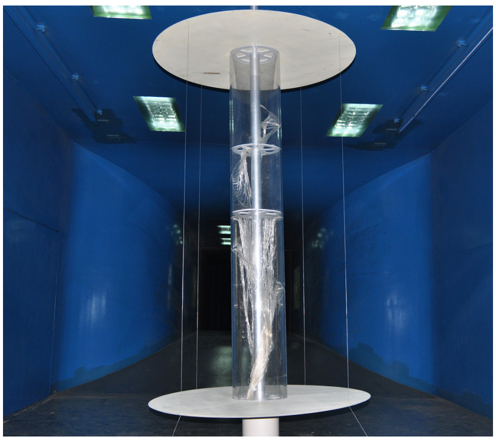


Fig. 2 Model for Pressure measurement

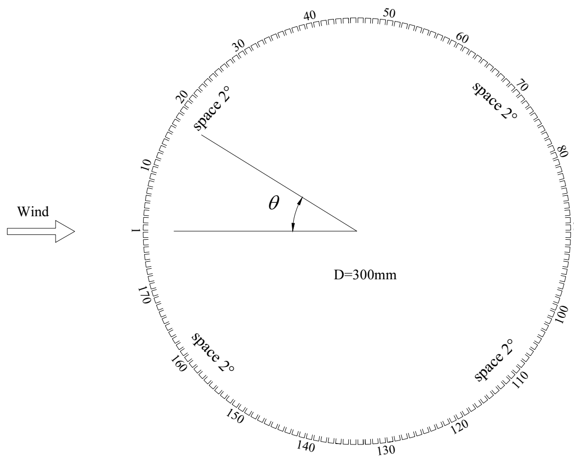


Fig. 3 Pressure holes on cable surface

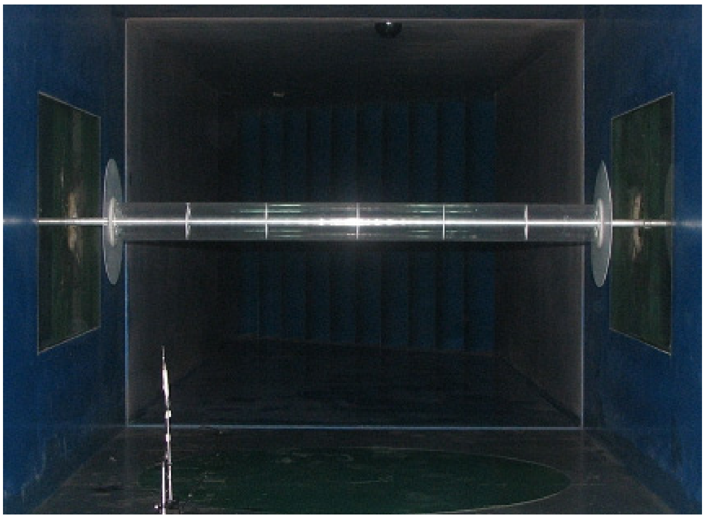
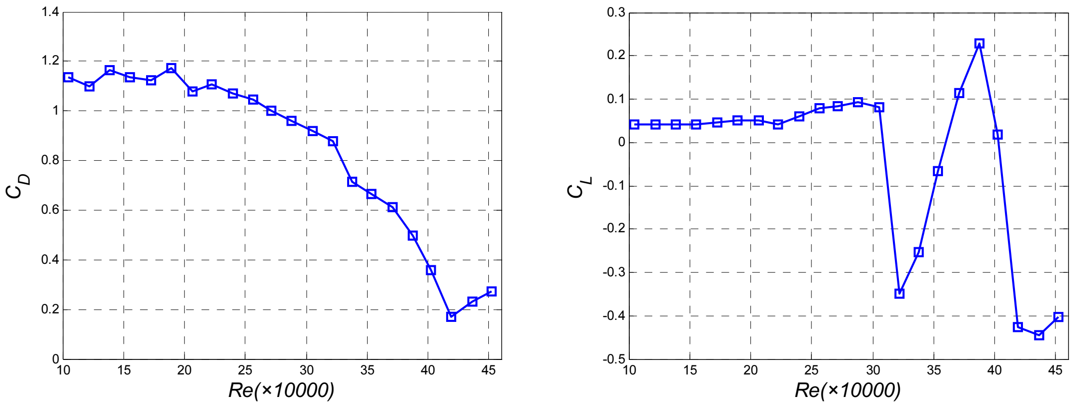


Fig. 4 Model for wind force and vibration

3. RESULTS ANALYSIS

3.1. FORCE COEFFICIENTS

Drag force coefficient and lift force coefficient got from surface pressure measurement are shown in Fig. 5. It can be found that mean lift force appears in Reynolds number range 300000~450000, indicated that this range is critical Reynolds number range.



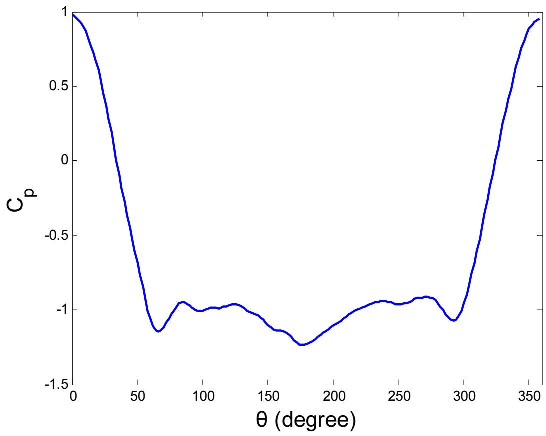
(a) Drag force coefficient (b) Lift force coefficient

Fig. 5 Drag force coefficient and lift force coefficient

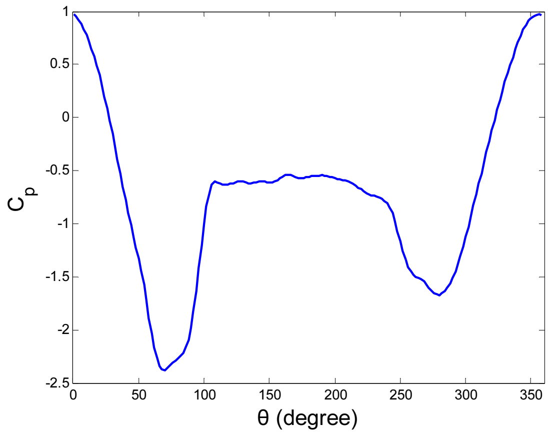
3.2. FLOW AROUND CABLE MODEL

The pressure coefficients around cable surface in different Reynolds number are shown in Fig. 6. It can be found that when Reynolds number is in sub-critical range, the pressure coefficient along both sides of symmetric line of the cylinder is symmetric (Fig. 6 a). Correspondingly, the mean lift force coefficient is around 0; When Reynolds number increases to critical range, the pressure coefficient becomes asymmetric and mean lift force appears. It is worth noting that there is certain randomness for the flow field around the cylinder in critical Reynolds number range. For some cases, the pressure coefficient in upper surface is smaller than that in lower surface (Fig. 6 b), while for some cases, it is on the contrary (Fig. 6 c). Correspondingly, the mean lift force coefficient can be positive or negative in critical Re range.

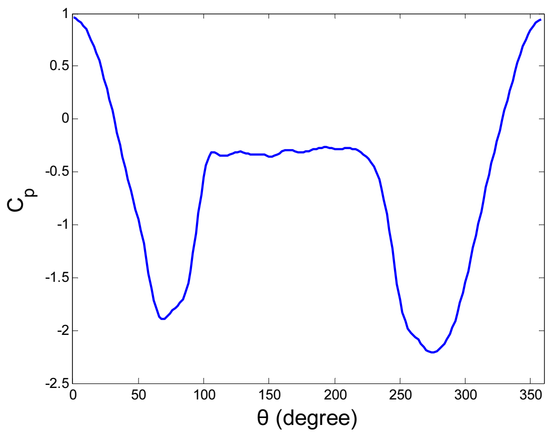
The experimental results shown that the mechanism of the phenomena stated above is that in critical Reynolds number range, regular Karman-vortex shedding around circular cylinder will disappear and complex asymmetric separation of the cable will occur, mainly laminar separation on one side and turbulent separation on another side, as Fig. 7 shows, and mean lift force will appear due to asymmetric pressure on the cable.



(a) Re=189000



(b) Re=387000



(c) Re=452000

Fig.6 Pressure coefficients around cable surface in different Reynolds number

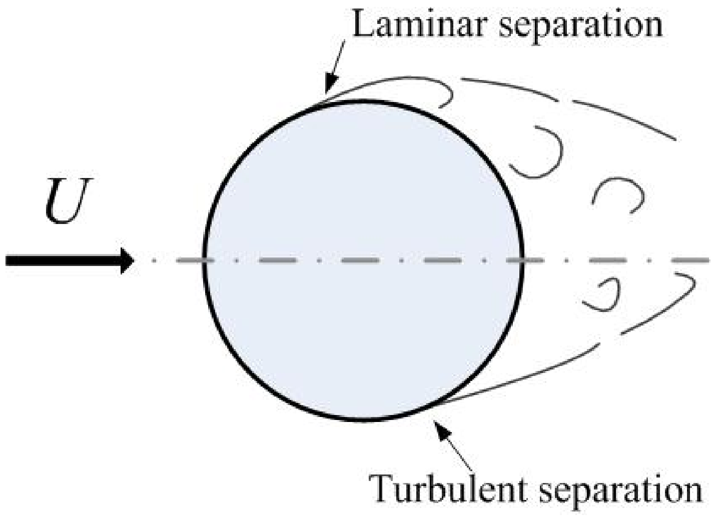


Fig.7 Sketch map of asymmetric separation in critical Reynolds number range

4. REYNOLDS NUMBER EFFECT ON WIND FORCE

The change curves of drag force coefficient and lift force coefficient obtained by wind force measurement are shown in Fig. 7. Comparing this resiult with Fig. 5, it can be seen that the change shape of C_D and C_L obtained from pressure measurement are almost same with the result got from force measurement. The drag and lift force coefficient obtained from pressure measurement is slightly smaller than that got from force measurement. One possible reason of the difference is that pressure result does not include friction force of model surface, which is included in force measurement result. There are certain differences between lift force coefficients got from every test case. This shows that flow field around the cable is unstable in such Reynolds number range and there is certain randomness for flow field changing from sub-critical state to critical state.

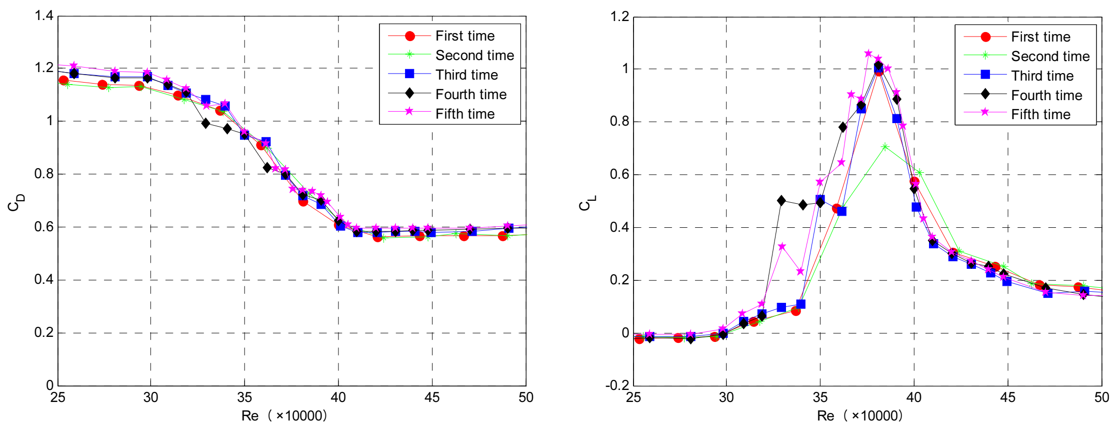


Fig.7 Drag and lift force coefficients in critical Reynolds number

In order to compare with Chinese code (JTG/T 2004), a resultant force coefficient is defined as follows：

$$C_F = \sqrt{C_D^2 + C_L^2} \tag{1}$$

The curves of drag force coefficient, lift force coefficient and resultant force coefficient are plotted in Fig. 8.

Taking Sutong Yangtze River Bridge as an example, the aerodynamic forces on stay cable evaluated by using wind tunnel result and by using Chinese code is compared and analyzed. There are eight types of stay cable in Sutong Yangtze River Bridge. Here type PES7-139 is chosen to be used. The diameter of this kind of cable is 105mm. It is assumed that the incoming wind is perpendicular to bridge deck. The drag force, lift force, resultant force and drag force based on Chinese code of cable A1 (the type of this cable is PES7-139) per unit length are shown in Fig. 9.

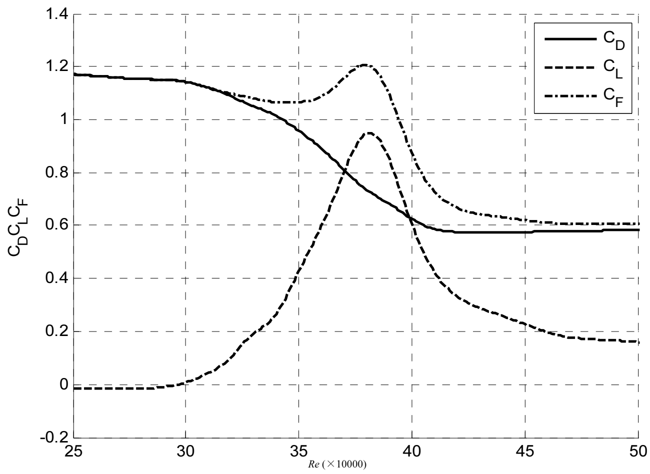


Fig. 8 Drag force coefficient, lift force coefficient and resultant force coefficient

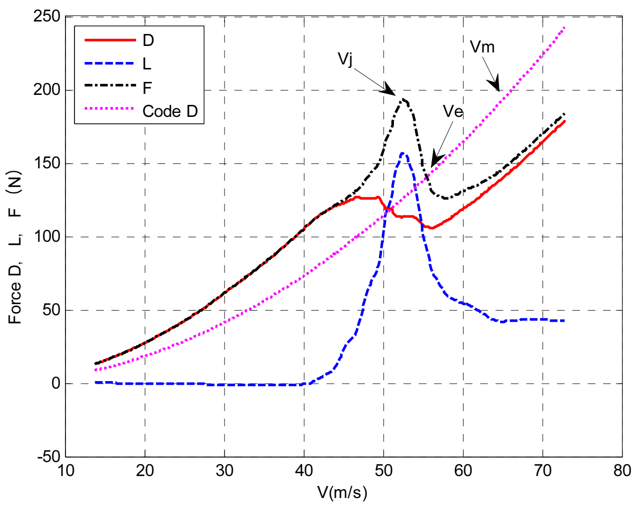


Fig. 9 Wind force based on tests and based on Chinese code

To analyze the relation among the wind forces, three wind speeds are defined. The first one is V_j in which the resultant force gets to maximum value. The second one is V_e in which the resultant force is equivalent to force evaluated by using Chinese code. The last one is V_m from which the force evaluated by using Chinese code starts to be greater than maximum value of the resultant force.

It can be found from Fig. 9 that when incoming wind speed $V < V_e$, the resultant force is greater than the force evaluated by using Chinese code; When $V_e < V < Vm$, the force evaluated by using Chinese code is greater than the resultant force for the same wind speed, but the force evaluated by using Chinese code is still smaller than maximum value of the resultant force, therefore, the result based on Chinese code is smaller than the resultant force; When $V > V_m$, the force evaluated by using Chinese code is greater than the resultant force.

Based on the analysis above, the calculating suggestion of wind load on cable is shown in Table 1.

Table 1: Calculation suggestion of wind load on cable

Calculating wind speed	Calculating method
Smaller than V_j	according to resultant force
Between V_j and V_m	according to maximum resultant force
Greater than V_m	according to code

5. REYNOLDS NUMBER EFFECT ON CABLE VIBRATION

Vibration amplitudes of spring supported cable models are plotted in Fig. 10. It is clearly indicated that cables show large amplitude in critical Reynolds number range, especially in transition from sub-critical range to critical range, and from critical range to super-critical range.

The vibration center positions (balance positions) of spring supported cable models are plotted in Fig. 11. In the critical Reynolds number range, these positions are different from those in the sub-critical and super-critical ranges. It is theorized that the lift forces push the cables into new positions in the critical ranges, and due to the absence of the lift force, the positions of the cables do not change in the supercritical and sub-critical ranges.

Fluctuating drag and lift force coefficients are plotted in Fig. 12. Analyzing the figures form 7-12, it can be seen that the coefficients of fluctuating drag force and fluctuating lift force increase dramatically with the mean lift force pushing the cables into new positions and making them vibrate. The mean and fluctuating lift force are possible factors that induce vibration. In transition from critical range to super-critical range, fluctuating drag force and fluctuating lift force increase again with the vibration amplitude becoming bigger. After that, mean drag force stops decreasing and mean lift force returns to zero. Cable models move back to the original position and large amplitude vibration disappears.

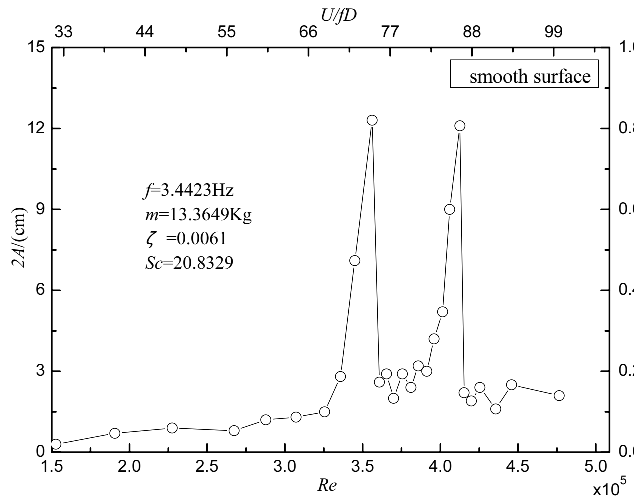


Fig. 10 Vibration amplitude of spring supported cable models

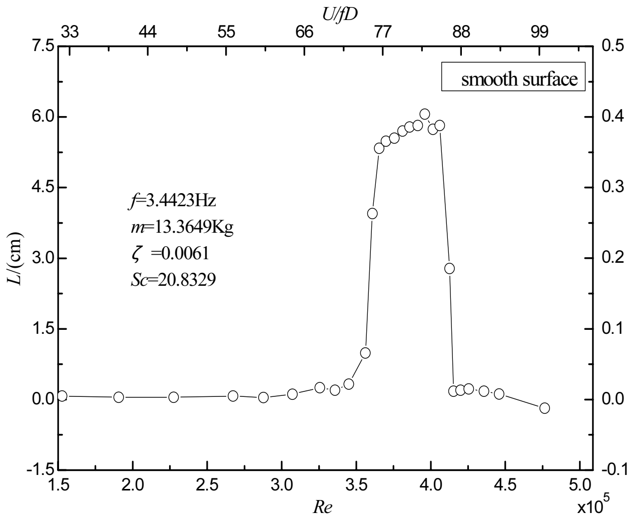


Fig. 11 Vibration center positions of spring supported cable models

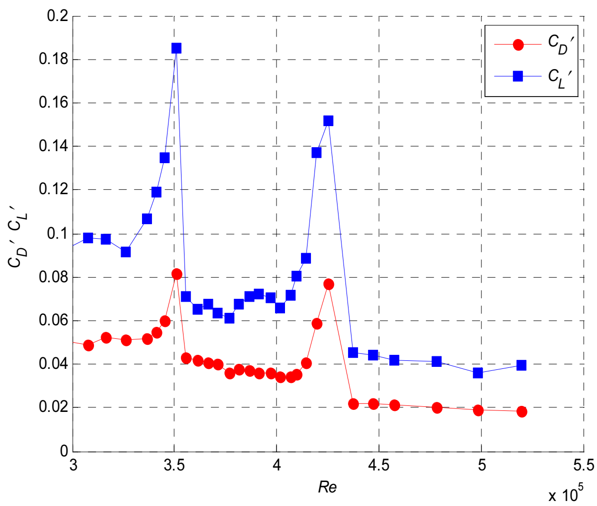


Fig. 12 Fluctuating drag force coefficient and fluctuating lift force coefficient

CONCLUSION

(1) Around the cable, asymmetric and unstable flow field appears under critical Reynolds number.

(2) In critical Reynolds number range, drag force coefficient decreases and lift force coefficient appears. The cable balance position is changed and large amplitude vibration is induced.

(3) In transition from sub-critical range to critical range, asymmetric pressure on surface and mean lift force appears because of formation of asymmetric separation on cable surface.

Acknowledgements

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