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MECHANISM ON REDUCTION OF AERODYNAMIC FORCES AND SUPPRESSION OF AERODYNAMIC RESPONSE OF A SQUARE PRISM DUE TO SEPARATION INTERFERENCE METHOD

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Abstract *The author developed a method for suppressing aerodynamic response of a slender structure which was named as Separation Interference Method (SIM). Although it has been applied on some civil engineering structures that SIM is effective to suppress the aerodynamic vibration of structure as a bridge girder, a bridge tower and a high-rise building, unfortunately the author could not obtain an opportunity for a long time to clarify the mechanism of SIM on control of aerodynamic forces and aerodynamic responses of the structure. The progress of electronic measurement instruments make us able to obtain the opportunity to clarify the Mechanism of SIM by using PIV as the method to visualize flow behavior around a bluff body. In the present paper, the detail flow velocity field around the structure with device of SIM was obtained by PIV measurement system. In SIM, an optimum size vertical plate is installed at optimum position around leading edge. The authors wanted to know the velocity distribution around the vertical plate. As the result, it was clarified that the existence of circulation in the windward place of the vertical plate generates the drag reduction and the flow behavior to suppress the aerodynamic response. By the occurrence of circulation, the pressure on the windward surface of the vertical plate is induced as the negative value and causes upwind direction force. For the galloping of the square prism, the occurrence of circulation prevents the periodic separation and enrollment of wake in the after-body region. The mechanism of SIM was made clear by using PIV measurement system. It can be said that the circulation generated at windward place of the vertical plate has similar effect as the rotors which are placed at the leading corners of the square prism.*

1 INTRODUCTION

Suppressing aerodynamic vibration is an important subject for structural engineers who design flexible structures such as long span bridges, high-rise building, tower, and so on. Up to now, a lot of devices have been proposed and applied on the flexible structures to suppress their aerodynamic vibrations. As one of devices, the author proposed Separation Interference Method (SIM) 1992 and applied it to some cable-stayed bridges in Japan[1)]. Although it has been tried to clarify the mechanism of SIM which suppresses the aerodynamic vibrations, the author could not find an opportunity because of lack of optimum measurement system for flow behavior. The author got information that Particle Image Velocitmetry (PIV) is useful to obtain detail velocity field of the fine portion of the structure.

The present paper deals with clarifying the mechanism of SIM. At the first, SIM is introduced by using Photo. 1. Upper photo is flow visualization of square prism and lower photo is that with vertical plate for SIM. The lower photo shows that the separation from leading edge of the square prism touches on the tip of the vertical plate and the separation flow flows down without enrollment. In the case where the optimum size vertical plate is installed at the optimum leeward place of the leading edge, the separation flow flows down without enrollment. This concept is Separation Interference Method (SIM). The size and position of vertical plate are determined experimentally that the angle θ shown in Fig.1 is around 30 deg. and the distance *p* from leading edge of vertical plate is larger than 0.3 times depth D of the square.

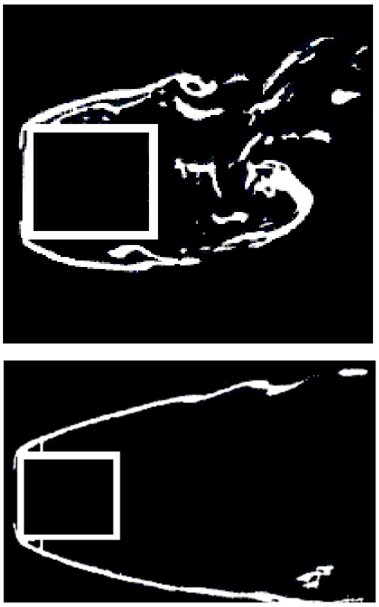


Photo. 1 Flow visualization of square prism w/o vertical plate for SIM

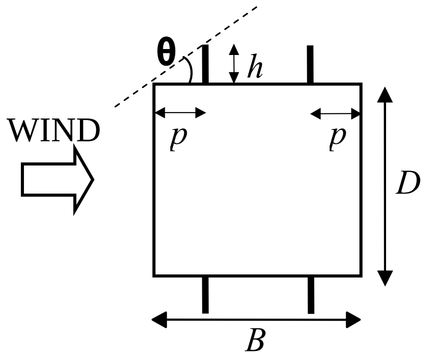


Fig.1 Experimental model of square prism

2. AERODYNAMIC FORCES AND VIBRATION OF SQUARE PRISM DUE TO SIM

The model used in the experiments is shown in Fig.1. The experiments were conducted for measuring aerodynamic forces and aerodynamic responses of the square prism with and without vertical plate for SIM. In the experiment, h is equal to 0.2D and separation interference angle θ is changed from 15 to 40 deg.

Fig. 2 is the measurement results of drag force coefficient to angle of attack. In focusing angle of attack of zero, C_D takes the value of 2.3 for the case without vertical plate and takes value from 1.2 to 2.2 corresponding to the cases with the separation interference angle θ from 15 to 30 deg.

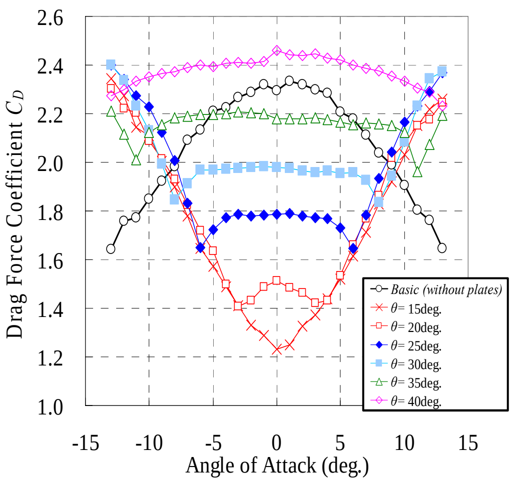


Fig.2 Drag force coefficient to angle of attack

Fig.3 is the measurement results of lift force coefficient to angle of attack. The slope of lift force coefficient is related to the possibility of occurrence of galloping based on the Den Hartog stability criterion. The case with negative slope has the possibility of occurrence of galloping. Referring to the experimental results, the cases with separation interference angle θ of 20 to 40 deg. have the positive slope of lift force coefficient at zero angle of attack and it is estimated that they have no possibility of galloping occurrence.

Fig. 4 is aerodynamic response results in heaving vibration of the square prism with and without vertical plate. In higher wind speed region, as estimated from lift force coefficient, the galloping disappeared in the cases with separation interference angle θ larger than 20 deg. These results show the efficiency of vertical plate on suppressing the aerodynamic amplitude and reducing drag force. On the other hand, even if in the case galloping disappears, the vortex-excited vibration appears. The present experiment was conducted in the condition with small logarithmic structural damping such as 0.002. The aerodynamic damping measured in the vortex-excited region was less than 0.02 in the cases except the case with θ = 40deg. Since the usual structures have the logarithmic structural damping larger than 0.02, it is estimated that there is no problem on occurrence of aerodynamic vibrations in the structure with vertical plate with separation interference angle θ between 20 to 35 deg.

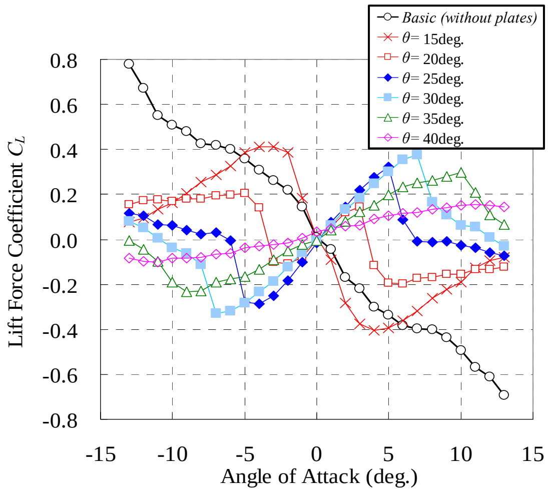


Fig. 3 Lift force coefficient to angle of attack

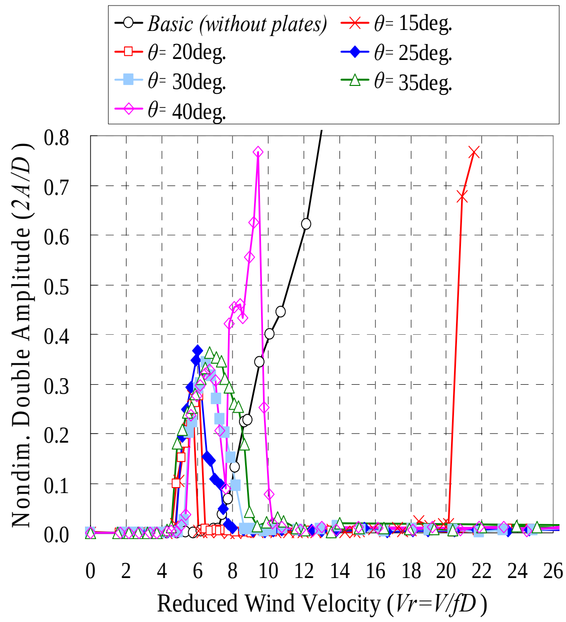
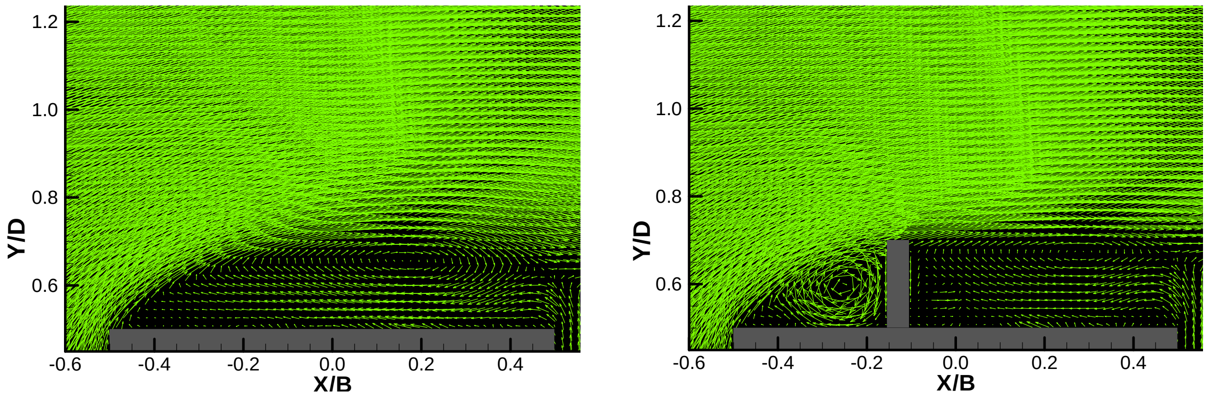


Fig. 4 Aerodynamic responses in heaving vibration of square

3. MECHANISM OF SIM

In order to clarify the mechanism of SIM effect, the flow behavior was measured by PIV system. Fig. 5 shows measurement results by PIV. The figure shows the velocity field in vector description. The horizontal and vertical axisis show nondimensional distance normarized by side length of square prism from leading edge and the arrows are velocity vectors. Fig.5(a) shows velocity field around the leading edge of the square prism and Fig. 5(b) shows that of the case with vertical plate for SIM. Although the velocity field in Fig. 5(a) has not strong circulation, the velocity field in Fig. 5(b) has strong circulation at windward place of the vertical plate. The occurrence of the circulation controls the separation flow from leading edge to flow down without enrollment of wake in leeward portion. When the vertical plate is installed at optimum angle and place, the strongest circulation is generated to be the most effective SIM. In order to know the pressure behavior on the plate, the pressure on both windward and leeward surfaces of the vertical plate was measured.



(a) without vertical plate (b) with vertical plate at θ = 30 deg.

Fig. 5 Vector description of flow speed measured by PIV, around the leading edge of square prism with/without vertical plate for SIM.

Fig. 6 shows the pressure measurement results and drag force coefficient to separation interference angle. The value indicated as darg force coeeficient of vertical plate in the figure is calculated by subtracting pressure at C from pressure at B. The pressure at B is negative, which is generated by the occurrence of circulation. Since the drag force takes negative value in the case with separation interference angle less than 35, the force generated on the vertical plate applies windward and total drag force become smaller than that of sqquare prism without vertical plate.

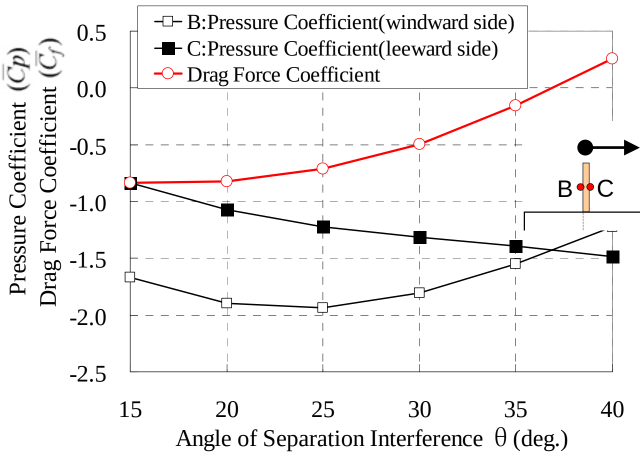


Fig. 6 Comparison of pressures of both surfaces of vertical plate with the drag force of the plate

Focusing on the state of aerodynamic vibration, in the galloping region shown in Fig.4, the wake of the case with vertical plate was also controlled to be a symmetric flow pattern and the symmetric flow pattern prevents generation of the galloping. The effect of SIM is closed to the effect of rotors installed at leading edge of bluff body. When rotating speed of rotor is raised, the drag force is reduced and the galloping is suppresed[2)].

4.CONCLUDING REMARKS

The SIM is useful to improve the aerodynamic instability and to reduce drag force. The mechanism of SIM is clarified by the present paper. The generation of circulation at windward place of optimum vertical plate gives improvement of aerodynamic characteristics. And the effect of SIM is similar to that of rotor installed leading edge of bluff body.

5. REFFERRENCES

1) Y. Kubo et al, A study on improving instability of closed and open decks for PC Cable-stayed bridge by means of separation flow mutual interference method, (in Japnese) Journal of Structural Engineering, JSSC, Vol.38A, pp.919-924,1992.

2) Y.Kubo, V. J. Modi, et al, On the suppression of aerodynamic instability through the moving surface boundary control, JWEIA, 41-44, pp.205-206, 1992.