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THE PASSIVE CONTROL OF SEPARATION FOR AERODYNAMIC STABILITY OF THE GIRDER OF LONG SPAN BRIDGES

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Abstract; *Aerodynamic vibration may occur in a long span bridge under strong wind. Additional aerodynamic devices are needed as usual procedure to control aerodynamic vibration. But, additional aerodynamic devices have problem on durability, because of less durability than structural members. Adding this, attaching such additional devices is not economical. The development of the bridge girder cross section for long span bridges is required for preparation of new bridge construction, which should satisfy the aerodynamic stability and durability for long term usage in higher wind speed than the current design wind speed. Then, the authors focused on the bridge girder with pentagonal cross-section. Because it may have enough aerodynamic stability without using additional devices, and besides, it is economical. The present paper treats the influence of the parameter such as the lower plate slope that determines the shape of the pentagonal cross-section girder to satisfy the aerodynamic stability.*

1. INTRODUCTION

In recent years, innovation of the bridge technology in Japan is remarkable, and long span bridges such as Akashi Bridge and Tatara Bridge were built. And there is a future plan to construct the longer span bridge than Akashi Bridge that is the longest in the world now. The further research on aerodynamic stability is required to realize the future plan. As one of the techniques to control aerodynamic vibration, there is a method that additional aerodynamic devices such as faring. However, since these aerodynamic devices are not structural members, additional installation cost and maintenance cost for long term usage are needed. Their durability in long term usage over 100 years is remarkably inferior to that of structural members. Considering the primary bridge design, the costs for construction and maintenance should be reduced to the utmost. In this sense, the above mentioned aerodynamic devices should not be used. So, its attention was paid to the pentagonal cross-section girder that has enough aerodynamic stability even if without using additional devices, and that is economical. The shape of the pentagonal cross-section girder is shown in Fig.1.

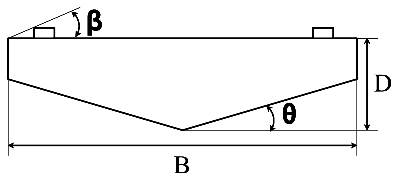


Fig.1 Pentagonal cross-section girder

In present research, by wind tunnel test, the aerodynamic characteristics of the pentagonal cross-section girder are investigated by changing the lower palate slope θ of the pentagonal cross-section girder and a good shape of the pentagonal cross-section girder is proposed, which has the aerodynamic stability without additional aerodynamic devices and excels in economical efficiency. Furthermore, the aerodynamically stable mechanism of the pentagonal cross-section girder is clarified.

2. OPTIMUM INTERFERENCE ANGLE β BASED ON SIM

There is the Separation Interference Method (SIM) developed by Kubo who is one of the authors, as the technique to control aerodynamic vibration. The concept of SIM is following. When a cross section is recognized as a non-streamlined section by the flow around the section, the non-streamlined section is changed to a streamlined section by forcing separation flow from leading edge to touch the second separation point installed behind the first separation point (leading edge) and the separation flow from leading edge flows leeward without generating vortexes.

Fig.1 shows the pentagonal cross-section used in the previous researches. There are two parameters which control the aerodynamic behavior of the pentagonal cross-section girder. They are the lower slope θ and the interference angle β between upper surface and the line connecting upper ends of girder and curbs. The experimental result of aerodynamic response of one degree of freedom in torsional vibration is shown in Fig.2. In this case, the interference angle β based on the concept of SIM is changed into 27deg. 30deg. and 33deg. under the lower plate slope θ=13deg. Referring to the experimental results, the case of β=27deg. has the highest flutter speed. Therefore, the optimum interference angle is β=27deg.

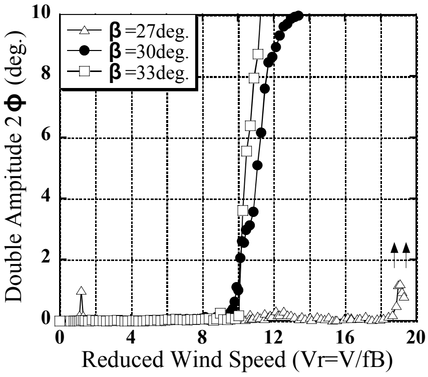


Fig.2 Aerodynamic torsional response at lower plate slope θ=13deg.

3. AERODYNAMIC FORCES OF PENTAGONAL CROSS SECTION

In order to know the relationship between aerodynamic force and lower plate slope, three components of the aerodynamic forces were measured by changing θ from 11 to 14deg. in every 0.5deg. in the cases with width-height ratio B/D of 4.0, 4.5, and 5.0. Furthermore, in each, angle of attack α was changed from -6deg. to +6deg. in every 2deg., under the interference angle β of 27 deg.

Figs.3 and 4 show the drag coefficient C_D and the lift coefficient C_L to angle of attack α in case of B/D=5.0. Referring to the experimental results, in the cases of θ=13deg. to 14deg., when angle of attack α changes, the values of the drag coefficient C_D are also changing a lot. As opposed to this, in the cases of θ=11deg. to 12.5deg., even if angle of attack α changes, the values

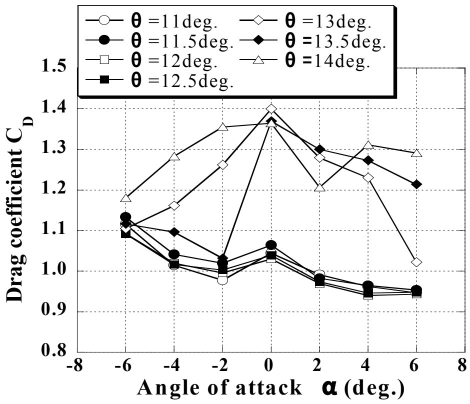


Fig.3 Drag coefficient to angle of attack in B/D=5.0

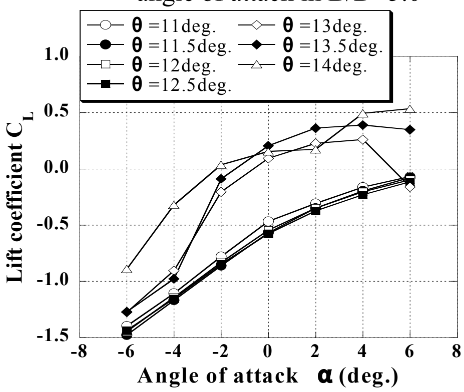


Fig.4 Lift coefficient to angle of attack in B/D=0.5

of drag force coefficient C_D do not change so much, and the values are relatively small. From Fig.4, in the cases of θ=13deg. to 14deg., when α is positive, the values of the lift coefficient C_L are positive, and the lift coefficient C_L are negative when α is less than -2deg. As opposed to this, in the cases of θ=11deg. to 12.5deg., in all α, the lift coefficient C_L are negative. The negative lift force has advantage for a bridge suspended by cable that the negative lift force in strong wind generates additional tensile force in the hanger cable of suspension bridge or in the stay cable of cable-stayed bridge and increases the total stiffness of the bridge.

Figs.5 and 6 show the drag coefficient C_D and the lift coefficient C_L to the lower slope θ in α=0deg. Referring to the experimental results, both the drag coefficient C_D and the lift coefficient C_L are remarkably influenced by the magnitude of the lower plate slope θ. In the case of B/D=5.0, both the drag coefficient C_D and the lift coefficient C_L increase greatly from 12.5deg. to 13deg., and in the cases of B/D=4.0 and 4.5, these increase greatly from 13deg. to 13.5deg.

Therefore, it can be said that the cases of θ=11deg. to 12deg. are more aerodynamically stable.

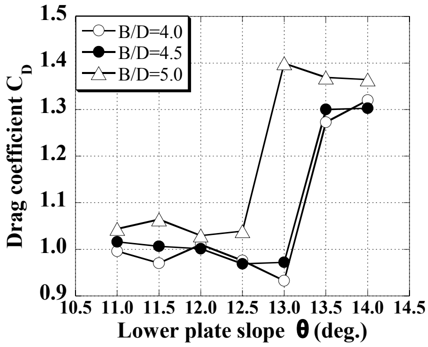


Fig.5 Drag coefficient to Lower plate slope in α=0deg.

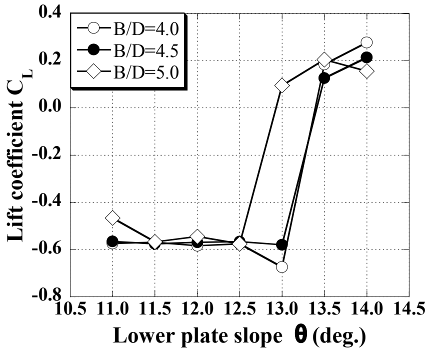


Fig.6 Lift coefficient to Lower plate slope in α=0deg.

4. FLOW BEHAVIOR AROPUND PENTAGONAL CROSS SECTION

In order to clarify aerodynamic mechanism, paying attention to the lower slope part with oblique line shown in Fig.7, flow visualization and the measurement of flow speed distribution was carried out around the section.

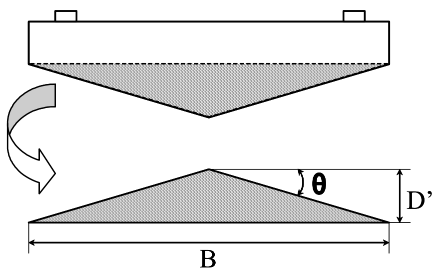
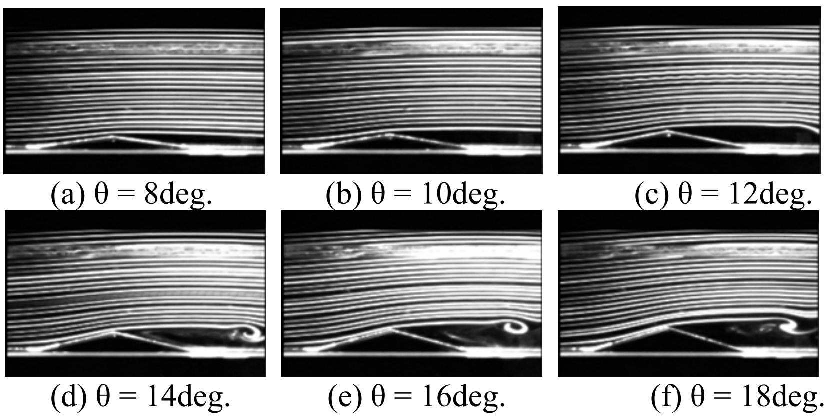


Fig.7 Outline of model section

4.1 Flow visualization

The smoke wire method was used for the flow visualization experiment. Wind speed was set on 0.6m/s to make clear the visualization images. The flow visualization of six cases was carried out, in which the lower plate slope θ was changed from 8 to 18deg. by 2deg.

The images obtained by the flow visualization are shown in Fig.8. In Fig.8 (a) and (b), turbulent flow does not



(a) θ = 8deg. (b) θ = 10deg. (c) θ = 12deg.

(d) θ = 14deg. (e) θ = 16deg. (f) θ = 18deg.

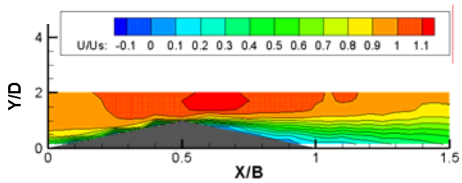
Fig.8 Results of flow visualization

appear at all in leeward part of the model, and the streamlines do not move. In Fig.8 (c), turbulent flow appears slightly in leeward part of the model, but there is no generation of vortex. On the other hand, in Fig.8 (d), (f), and (g), the flow separated from the edge of the lower slope part are generating the vortices in leeward part of the model. Adding this, when the lower plate slope θ is the lager, the vortex generation position is the closer to a model. In the measurement results of aerodynamic forces, both the drag coefficient C_D and the lift coefficient C_L have not scattered values against angle of attacks in the case of θ smaller than 12deg. The results of the flow visualization are in good agreement with the results of aerodynamic force measurement.

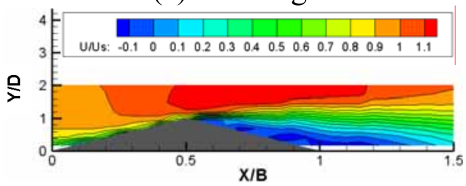
4.2 Flow speed distribution

The split film probe was used to measure wind speed distribution around the section. The experiments were conducted in the cases that θ was 12deg. and 14deg. under the wind speed of 2.0 m/s, 4.0 m/s, and 6.0 m/s. Here, the experimental result for the case of 6.0 m/s is shown.

Figs.9 (a) and (b) show distribution of mean wind speed ratio of distribution of main flow, and Figs.10 (a) and (b) show distribution of turbulence intensity. The horizontal axis of these figures shows X/B and the vertical axis shows Y/D. From Figs.9 (a) and (b), in the case of θ = 12deg., the reverse flow does not appear but in the case of θ = 14deg., the reverse flow can be seen in leeward part of the model. From Figs.10 (a) and (b), in the case of θ=12deg., the turbulence intensity is larger only in the region where the mean wind speed in leeward part of the model is lower than other part, but the turbulence intensity is smaller in leeward and remote area of the model. On the other hand, in the case of θ = 14deg., the turbulence intensity is smaller in the region where the reverse flow can be seen in leeward part of the model, but the magnitude of the value is very large in the same region. This region corresponds to the vortex generation area shown by the results in the flow visualization.

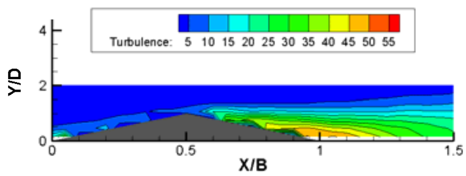


(a) θ=12deg.

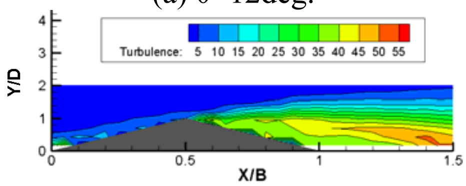


(b) θ=14deg.

Fig.9 Distribution of mean wind speed ratioof distribution of main flow



(a) θ=12deg.



(b) θ=14deg.

Fig.10 Distribution of turbulence intensity

5. CONCLUDING REMARKS

In the present paper, the pentagonal cross-section was proposed for the bridge girder of the longer suspension bridge than the current longest bridge. And the aerodynamic characteristic of the pentagonal cross-section girder was investigated by changing the lower palate slope θ. Furthermore, the aerodynamic mechanism of the pentagonal cross-section girder was clarified. The following concluding remarks were obtained.

1) The lower plate slope controls the aerodynamic performance.

2) The pentagonal cross section with lower plate slope of 12 deg. is most recommended for the bridge girder of longer suspension bridge than the current longest bridge.

3) The aerodynamic characteristics of the pentagonal cross-section depends on the flow separated from the edge of lower slope part.