A NUMERICAL INVESTIGATION INTO THE IMPACT OF FLAP ON A RECTANGULAR CROSS-SECTION USING RANS APPROACH

Yokohama National University Student Member ○ Dat Anh Tran
Yokohama National University Regular Member Hiroshi Katsuchi
Yokohama National University Fellow Member Hitoshi Yamada
Yokohama National University Regular Member Mayuko Nishio

1. INTRODUCTION

In wind resistant design, flaps are known as aerodynamic countermeasures attached to bridge girders so as to control wind flow in effort of wind-induced vibration mitigation. Using flaps could suppress the separation of flow from the upper edge of the girders. The mechanism of the wind flow around girders in the presence of flaps, however, is still not completely comprehensible. Normally, the selection of a suitable flap is carried out in wind tunnel tests which take expensive time and sometimes do not provide enough information about the behavior of wind flow. Hence, it is necessary to build up a common guidance of aerodynamic countermeasures in general and flaps in particular. Nowadays under the development of Computational Fluid Dynamics (CFD) technology application in wind civil engineering, this mission seems to be feasible. Some promising results can be found in Sarwar's research[1)] and the authors' research[2)]. In the authors' previous study, it was concluded that flaps having large gaps and angles installed in a box girder tend to reduce vortex-induced vibration. In order to provide more foundation for building up the common guidance in flap application, it should be expanded the study towards investigation into the impact of flap on a rectangular cross-section. This paper concerns the effect of flap attached to the rectangular cross-section with the width-to-depth ratio of 4 by means of using Reynolds Average Navier-Stokes (RANS) approach coupled with a new k-ε eddy viscosity turbulent model. Firstly, the validation of numerical simulations is confirmed by comparison with previous researches. Then, the geometric configurations of flap are changed in numerical simulations to clarify their influence on the behavior of wind flow, as well as their significant effects. Particularly, the Power Spectrum Density (PSD) of lift force, the Root Mean Square (RMS) of surface pressure coefficient and the flow pattern obtained are presented to examine the role of flap.

2. GOVERNING EQUATIONS AND NUMERICAL SIMULATIONS

All numerical simulations are governed by the RANS equations. In this approach, the Navier-Stokes equations are solved by averaging out all the unsteadiness to tackle turbulence. In addition, the new k-ε eddy viscosity model is utilized to close the governing equations. The study utilizes the commercial software STAR-CCM+ to run analysis with the finite volume method for discretization. The width and height of analysis domain are 20D and 40D, respectively, where D is the height of the section. Fine mesh is used in the vicinity of the section and coarser mesh is used at the areas far from section. The non-slip boundary is assigned at the perimeter of section and slip boundary is set up at the top and bottom wall. Table 1 indicates the analytical parameters set up in numerical simulations. In addition, figure 1 depicts the rectangular cross-section with the width-to-depth ratio of 4 in the presence of flap countermeasure (b, a, θ) whose the length b is 0.2D (1000 mm) and the gap a is changed from 0.03D to 0.24D (150 mm, 600 mm, 800 mm, 1000 mm and 1200 mm) and the angle θ is also varied in turn (0^o, 30^o).

Table 1. Dimension and analysis parameters

Parameter	Units	Model Scale	Full Scale
Width (B)	(m)	0.4	20
Height (D)	(m)	0.1	5
Aspect Ratio (B/D)		4	4
Number of elements		200,000	
Reynolds number		10,000	
Scale		1/50	
Time step (Δt)	(s)	0.0005	

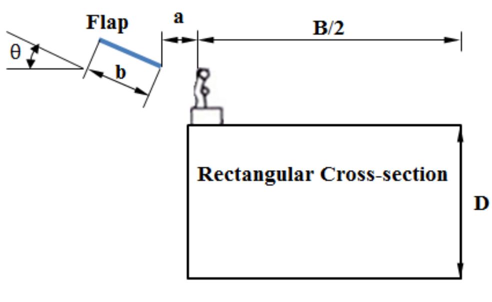

Figure 1. Rectangular cross-section and flap

3. VALIDATION

The validation of numerical analysis simulations is checked by comparison between the obtained results in this study with the ones of previous researches[3,4)] in some cases of rectangular cross-sections having different width-to-depth ratios (3.0, 3.5 and 4.0). The values of drag force coefficient C_D and RMS of lift force coefficient C'_L have a close agreement, especially in case of ratio 4, as shown in figure 2 and 3. Therefore, the reliability of numerical analyses in the study is confirmed.

Keywords: CFD, RANS, Box girder, Rectangular section, Flap.
Contact address: Structural Eng. Lab., Dept. of Civil Eng., Yokohama National University, Yokohama 240-8501, Japan.

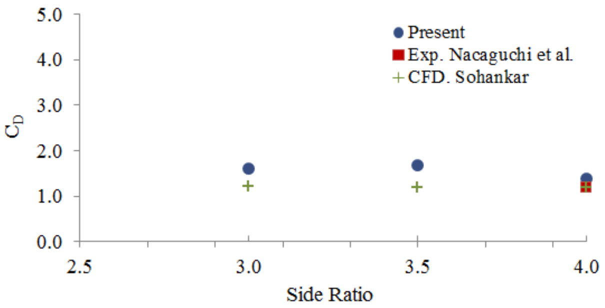

Figure 2. Drag force coefficient C_D

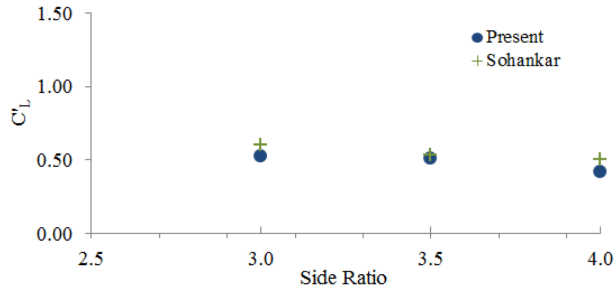

Figure 3. RMS of lift force coefficient C'_L

4. RESULTS

Figure 5 and 6 show the PSD of C_L and the RMS of surface pressure coefficient of the rectangular section. The high values are found in case of the section having no flap attached and the smaller ones are discovered in the presence of flap. These values deeply decrease when the flaps have large gaps and angles, especially in case of the angle of 30^0. The flow at the leeward region is intercepted by flap. Hence, it goes down stronger and can weaken the fluctuation of vortex formation, as indicated in figure 6 and 7.

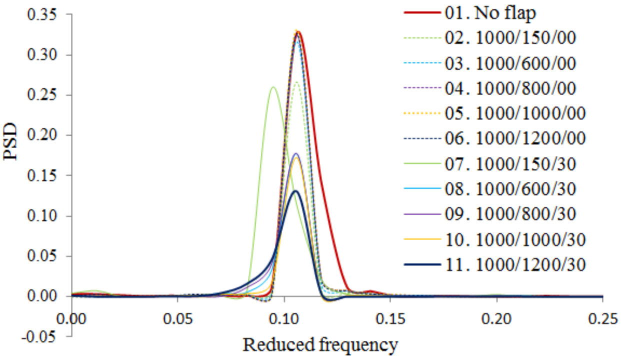

Figure 4. PSD of lift force coefficient C_L

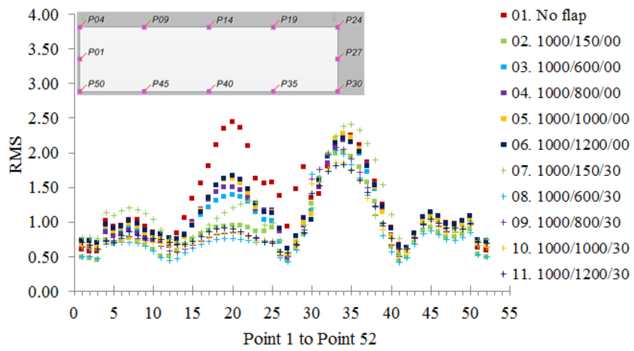

Figure 5. RMS of surface pressure coefficient

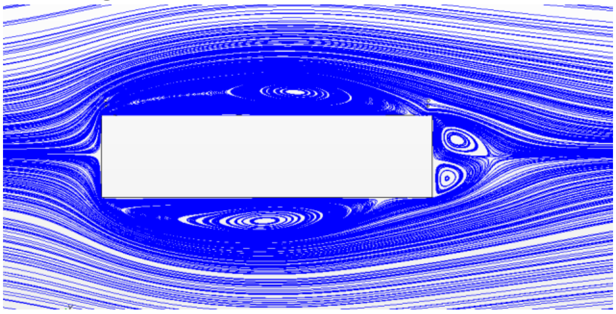

Figure 6. Flow pattern in case of no flap

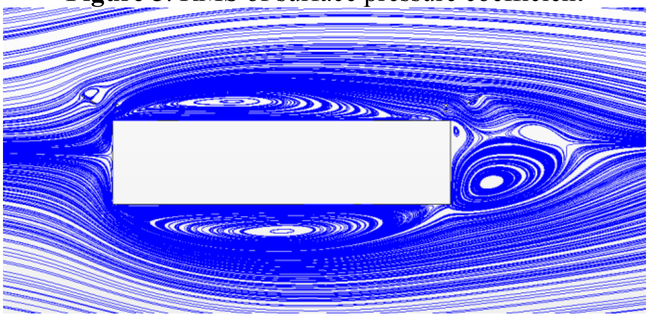

Figure 7. Flow pattern in case of 1000/1200/30 flap

5. CONCLUSIONS

The outcomes, obtained from numerical analysis CFD using RANS approach coupled with the new k-ε eddy viscosity turbulence model in this paper, has the agreement with the results of some previous researches, and it is considered as the confirmation for the validation of numerical simulations. In terms of the effect of flap attached to the rectangular cross-section with the width-to-depth ratio of 4, it proves that the presence of flap has resulted in the change of wind flow behavior and has significantly impacted on reducing aerodynamic instability characteristics involved with wind-induced vibration. Basing on the PSD of lift force, the RMS of surface pressure coefficient and the flow pattern, it can be concluded that the angle of flap plays a vital role in controlling the mechanism of wind flow. The flaps with large gaps and angle 30^0 are recommended to improve aerodynamic instability for the rectangular cross-section.

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