EFFECT OF THE SIDE-SURFACE OPENINGS ON TIME-AVERAGED FLOW CHARACTERISTIC OF A RECTANGULAR CYLINDER

Yokohama National University Student Member ○Pham Thi Lien Thuc
Yokohama National University Fellow Member Hiroshi Katsuchi
Yokohama National University Regular Member Jiaqi Wang

1. Introduction

Recently, butterfly web girders have become increasingly popular in bridge construction due to their numerous advantages in terms of structure, construction, and maintenance (Kasuga, 2017). Butterfly web girder is a box girder with discretely distributed openings on the side surfaces.

With the increase of openings, the side-surface openings were confirmed to stabilize vortex-induced vibration and torsional flutter of a rectangular cylinder with a side ratio *B/D*=5, where *B* refers to the width of the girder and *D* refers to the height of the girder (Thuc, et al., 2023) .

In addition to the stabilization of the girder, it is important to note that the flow around the girder was also affected. Particle Image Velocimetry (PIV) tests were conducted to investigate the changes in time-averaged flow. The results of these tests revealed significant variations in the time-averaged flow, suggesting that the presence of the butterfly web girder with side-surface openings has a measurable impact on the flow dynamics.

In this study, a stationary model was used for the flow visualization to observe the separated flow considering the simplicity of the test.

The purpose of this paper is to investigate the time-averaged flow around the *B/D* = 5 rectangular cylinder with different-sized openings.

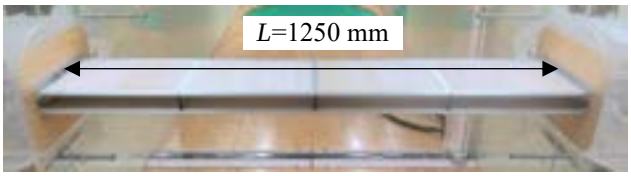


Fig. 1 Model of a rectangular cylinder

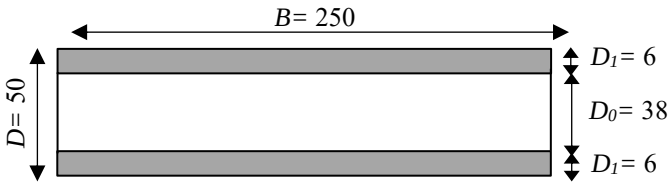


Fig. 2 Cross section of the model (unit: mm)

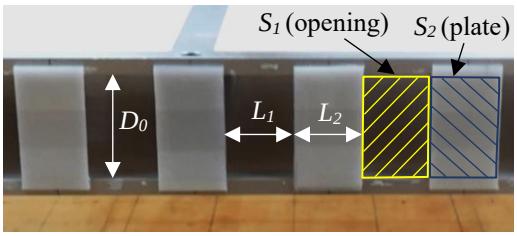


Fig. 3 Side-surface openings detail

2. Wind tunnel tests

The model is a rectangular cylinder having openings on the side-surface, with a height of the opening *(D_0)* is 38 mm. The model has a length *(L)* of 1250 mm, and a side ratio *B/D* of 5, where the width *(B)* and the height *(D)* are 250 mm and 50 mm, respectively (Fig.1). The detail of the cross section is depicted in Fig.2.

The opening size is decided by two parameters, i.e., Opening-area Ratio (*OR*) and Repeating Element-size Ratio (*RER*). The formulas of *OR* and *RER* are defined below (Fig. 3):

$$OR = L_1/(L_1 + L_2) \quad (1)$$

$$RER = (L_1 + L_2)/D_0 \quad (2)$$

In this research, the *OR* cases included *OR*=0, *OR*=0.15, *OR*=0.5, *OR*=0.75, and *OR*=1. *OR*=1 represents the case that the side surface is opened, whereas *OR* = 0 indicates that the side surface is closed with the cover. Assigning 1.316 to *RER* to reflect the actual condition of the bridge section (Kasuga, 2017). The models with openings of different *OR* for *RER*=1.316 are listed in Table 1.

Table. 1 Experiment cases

Case name	*OR*	*RER*	Configuration
Case 1	0		
Case 2	0.15	1.316	
Case 3	0.5		
Case 4	0.75		
Case 5	1		

Keywords: side-surface openings, PIV, time-averaged flow
Contact address: Yokohama National University, 79-5 Tokiwadai, Hodogaya-ku, Yokohama, Japan. Tel: 045-339-4041

3. Methodology

The velocity measurment around the girder was conducted in the vertical plane, which was perpendicular to the girder surface (Fig. 4).

The flow field around the stationary rectangular cylinder for vortex-induced vibration was observed at wind velocity U = 2m/s. The images were captured at 2000 fps with a shutter speed of 1/2000 s, and the observation period was 14 second.

The flow was observed at two positions, i.e., at the closed section (middle of plate) and at the open section (middle of the opening), these positions are shown in Fig.5.

After recording the videos, these videos were used to extract wind velocity through Particle Image Velocimetry (PIV) analysis.

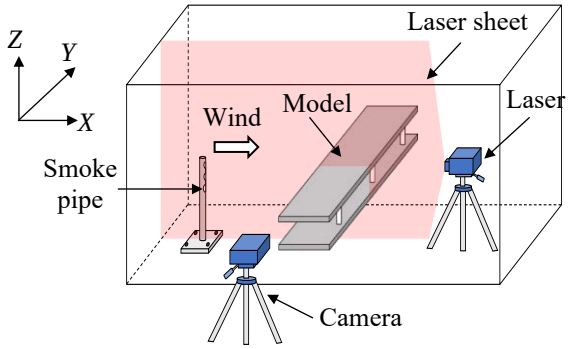
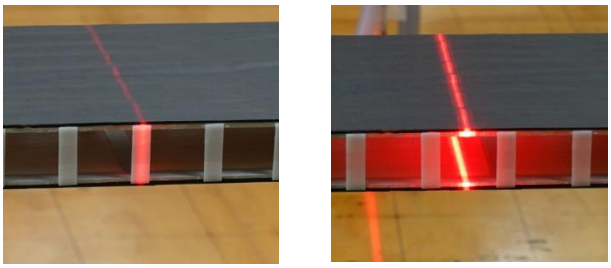


Fig. 4 Setup for the velocity measurement in vertical plane



(a) Closed section (b) Open section

Fig. 5 Velocity measurement positions

4. Discussion and Conclusion

This subsection describes the time-averaged flow of the transverse velocity U_x (m/s) as the *OR* increased.

The height from the girder surface to the contour line of the time-averaged separated shear layer is denoted by H_{sf} (mm).

Referring to the Fig. 6, it can be observed that as the *OR* increased, the height H_{sf} of time-averaged separated shear layer gradually decreased from 15.7mm (*OR*=0) to around 0 mm (*OR*=1). This indicates that the side-surface openings promoted the time-averaged separated shear layer to approach gradually the girder surface.

By increasing *OR*, the re-attachment points gradually moved upstream side, and the distance from leading edge to the re-attachment points became shorter as the *OR* increased.

In addition, in each *OR* case, the H_{sf} at the opening section was found to be approximately equal to that at the closed section. This is demonstrated in Fig. 6 as pairs (c) and (d), (e) and (f), and (g) and (h), for *OR* = 0.15, 0.5, and 0.75, respectively.

The presence of side-surface openings promoted the time-averaged separated shear layer to approach the girder surface. This probably resulted in the increasing aerodynamic stability of the girder with the increase of OR.

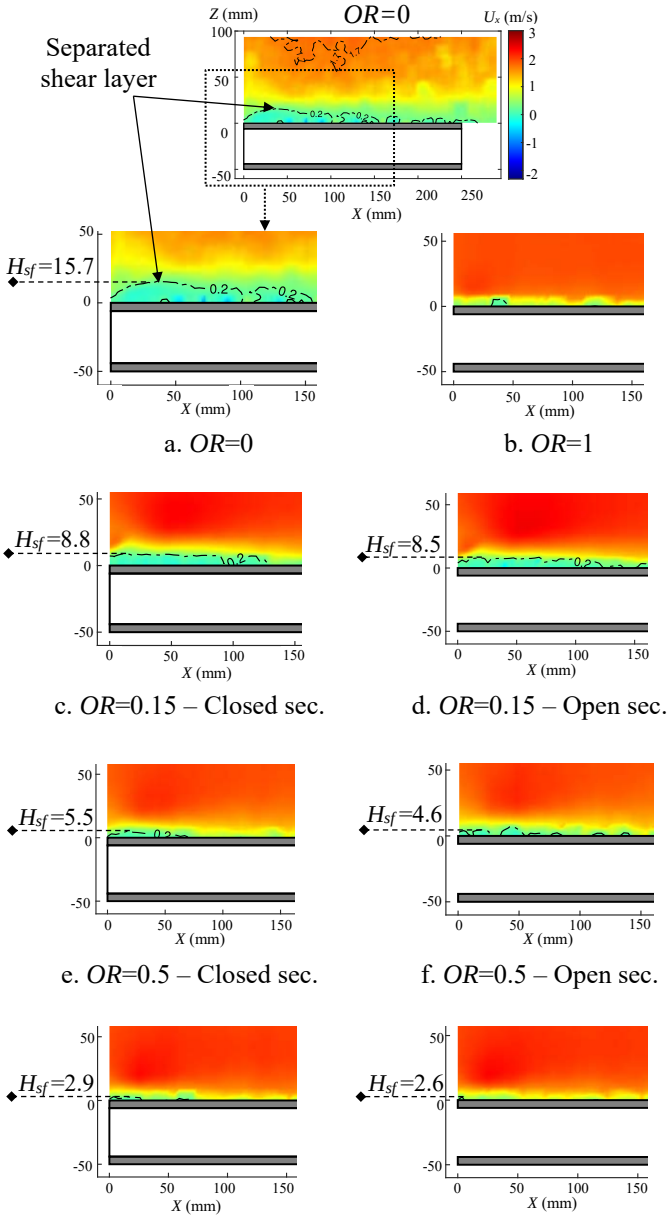


Fig. 6 The H_{sf} (mm) of the time-averaged separated shear layer at the leading edge for *OR* cases

Reference

1. Kasuga, 2017. Effects of butterfly web design on bridge construction. *International Federation for Structural Concrete*, pp. 128 - 142.

2. Thuc, P., Wang, J. & Katsuchi, H., 2023. Effect of side-surface openings on the torsional flutter instability of a rectangular cylinder. *Journal of Structural Engineering (JSCE).*