AERODYNAMIC CHARACTERISTICS OF RECTANGULAR CYLINDER WITH VARIOUS CORNER SHAPES

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1. INTRODUCTION

Rectangular cylinder has been one of the common shapes utilized in many civil infrastructures such as bridge towers and skyscrapers. However, they are vulnerable to both vortex-induced vibration (VIV) and transverse galloping due to its non-axisymmetric cross-section. According to previous researches, corner cutting method became one of the effective methods to improve the aerodynamic behaviors of structures since it controls the circumferential separated flow patterns and aerodynamically stabilizes galloping oscillation of rectangular cylinder. In this study, the aerodynamic characteristics of the rectangular cylinder with the side ratio (B/D, being B is the width and D is the depth of the section) of 1.5 were investigated experimentally.

2. WIND TUNNEL EXPERIMENT OUTLINES

Both of the static force measurement test and the vertical 1DOF forced vibration test were carried out under the uniform flow condition in the room-circuit Eiffel type wind tunnel at Kyoto University (height=1.8m, width=1.0). The blockage ratio during the experiment is 5%. Two load cells were utilized to measure the aerodynamic forces acting on the model. Fig. 1 shows the wind tunnel setup. The width of the rectangular cylinder (B) is 135 mm and the height (D) is 90mm. The corners of the rectangular cylinder were modified into various shapes by attaching additions to the basic model as shown in Fig. 2 and Fig. 3 and tabulated in Table 1. Both a_x and a_y are measured from the origin and then added in sequence. The corner modification ratio (a/D) is kept at 3/18 for both x and y direction. This study was carried out in the wind speed range of 1.7m/s<U<14m/s ($1.02\times10^4<$ Re $<8.40\times10^4$). In order to study the aerodynamic characteristics of the rectangular cylinder with various corner shapes, the steady aerodynamic force coefficients (C_D, C_L), and the unsteady aerodynamic coefficient H_1^* are calculated based on the following equations:

$$C_D = (\text{Drag Force}) / (0.5\rho U^2 DL) \quad (1)$$

$$C_L = (\text{Lift Force}) / (0.5\rho U^2 BL) \quad (2)$$

$$H_1^* = -\frac{L_{\eta 0}\sin\psi_{L\eta}}{\rho b^2\omega^2\eta_0} \quad (3)$$

Fig. 1. Wind Tunnel Set-up

Fig. 2. Corner Modifications

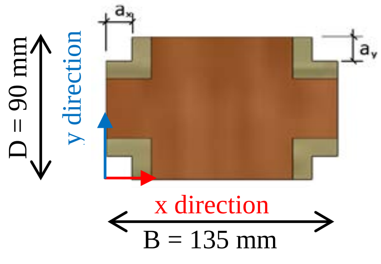

Fig. 3. Model with SR Modification

Table 1. Corner Dimensions

Corner Type	a_x (mm)	a_y (mm)
Rectangular(R)	-	-
Single Recession (SR)	15	15
Double Recession(DR)	7.5+7.5	7.5+7.5
Triple Recession(TR)	5+5+5	5+5+5
Chamfer (C)	15	15

3. STEADY AERODYNAMIC CHARACTERISTICS

Fig. 4 shows the drag force coefficient at Re = 6.48×10^4. Except the triple recession section, the C_D value of all modified corner shapes reduces to about half of the rectangular section between α=-3° to +5°. After α=+5°, the C_D values of the single recession and double recession section begins to increase slightly. However, the C_D values of the triple recesion and chamfer section increases moderately compared to the previous sections and begins to overlap each other. For α=0°, the drag coefficient of the rectangular section is 1.72 for a Reynolds number of 6.48×10^4. This is in good agreement with the wind tunnel results of Mannini et al. (2014).

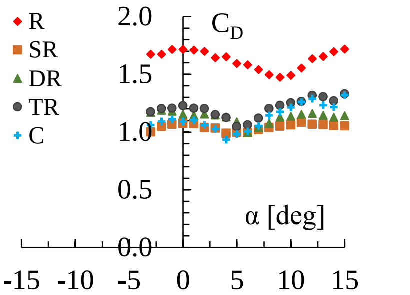

Fig. 4. Drag Coefficient (U=10.8m/s)

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The drag coefficient of the SR section is 1.12 for a Reynolds number of 1.02×10^4 and this also agrees well with the results of Shiraishi et al. (1988). Fig. 5 shows the lift force coefficient at Re = 6.48×10^4. The lift force coefficients of all section cases except the double recession section has the symmertic time averaged flow at α=0°. Therefore, additional measurements for the double recession section were made at different wind velocities. Even though all corner shapes reduces the drag force without significant Reynolds number dependency, Reynolds number dependency is found at higher wind velocity regions on the lift force coefficient of the double recession section as shown in Fig. 6. Non symmetric time averaged flow appears to occur after the wind velocity of 6m/s. The lift force slope is calculated from the lift force coefficient of each section for different wind velocities too. The lift force slope becomes smaller as the wind velocity increase.

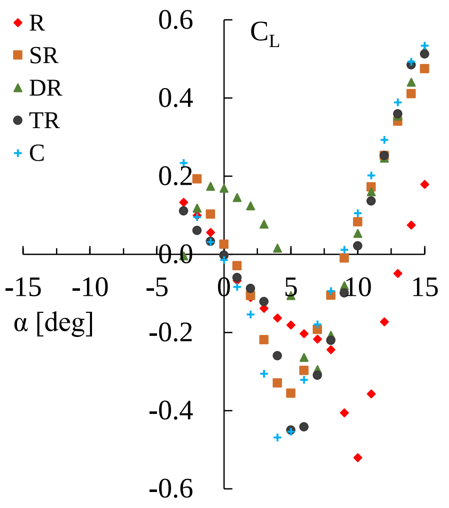

Fig. 5. Lift Coefficient (U=10.8m/s)

4. UNSTEADY AERODYNAMIC CHARACTERISTICS

The unsteady aerodynamic coefficient H_1^*, which represents the vertical aerodynamic damping of various corner shapes, for the forced vibration frequency of 2Hz and a double amplitude of 0.1D is illustrated in Fig.7. The onset-galloping reduced wind speed of approximately 18 for the single recession section also agrees with Shiraishi et al. (1988). Compared to the original rectangular section, all corner shapes helped in the reduction of the instability by lowering the H_1^* value and increasing the on-set galloping reduced wind speed. However, H_1^*values for the chamfer section exceed that of the rectangular section in certain reduced wind speed regions. The onset galloping reduced wind speed increases by around twice that of the rectangular section when the double recession section is used. Although the double recession section yields a relatively low H_1^* value throughout the measured reduced wind speed range, the value is still positive between the reduced wind speed region of 24 to 40. Moreover, the value is not completely negative and fluctuates at higher reduced wind speed region (U_r > 56).

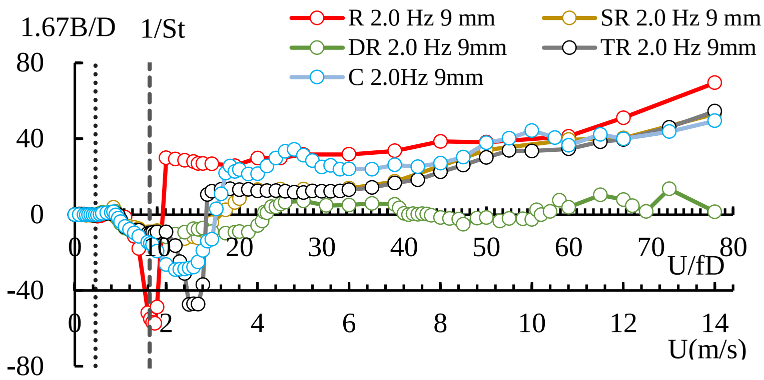

Fig. 7. Comparison of $H_1^*$for Various Corner Shapes

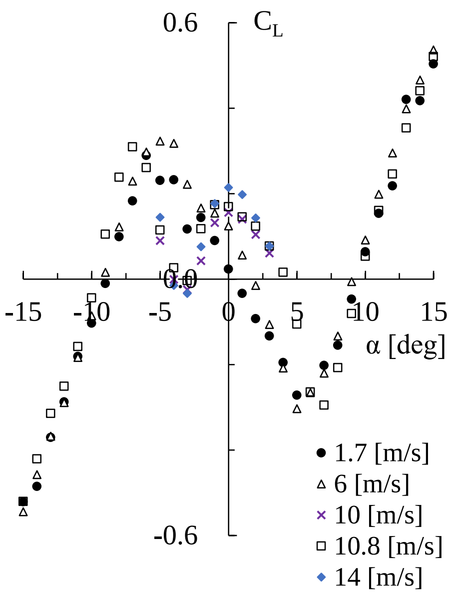

Fig. 6. Lift Coefficient for DR Section

5. CONCLUSIONS

Among all sections, the double recession section proved to be the most effective with higher on-set galloping reduced wind velocity and lower values for negative damping. The results also show that the section exhibits Reynold's Number dependency, which may be included in stabilizing the galloping phenomenon. The unsymmetrical time averaged flow at α=0° might be due to the sensitivity of the model shape, which might also be contributing to the Reynold's number dependency. This however requires further investigation.

ACKNOWLEDGEMENT

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