

## Correction factor of drag coefficients for emergent obstacles in open-channel flows

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### 1. INTRODUCTION

As floods become more common due to climate change, the forces brought by flood flows also damage hydraulic structures in rivers more frequently. For this reason, we need further understanding and a reliable estimation method for the hydrodynamic forces acting on obstacles in open-channel flows. In previous studies, drag force as the most significant effect on the structure, attracted the interest of many researchers. To facilitate the analysis of the force and flows with obstacles, the corresponding concept of drag coefficient  $C_D$  has been used to define the drag force as:

$$F_D = \frac{1}{2} \rho U^2 C_D A \quad (1)$$

where  $\rho$  is the fluid density,  $U$  is the flow velocity and  $A$  is the projected area of the obstacle.

In order to investigate the drag force acting on a hydraulic structure, emergent obstacles such as cylinders are widely used as experimental models. Using a cylinder as the experimental object, Braza et al <sup>1)</sup> conducted an experiment of the flow around a circular cylinder with a low aspect ratio and a high blockage coefficient. Similarly, Dubois and Andrianne <sup>2)</sup> investigated the pressure distribution around two static tandem cylinders with different aspect ratios and Reynolds numbers. Although the experiments in above two studies were performed in wind tunnels with air as the fluid, they were still of reference value for open channel flows of the main research object of this study, the drag coefficient. In addition, Etminan et al <sup>3)</sup> used a cluster of cylinders to mimic the effect of river bottom vegetation on the flow structure and obtained the pressure distribution inside the cylindrical cluster for different canopy densities and Reynolds numbers. However, our recent analysis <sup>5)</sup> revealed that the drag coefficient on emergent obstacles in open channel flows needs to be corrected to consider of water surface effect. The objective of this study is to investigate the correction factors of the drag coefficient and to develop a simpler and more efficient way to evaluate the drag force for application in river engineering practices.

### 2. CORRECTION FACTOR OF DRAG FORCE COEFFICIENT FOR OPEN-CHANNEL FLOWS

For the case of an open channel flow, the drag force acting on an emergent obstacle consists of the base component  $f_0$  and the additional component  $f_s$  caused by water surface variation as

$$F_D = f_0 + f_s \quad (2)$$

According to Tomiyama et al. <sup>5)</sup>, the following equation can be derived to evaluate the influence in drag coefficient due to the water surface variation

$$\frac{C_D}{C_{D0}} = 1 + \frac{1}{2} \beta_{C_p} C_{D0} F_r^2 \quad (3)$$

where  $F_r = U/\sqrt{gh}$  is the Froude number,  $C_{D0}$  is the drag coefficient for  $f_0$  while the correction factor  $\beta_{C_p}$  is the second-order moment of the pressure coefficient and can be expressed as

$$\beta_{C_p} = \frac{\int_0^{2\pi} C_p^2 \cos\theta d\theta}{\left(\int_0^{2\pi} C_p \cos\theta d\theta\right)^2} = \frac{\int_0^{2\pi} C_p^2 \cos\theta d\theta}{4C_{D0}^2} \quad (4)$$

### 3. RELATIONSHIP BETWEEN $C_{D0}$ AND $\beta_{C_p}$

It can be seen from Eq. (3) that the effect of water surface variation on the drag coefficient is mainly related to  $\beta_{C_p}$ ,  $C_{D0}$  and  $F_r$ . Furthermore, the analysis of experimental data reveals that there is a relationship between  $\beta_{C_p}$  and  $C_{D0}$ .

Keywords: Hydrodynamic force, Drag coefficient, Correction factor, Emergent obstacle, Open-channel flow

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Fig. 1 shows the relationship between  $C_{D0}$ ,  $\beta_{C_p}$  and canopy density  $\lambda$ . The pressure coefficient distributions were redefined to take one at the front stagnation point, which means the representative velocity were corrected. Besides, in Dubois and Andrianne<sup>2)</sup>, due to the two tandem cylinders arrangement,  $C_{D0}$  of rear cylinder appears to be less than 0 and it is difficult to redefine the pressure coefficient distribution. Therefore, in this paper, only the  $C_{D0}$  of the front cylinder is selected with  $\beta_{C_p}$ . In this figure,  $C_{D0}$  shows an increasing trend with increasing canopy density for each set and  $\beta_{C_p}$  distributes around -0.40. However, one set of experiments of Dubois and Andrianne<sup>2)</sup> was conducted under the critical flow regime ( $F_r \approx 1$ ) and the pressure distribution is strongly asymmetric, so the value of  $\beta_{C_p}$  becomes high due to small  $C_{D0}$ . Also, from here we conjecture that there may be a relationship between  $C_{D0}$  and  $\beta_{C_p}$ . Fig. 2 shows the relationship between  $C_{D0}$  and  $\beta_{C_p}$ . In this figure,  $\beta_{C_p}$  gradually decreases as  $C_{D0}$  increases and finally stabilizes around -0.40. Combining this figure with Eq. (3), it can be concluded that in most cases, the product of  $C_{D0}$  and  $\beta_{C_p}$  is negative, which means that the change caused by the water surface variation tends to reduce the drag coefficient. However, in the experimental results of Gu and Sun<sup>4)</sup>, there are some cases in which the product of  $C_{D0}$  and  $\beta_{C_p}$  is positive, which is possibly related to the three-cylinder arrangement. In the three-cylinder arrangement form, the  $C_{D0}$  and  $\beta_{C_p}$  both appear to be greater than 0 for the foremost cylinder along the flow direction.

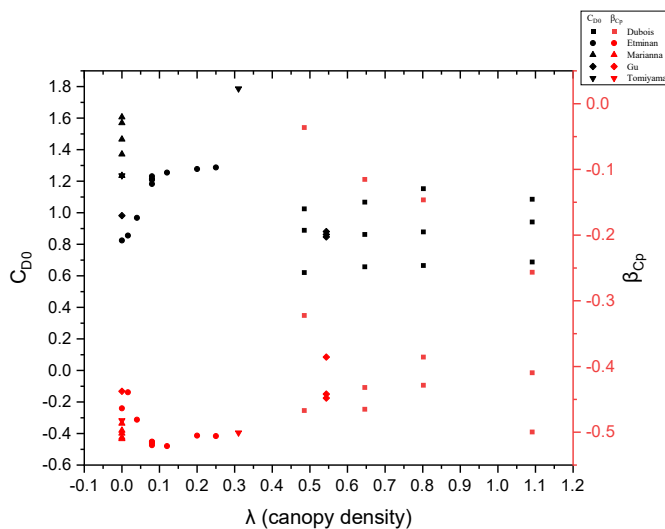


Fig. 1 Variation of  $C_{D0}$  and  $\beta_{C_p}$  with canopy density  $\lambda$

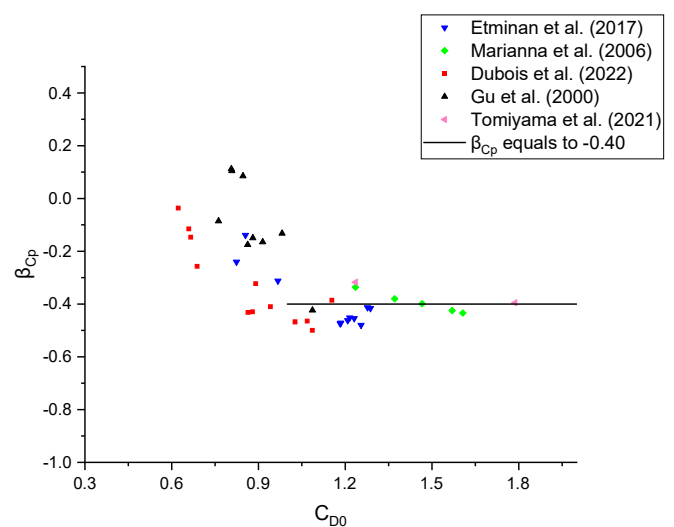


Fig. 2 The relationship between  $C_{D0}$  and  $\beta_{C_p}$

#### 4. CONCLUSION

This study mainly investigates the way of evaluating the drag force acting on emergent obstacles, circular cylinders, in open-channel flow and the relationship between the drag coefficient  $C_{D0}$  and  $\beta_{C_p}$ . It was found that there is indeed a certain numerical relationship between  $C_{D0}$  and  $\beta_{C_p}$ .  $\beta_{C_p}$  decreases gradually with the increase of  $C_{D0}$  to approach asymptotically the constant value about -0.40. Although the experimental data used in this study still have some limitations, for example, it does not involve the trends of  $\beta_{C_p}$  after  $C_{D0}$  is greater than 1.80, it provides a possible idea to evaluate the effect brought by the water surface variation on emergent obstacles under open-channel flow conditions. This study preliminarily investigated the relationship between  $C_{D0}$  and  $\beta_{C_p}$ , more research on the relationship between  $C_{D0}$  and  $\beta_{C_p}$  is needed to further simplify formulas such as Eq. (3) for calculating the change in drag coefficient considering water surface variation and to further simplify the steps for evaluating the effect of water surface variation on the drag coefficient.

#### REFERENCES

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