NUMERICAL INVESTIGATION ON ESTIMATING FLUID FORCE ON IMMERSED RECTANGULAR BEAM STRUCTURES WITH LOW GROUND CLEARANCE

Taisei Corporation Regular Member ○Chathura Manawasekara
Taisei Corporation Regular Member Yukinobu Oda
Taisei Corporation Regular Member Takahide Honda

1. INTRODUCTION

In hydraulic engineering aspect, free surface flow over horizontal beams is a general phenomenon which can occur under number of circumstances (i.e. tsunami or river overflow of bridges, flow over immersed pipelines or transportation ducts etc.). Most of those structures are generally composed in either circular or rectangular shape sections. Even though numerous studies have been carried out to assess the fluid force on such basic shaped structures under unbound flow conditions, only limited number of studies has addressed the situations where the structure is located closely to a fixed boundary such as a wall or ground. Under such conditions the force coefficients can be varied from general unbound flow conditions, due to the effect of proximity [Sarpkaya and Isaacson, (1981)] and relatively low free surface elevation of the flow. Current study focus on the estimation of fluid force on immersed rectangular beams in free surface flows.

2. STUDY DESCRIPTION

Numerical studies were carried out using CADMAS-SURF/3D [CDIT, (2010)] numerical code which is commonly used in maritime structure design. The code adopts VOF method for the evaluation of free surface of the fluid and two equation *k-ε* model as turbulent model at high Reynolds numbers. Analysis was conducted as a two-dimensional simulation and the basic outline of the computational domain around the structure is depicted in Fig. 1. Simulation started with water level below the structure and conducted under uniform inflow condition where flow discharge was gradually increased over a period of 600s. The Reynolds number (*Re*) throughout the simulation was varied in the range of $5.0\times10^4 < Re < 1.4\times10^5$. The sharp edged rigid rectangular structure (0.07m x 0.14m) was located with a clearance (h_1) from the bed and length (l) of the section in parallel to the horizontal bed. Minimum cell sizes in the computation was 0.01m in both x and z directions. Study was conducted for four values of h_1 and four values of aspect ratios (l/d) of the structure, and the test combinations are tabulated in Table 1 and Table 2. Incoming flow depth (h_0) and the downstream flow depth (h_3) were measured at distances of 0.5m and 2.6m away from the center of the structure, respectively.

3. RESULTS AND DISCUSSION

Table 1 h_1/d ratios

d [m]	l [m]	h_1 [m]	h_1/d
0.07	0.14	0.06	0.85
		0.09	1.30
		0.12	1.70
		0.15	2.15

Table 2 l/d ratios

d [m]	l [m]	h_1 [m]	l/d
0.07	0.07	0.12	1.0
	0.10		1.4
	0.12		1.7
	0.14		2.0

The horizontal drag force (F_x), vertical lift force (F_z) and rotational moment (M_y) acting on the beam section were estimated for each case over the time and Fig. 2 shows the variation of F_x and F_z (considering a unit width of the beam) against the non-dimensional flow depth measured from the base of beam (h_2/d) for the case of h_1/d=0.85. It can be seen from the figure that following the overtopping of the structure both F_x and F_z gradually increase with h_2. However, variation of lift force shows more scattering behavior than the drag force especially at the higher h_2 values. Considering the fact that the beam is fixed in the space, such behavior is generally occurred in accordance with the development of vortex at the leeward end of the structure which leads to the fluctuation of force in transverse direction [Sarpkaya and Isaacson, (1981)]. Even though it also affect the drag force on the structure, the fluctuation in the drag force does not significant as in the lift force.

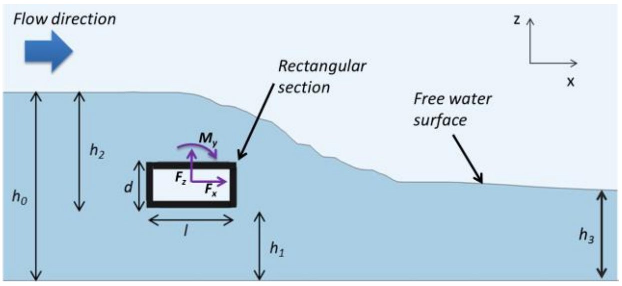

Fig. 1 Sectional view and dimensions

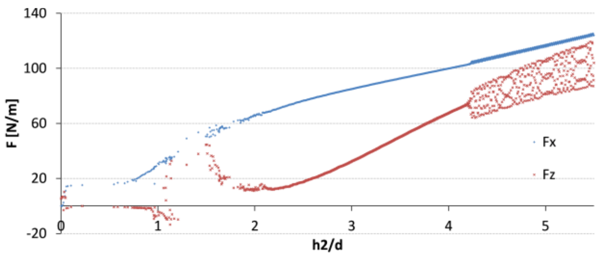

Fig. 2 Drag and lift forces (h_1/d=0.85)

The drag, lift and moment coefficients for the beam under each scenario were estimated considering a unit width of the beam, using the Eq. (1), Eq. (2) and Eq. (3) respectively

$$C_d = F_x / 0.5 \rho d V_0^2 \tag{1}$$

$$C_z = F_z' / 0.5 \rho d V_0^2 \tag{2}$$

$$C_m = M_y / 0.5 \rho d l V_0^2 \tag{3}$$

Here, ρ is the density of water and V_0 is the inflow velocity.

Keywords: Immersed Beam, Free Surface Flow, Low Clearance, Drag Coefficient
Contact address: 344-1, Nase-cho, Totsuka-ku, Yokohama, 245-0051, Japan, Tel: +81-45-814-7257

3.1 Effect of the Bottom Clearance

Fig. 3 shows the variation of drag and lift coefficients for the beam for different clearance levels (h_1) from the fixed bottom boundary. According to the figure, for one particular value of incoming flow depth, C_d decreases with the increase of h_1. This behavior is quite significant for lower values of h_0, and C_d eventually converge to a value around 2.0 as the incoming flow depth increases. Moreover, the effect of the level of submergence is clearly visible in the case of lift force as well. Thus, locating the beam section closer to the fixed boundary has a clear influence on both drag and lift force coefficients when compare with the unbound flow situation.

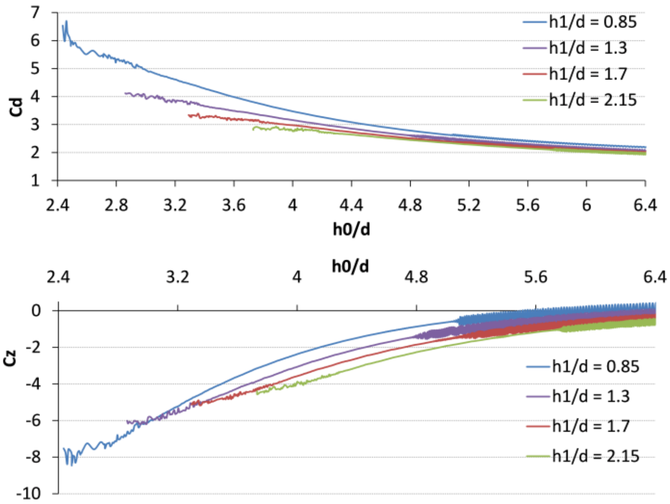

Fig. 3 Variation of drag and lift coefficients against h_0/d

3.2 Effect of the Free Surface Elevation

Further, for one particular value of h_1/d, C_d gradually decreases with the rise of free water surface above the beam. Generally, in subsequent to the rise of incoming flow depth (h_0) the downstream flow depth (h_3) also increases, while the discrepancy between the depth levels reduces. Therefore, the effect of free surface level difference, on the force coefficients for different values of h_1 is less influential in higher h_0/d values. Fig. 4 shows the variation of C_d over h_0/h_3 ratio for different submerge level of the beam. In the figure, for lower values of h_0/h_3 no significant difference can be observed between the C_d for different h_1 values. At the same time, the change in the submerge level of the beam is more effective for force coefficients under low depth free surface flows where h_0/h_3 ratio is higher.

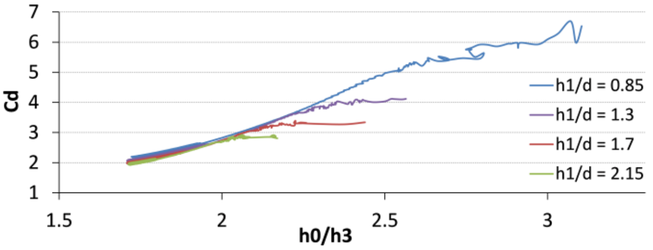

Fig. 4 Variation of Cd against h_0/h_3

3.3 Effect of the Section Aspect Ratio

Several aspect ratios for the beam section was considered in the simulation as demonstrated in Table 2. Analysis was conducted for a constant submerged level of the beam (h_1/d=1.7) and the results for the variation of C_d are depicted in Fig 5. Square shape beam shows the lowest C_d among the considered sections and the C_d increase with the increase of l/d ratio for a particular value of h_0. However, the difference in the C_d is significant only at low h_0/d ratios and eventually converge to a value around 2.0 as inflow depth increases. Hence the aspect ratio of a rectangular section should be taken in to account when estimating the C_d for low lying submerged beams when h_0/d is relatively low.

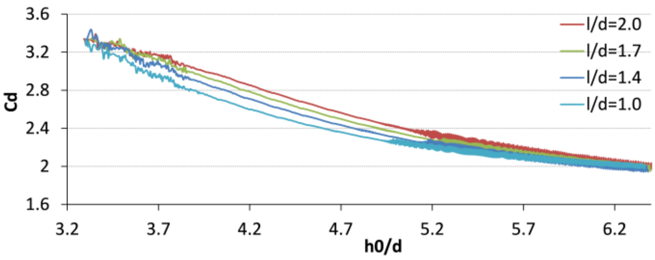

Fig. 5 Variation of C_d for different l/d ratios against h_0/d

4. CONCLUSIONS

A two-dimensional numerical simulation study was carried out to assess the fluid force acting on low-lying rectangular beams under free surface flow. It was found from the study that clearance between the ground and beam is an influential factor in estimating the force coefficients especially under low free surface flows. Under such conditions C_d is higher than the value for general unbound condition. However, it decreases with the increase of incoming flow discharge and eventually converge to a value around 2.0 as free surface elevation reaches higher levels.

Moreover, C_d decreases with the decrease of h_0/h_3 when h_1 is a constant, thus suggesting that the drag force on a beam with a constant clearance can be controlled by changing h_0/h_3 ratio. Also for a given h_0/h_3, C_d increases with the decrease of h_1. The effect of the h_1 on C_d is quite significant in high h_0/h_3 values and is less influential in flows with low h_0/h_3.

The aspect ratio of the beam affects the C_d at lower discharges and C_d increases as the increase of l/d ratio.

Overall, the clearance of the low-lying rectangular beams under free surface flow is a significant factor in estimating the force coefficients and should be taken in to account when estimating the fluid force.

REFERENCES

Sarpkaya, T., and Isaacson, M.: Mechanics of Wave Forces on Offshore Structures, Van Nostrand Reinhold, New York, 1981.

Coastal Development Institute of Technology: CADMAS-SURF/3D Development of Numerical Wave Flume, Coastal Technology Library No.39, 2010 (In Japanese)