# INTERACTION OF OSCILLATING FLOW WITH A PAIR OF SIDE-BY-SIDE SQUARE CYLINDERS

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*Summary* The behaviour of vortices induced by a pair of square cylinders in an oscillating flow was investigated. The flow pattern in the vicinity of the square cylinders was visualized using the experimental approach and the numerical model. Strong interaction among vortices was found. Force coefficients of cylinders become chaotic as the gap ratio decreases and Keulegan-Carpenter number increases.

## INTRODUCTION

Oscillating fluid flows are very common in ocean engineering problems. It may be induced by traveling waves or tides. Hence, offshore structures may experience oscillating flows. It is well known that vortices are generated by solid structures in flows. In the past, oscillating flows interacting with a single obstacle was investigated by several researchers. For example, Bearman and Obasaju [1] conducted experiments to investigate the force variation exerted on a square cylinder in oscillating flows. However, there may be more than one structure in practice. Vortices induced by multi-obstacles may interact with others. Subsequently, forces exerted on those obstacles may be different from the case with a single obstacle. Williamson [2] performed the flow visualization and force measurement for a pair of circular cylinders in oscillating flows. He found the various patterns due to the interaction of vortices due to the pair of circular cylinders. The purpose of this study is to investigate oscillating flows interacting with a pair of side-by-side square cylinders. The vortices are affected by Reynolds number, Keulegan-Carpenter ($KC$) number and the gap between them. Especially when the gap is very small, the interaction among vortices is very strong. Numerical and experimental approaches were utilized to observed the flow variation. The flow structure were visualized. The forces exerted on two cylinders were determined using the numerical model.

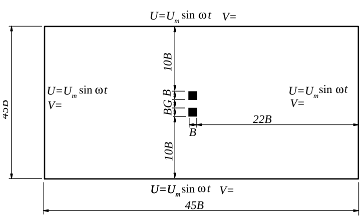


Figure 1: Configuration of the study problem

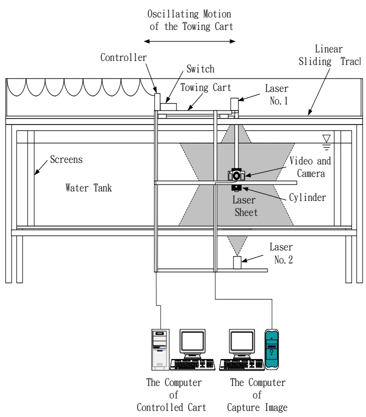


Figure 2: Configuration of the experimental facility for flow visualization

## MATHEMATICAL MODEL & NUMERICAL APPROACHES

Figure 1 shows the configuration of the problem. Fluids considered are incompressible. The 2-D continuity equation and Navier-Stokes equations were utilized as the governing equations. The oscillating flow condition was imposed on the far-field boundaries and given by

$$\mathbf{U} = \mathbf{U_m} \sin(\omega t) \quad , \tag{1}$$

where $\omega$ and $\mathbf{U_m}$ refer to the angular frequency and the amplitude of the velocity variation. Moreover, the non-slip boundary condition was imposed on the solid boundaries of two square cylinders. The initial-boundary-value problem (IBVP) was solved by the proposed numerical model based on the finite volume method. Cartesian cells constituted the whole computational domain. The numerical simulations were performed in a PC cluster which includes 16 AMD 2.5G CPUs.

## PARTICLE TRACKING FLOW VISUALIZATION TECHNIQUE

The flow visualization technique based on the particle tracking technique was also used to observe the flow patterns. The results were used to validate the numerical solutions. Figure 2 reveals the schematic configuration for the experiments. A water tank with a towing cart was used to perform the oscillating motion for those two square cylinders. PS particles of diameters 50-70 $\mu$m were employed to traced the flow motions. When particles experienced the laser sheet, light was scattered by particles. Subsequently, the flow patterns can be captured by a CCD camera. Due to the page limit, the flow pattern can be shown in the final manuscript.

## PRIMARY RESULTS AND DISCUSSION

Figure 3 demonstrates one of numerical solutions at $KC = 5$ and $Re = 400$ in a period. Flows were visualized in terms of the vorticity distribution. The gap, $G$, between two cylinders was equal to their length, $B$. It reveals that vortices shedded successively from the two sides of cylinders. The strong flow in the gap affects the vortices in the vicinity of the gap. This phenomenon is different from the case with a single cylinder. Furthermore, Figure 4 shows the time histories of lift coefficients of those two cylinders. The lift coefficient for a single cylinder is very small compared with the studied case. The main reason is that the symmetry of the vortical system is broken due to the gap flow. The variation of peak in the time histories were found in Figure 4. When the flow is at large gap ratios and low $KC$ numbers, the wave forms of time histories are the same at each periods. As the interaction becomes strong due to small gap ratios and high $KC$ numbers, nonlinearity in the flow can be observed and the wave forms are distorted.

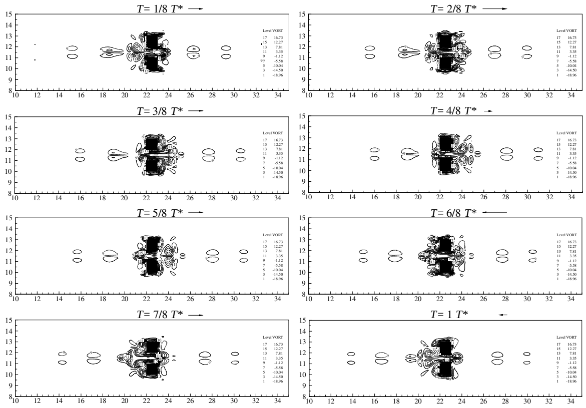


Figure 3: Flow patterns in a period in terms of vorticity distribution

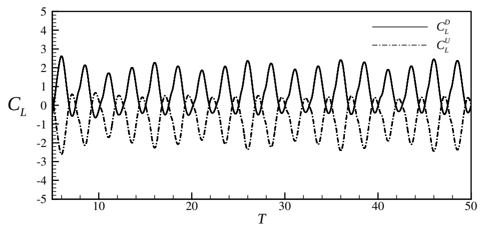


Figure 4: Time histories of lift force exerted on two square cylinders

## CONCLUSIONS

The force variation and flow patterns for an oscillating flow interacting with a pair of side-by-side square cylinders were obtained. Vortices induced by square cylinders were strongly affected by each other. Nonlinearity in the vortical system was induced in small gap ratios and high Keulegan-Carpenter numbers.

### References

[1] Bearman, P.W. and Obasaju, E.D.: An experimental study of pressure flucturations on fixed and oscillating square-section cylinders. *J. of Fluid Mech* **119**:297-321, 1982.

[2] Williamson, C.H.K.: Sinusoidal flow relative to circular cylinders. *J. of Fluid Mech*: **155**:141-174, 1985.