Two elastically coupled cylinders in combined wave-current flows

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HIGHLIGHTS

- Model tests are performed to study the effects of wave, current and coupling interactions on two floating bodies linked by elastic connectors.
- The relative motion of the two coupled cylinders is investigated in waves and currents in-line and in opposing directions.

1. INTRODUCTION

The necessity to connect a Tender Assisted Drilling (TAD) unit to a dry tree unit (DTU) opens up the topic of two-body floating systems in waves and currents. However, the problem of two bodies interacting with each other has not been investigated widely. Several model tests have been carried out for real specific cases yet they have not extended the knowledge of the physics governing the response of such coupled structures under combined wave and current conditions.

Previous studies (Haslum et. al, 2006; Ng et. al, 2010) have demonstrated the unusual behaviour of resonant out-of-phase surge relative motions which has been observed in a certain range of wave and current conditions. This behaviour is important because relative motions will influence the connectors (lashing system) between the two bodies and may impose operational limits for close-coupled operation. Therefore, the objective of this research is to investigate the relative motions of two floating bodies in the presence of waves and currents and to attempt to understand the physics affecting the relative motions and so to help design an improved connector system. What is reported here is the first part of this research: experimental study of the two floating cylinders in combined wave-current flows.

2. EXPERIMENTAL SETUP

The experimental investigations were carried out in the Hydraulics Laboratory of the National University of Singapore. The system is mounted on the tow carriage in the Ferrocement wave flume in Hydraulics Laboratory, which is 36 m long, 2 m wide and 1.3 m deep. The tow carriage is commissioned to run on parallel rails along the flume and has the capability of towing models at constant speeds to simulate steady currents acting on the model. A HR Wallingford wave maker system generated the regular waves for the experiments. Fig. 1 shows a schematic view of the experiment layout.

The system consists of a coupled pair of cylinders, placed in waves only, currents only, and waves and currents in-line and in opposing directions, with a still water depth of 0.58 m. They are rigidly mounted to circular flange sockets that are suspended by light aluminium profiles to an overhead frame, constraining the bodies' motions to surge and sway only. The coupling and mooring lines are made by means of linear springs. In the set-up, the linear springs all have stiffness k=29.2 N/m.

These springs are connected from the body above the flange sockets to an adjustable frame that can be tilted in order to change the angle of incidence of waves and currents (see Figs. 1 and 2). In the present study, the frame is shifted by angle of 21.8 degree with the direction of the wave flume (see Fig. 3). Time series of cylinders' displacement and mooring lines' tensions are measured with ultrasonic sensors and load cells, respectively.

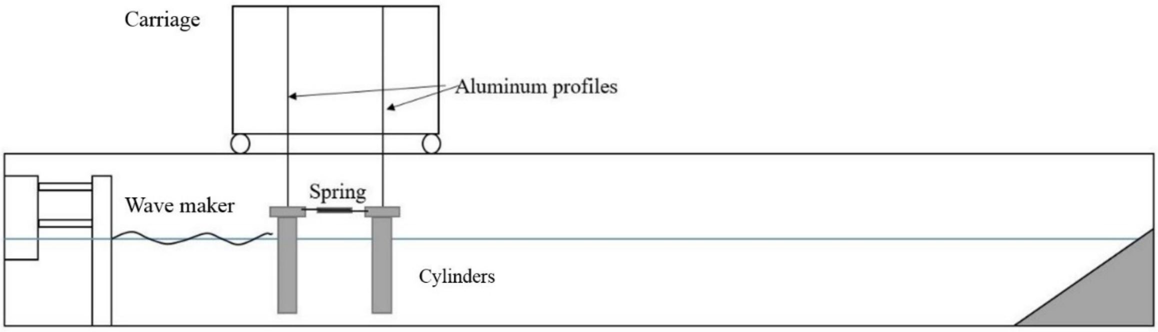

Fig. 1 Schematic of tow carriage and wave flume facility.

The experiment datasets were collected with the following procedure: commence data acquisition, start wave maker, start carriage when the wave reached the beach end of the flume and became steady.

3. TEST SPECIFICATIONS

The two same cylinders used in this study are made up of rigid PVC pipes, of the following physical dimensions listed in Table 1. The currents and waves that are used in this study and the flow characteristics are presented in Table 2.

Table 1 Cylinder information

	cylinder
Mass	17.5 kg
Diameter	0.16 m
Length	1.2 m

Table 2 Current and wave parameters

Parameters	Range
Current (U)	0.05-0.15 (m/s)
Wave Amplitude (A)	0.0125 (m)
Wave Period (T)	0.7 – 2.0 (s)
Reynolds number *Re* (current)	8000-24000

The mooring layout can be seen in Fig. 3. Each cylinder is anchored by 3 points, with one mooring line-ML-parallel to surge direction and the other two making angles of 30 degree with the sway direction.

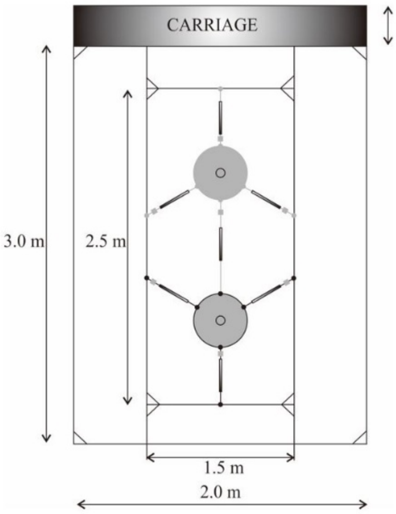

Fig. 2 Experimental apparatus (top view).

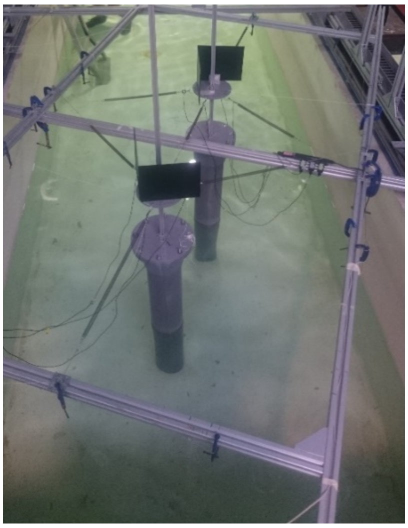

Fig. 3 Complete setup.

4. RESULTS

This paper focuses on the results of the relative motions of two floating cylinders in the presences of waves and currents. Figs. 4 and 5 provide the spectra of the relative motions.

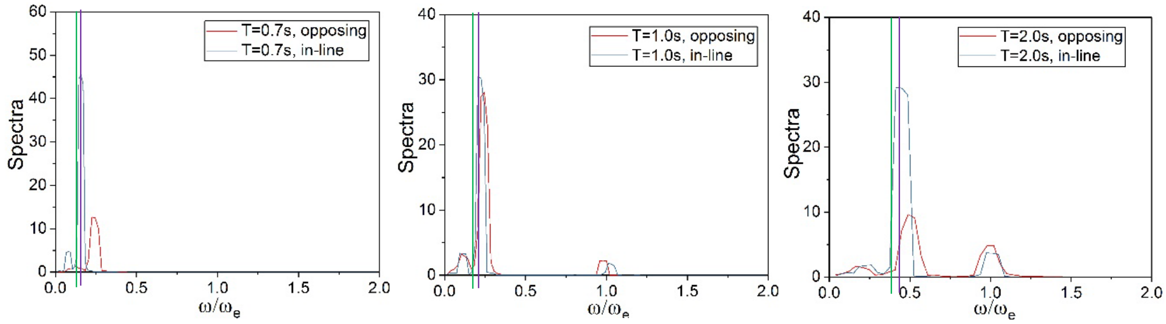

Fig.4 Spectra of relative motion for different waves under current Uc=100mm/s.

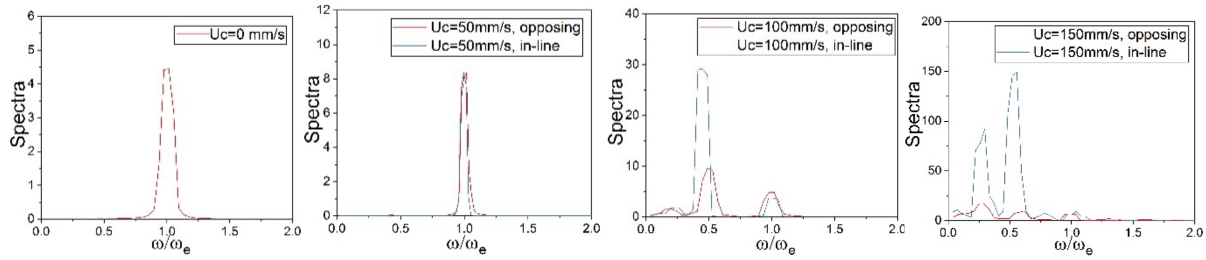

Fig.5 Spectra of relative motion for different currents for wave T=2.0s.

In Fig.4, the green and purple line indicates the natural frequency of the relative motion for wave and current in opposing and in-line direction. Obvious shift is observed, which could be caused by the vortex shedding in waves and currents. In Fig. 5, the relative motion increases rapidly as the current speed becomes larger. As expected, larger relative motion is induced when the current and wave is in same direction. At low frequency, double peak can be observed. This might be due to vortex shedding in waves and currents from the upstream body exciting the downstream body. The shedding behaviour in waves and currents may be different compared to either waves alone or current alone and results in excitation force due to the viscous wake. This effect might be larger for two cylinders compared to realistic TAD/TLP coupled system, which may not necessarily manifest itself to the same degree.

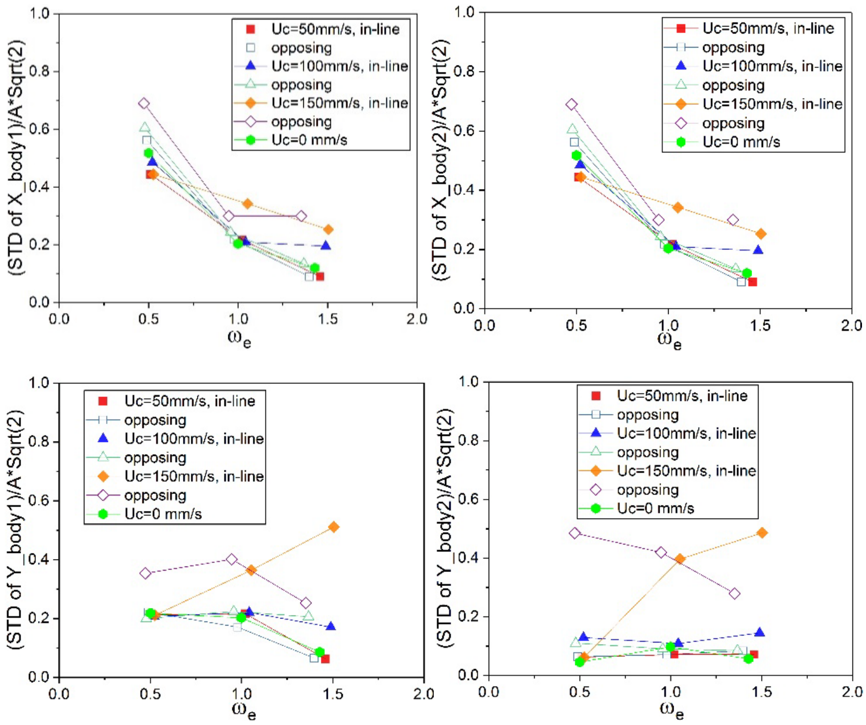

Fig.6 RAOs of recorded displacement for wave frequencies vs. encountered frequency.

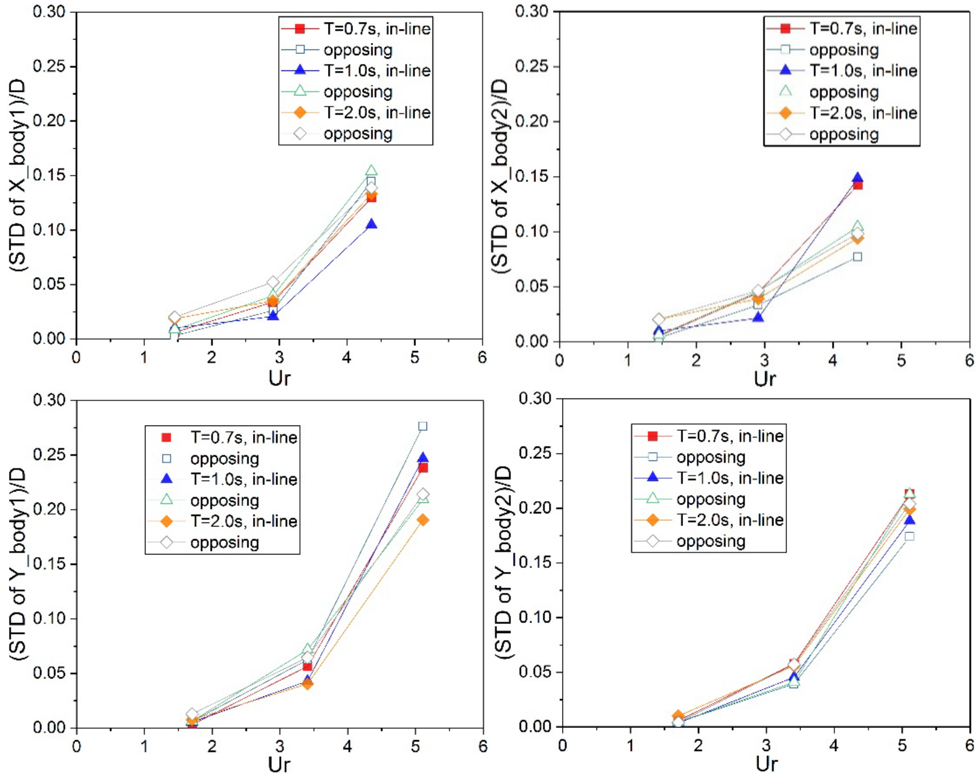

Fig.7 STD of recorded displacement for low frequencies vs. reduced velocity.

Fig. 6 shows the RAOs of the two cylinders for wave frequencies. Lower wave frequencies generally induce larger surge motions. But under high current speed, higher sway motions are also observed which is likely due to the vortex effects. Fig.7 plots the standard deviation of two cylinders' motions against the reduced velocity, which is defined by Ur = Uc*Tn/D. As expected, larger motions are induced as the current speed increases, especially the sway of the cylinder.

5. CONCLUSION

An experimental investigation on the relative motions of two elastically coupled floating cylinders in the presence of wave and current is carried out. Frequency shift is observed for the relative motion at high current speed for both wave-current in-line and opposing directions. Larger sway motions at high current speed are also captured. To better account for this phenomenon, the behaviour of two dissimilar bodies (TAD and TLP) needs to be verified with empirical relationships and model tests.

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