DEVELOPMENT OF A HYDRAULIC-CONTROL WAVE-MAKER (HCW) FOR THE STUDY OF COMBINED WAVES AND FLOWS

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The aim of the research presented here is to develop a new experimental device which would permit the study of multi-scale and vertically-variable oceanographic flows using a system called the Hydraulic-Control Wave-maker (HCW). Both the inlet and outlet flume boundaries are composed of an adjustable set of vertical baffles. Each baffle is connected to an individual flow control system, such that the vertical distribution of flow is entirely controllable. In such a system, any arbitrary flow can be reasonably created, and different sets of baffles can be connected to different reservoirs to create vertical density profiles. In this study, before constructing the experimental device, numerical analyses to verify the method of HCW, such as its ability to generate waves are carried out. Moreover, the small physical model with one baffle connected to our own flow control system is developed by ourselves. Long and short sine wave are generated by a small-scale HCW and the snapshots are presented. In practical, thus, The possibility of system can be confirmed.

Keywords: wave-maker; HCW; flow control system

INTRODUCTION

For complex oceanographic flows, those governed by nonlinear and multi-scale physics, very little has been done in relevant experimental studies up to date. To study wavy oceanographic flows, most of studies have been used traditional techniques of wave generation with solid boundary movement. The movement is based on the velocity profile under the wave to be created. For long wave generation, for instance, the vertical wavemaker is commonly driven by a pison, while for short wave generation the wavemaker hinged and inclined is flapped with some average curvature is employed to mimic the exponential velocity profile under a dispersive wave. When the wavemaker shape does not perfectly match the vertical kinematic profile of the targeted wave, evanescent modes result. In cases of poor wavemaker-wave matching, spurious and undesirable free waves are generated. The corresponding wave-maker theories encompass dispersive and shallow water theory, and linear to weakly nonlinear waves. In general, these wave-maker theories are well established [3]. In the field of internal wave laboratory studies, a wide range of generation approaches has been used, and similar to the free surface wave studies. The most common types are hinged flap and plunger wavmakers. The flap type wave-maker which here is located at the fluid interface, has been studied [4, 8, 10]. A plunger type wave-maker, where a solid object vertically oscillates near the interface, also has researched [5, 7, 9]. The internal wavemaker for natural generation approaches, such as forcing a stratified current over a sill [1] and a vertically-segmented, dual-plunge wavemaker [6] and dual-piston wavemaker [11]. These wavemakers can successfully generate the internal waves of usually targeting a narrow frequency range. the equipment is designed to isolate a particular element of an interesting physical question; multi-scale and nonlinear wave interactions are ofter too complex a problem to tackle with these existing laboratory devices. The true complexity of oceanographic flows can only be observed in the field, but, of course, fields experiments suffer from the enormity of scales that must be covered. Most of field instruments can capture good time resolution data at a limited number of points. To map a flow field, for instance, velocity profiles can be collected along a network of tracks use a bottom-tracking Acoustic Doppler Current Profile (ADCP). The ADCP records a short-term average velocity in several bins below the towing platform. Though each instantaneous profile has high resolution, the data along a track is not synoptic, and the tracks are very sparse when a large region must be mapped, such as an inlet or headland. Turbulence data can be collected at individual points using Acoustic Doppler Velocimeters (ADV), and these can be moored at important locations to get a complete view of the velocity structure of the water column at a point. Yet, to understand the directional wave spectrum of the surface waves, multiple moorings are required at high expense. Moreover, all of these acoustic methods are strictly limited to weakly stratified flows and none give an accurate measure of the turbulent mixing over large scales. Conductivity, Temperature and Depth (CTD) profilers equipped with fluorometers can be used to track natural or injected dye tracer to better understand mixing [2]. However, these results are still limited to non-synoptic profile data. To capture the dynamics of an internal breaking wave, laboratory experiments are still required [9].

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This study is aimed at developing a new experimental device which would permit the study of multi-scale and vertically-variable oceanographic flows using a system called the Hydraulic-Control Wave-maker (HCW). Both the inlet and outlet flume boundaries are composed of an adjustable set of vertical baffles, as shown in the Fig. 1. Each baffle is connected to an individual flow control system, such that the vertical distribution of flow is entirely controllable. In such a system, any arbitrary flow can be reasonably created, for long and short wave generation, for instance, each flow control system can make each target flow at each position to mimic the shape of quadratic and parabolic velocity profile, respectively. If different sets of baffles can be connected to different reservoirs to create internal wave with multi multi phase profiles. In this study, before constructing the experimental device, numerical analyses to verify the method of HCW, such as its ability to generate waves are carried out. In addition, a small scale physical model of HCW is built and the snapshots from it to generating sine wave are presented.

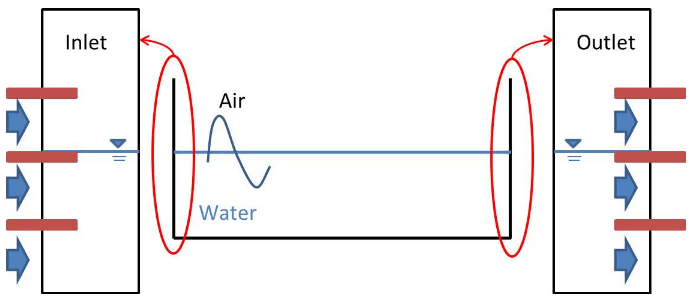


Figure 1: General schematic of the HCW

SENSITIVITY ANALYSIS

In this study, long, intermediate and short sine waves are generated by horizontal particle velocity formulation in linear wave theory. The first step for wave generation is horizontal particle velocities along water depth are averaged over each baffle height, and then the averaged velocities are imposed at each baffle as inlet condition. To verify this HCW wave generation technique, numerical simulations were performed by OpenFOAM® which is open-source Computational Fluid Dynamics (CFD) software, and the results were compared with analytical solutions. In addition, to design the optimized HCW, sensitivity analyses with respect to baffle height, length, number and position were carried out as shown in the Fig. 2 to 4. For sensitivity analysis, the time series of water surface by numerical simulation are compared with it by linear wave theory as the analytical solution. The Fig. 2 is the sensitivity analysis with respect to baffle height, vertical length of baffle, and shows baffle height does not affect the results.The fig. 3 is the sensitivity analysis with respect to baffle length, horizontal baffle length, and shows the longer baffle length is , the longer the phase lag is. For an optimized design, baffle length should not be relative long. For the sensitivity analysis about baffle number and position, baffles are regularly position at inlet boundary in 3 inlets and 5 inlets, and only the number of baffles are different. In the case of 6 inlets, baffles are irregularly position at inlet boundary, and two upper baffles are located over wave crest and trough generated As may be intuitively expected, results with increased number of baffles show agreement closer to the analytical solution as seen in the Fig. 4. Additionally, when more baffles are located between the wave crest and trough, the better the agreement is.

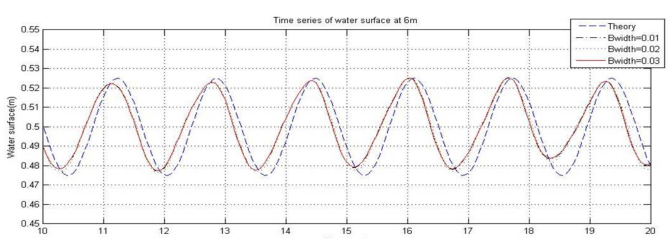


Figure 2: The comparison of time series of water surface with different baffle heights

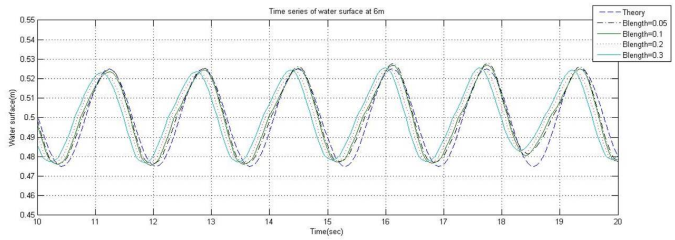


Figure 3: The comparison of time series of water surface with different baffle lengths

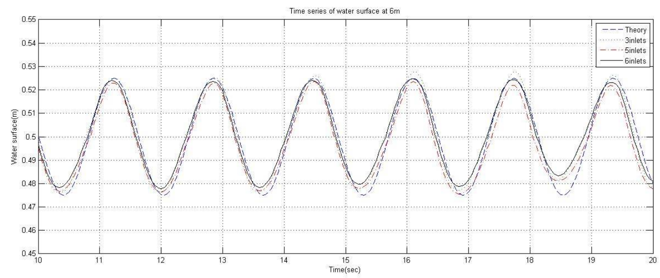


Figure 4: The comparison of time series of water surface with different baffle number and position

RESULTS AND ANALYSIS

Optimized Design

The design of optimized baffle is suggested by sensitivity analysis. Baffle height is not considered because it does not affect the result. Baffle length is 0.05m to avoid phase lag to create various amplitude wave. 10 baffles are positioned over wave amplitude range of a/h=0.05, and 2 baffles are placed in under wave trough. To verify this design, relative long wave (kh=0.1) and short wave (kh=1) with a/h=0.01 and 0.05 are simulated, and then wave surface elevations and horizontal and vertical velocity profiles near wave crest and trough are compared with analytical solutions as shown in the Fig. 5 to 8. The results of relative short wave are pretty in agreement with the analytical solution as seen in the Fig. 5 and 6. The results of relative long wave show phase difference as shown in the Fig. 7 and 8. Wave crest and trough points in the numerical results lag behind the points in the analytical solution and the comparison of vertical velocity profile notes almost the opposite direction to analytical solution. It means sine wave with relative high wave amplitude is caused in phase lag more than it with small wave amplitude . In this case, high velocity water flow in and out baffles so the fluid can be more affected by baffle boundary than other cases. Especially, the phase lag can obviously be shown in the case of high frequency water flow in an out baffles as seen in the Fig. 8.

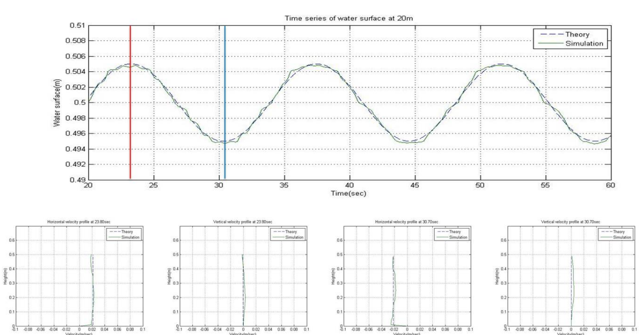


Figure 5: The comparison of time series of water surface and horizontal and vertical velocity profile with analytical solution (a/h=0.01, kh=0.1)

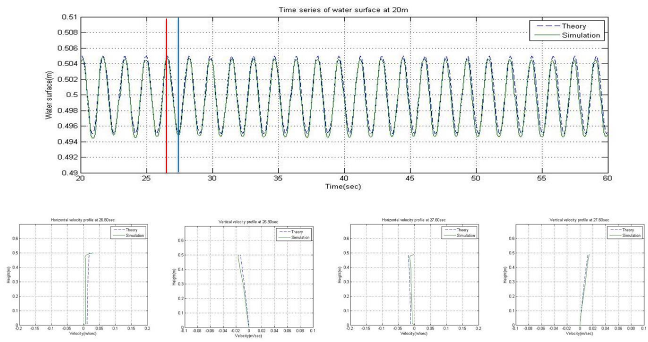


Figure 6: The comparison of time series of water surface and horizontal and vertical velocity profile with analytical solution (a/h=0.01, kh=1)

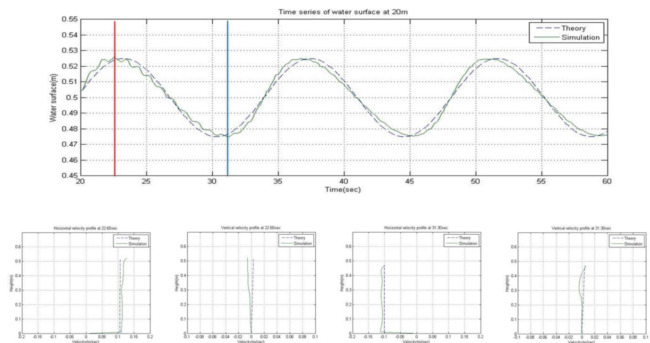


Figure 7: The comparison of time series of water surface and horizontal and vertical velocity profile with analytical solution (a/h=0.05, kh=0.1)

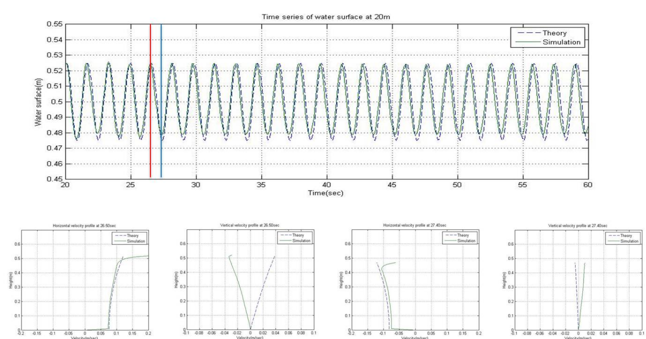


Figure 8: The comparison of time series of water surface and horizontal and vertical velocity profile with analytical solution (a/h=0.05, kh=1)

PROTOTYPE

A flow control system is the most important in HCW system. A peristaltic pump, one of flow control systems, was used to make a small scale physical model, but the flow pulsation made the resulting flow into the flume horribly messy, especially at lower flow rates. A flow control system is developed by using a piston action in a cylinder with a motor and screw-jack as shown in the Fig. 9. The motor is connected the screw-jack by shaft coupling and the plate end of screw-jack is connected to the piston as well. The screw-jack function for changing rotary motion of the motor to translation of the piston. an air-release valve installed on the top of cylinder because trapped air in cylinder make an extra force to the piston. To generate wave, the flow rate should be known according to motor speed change, so the velocity of piston displacement are calibrated. The Fig. 10 shows a comparison between flow rate for piston movement and flow meter as calibration before generating wave. The flow rate for piston is calculated by multiplying cylinder area and velocity of piston movement. Both results are similarly and linear increase by satisfying mass conservation.

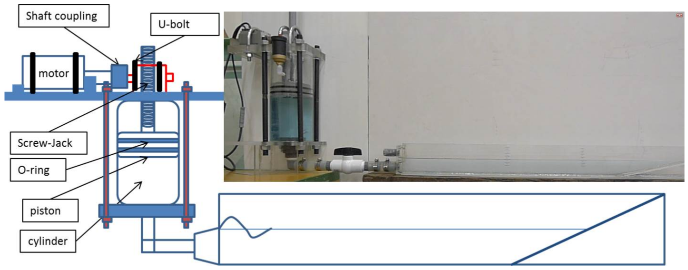


Figure 9: Design of prototype (lower) and physical model (upper)

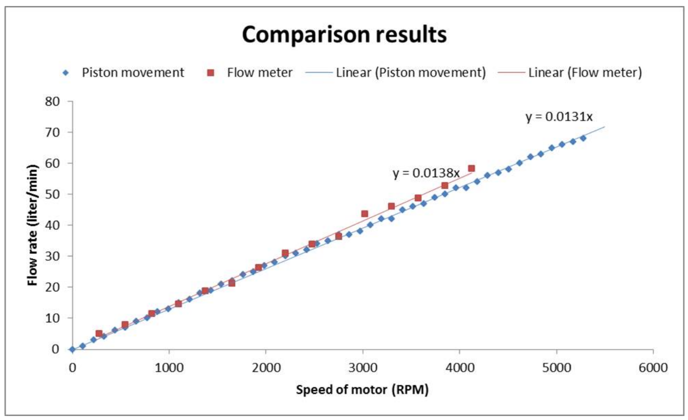


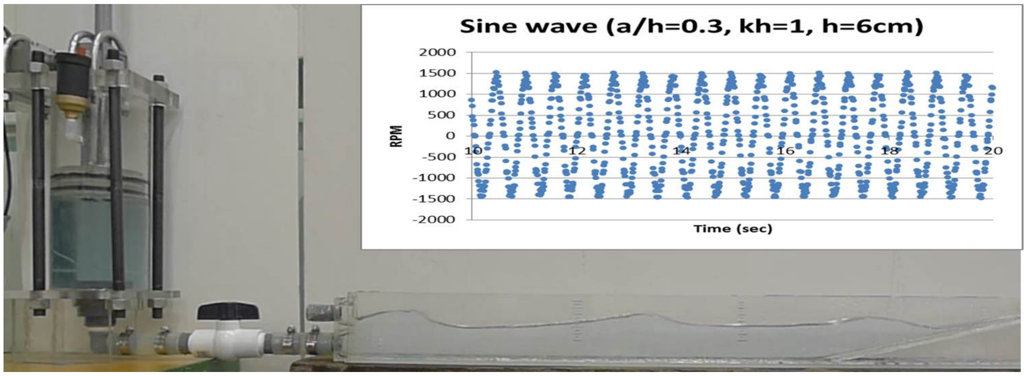
Figure 10: The comparison between flow rate for piston and flow meter

Using the small physical model, sine wave with a/h=0.3 and kh=1 and kh=0.1 are created. The Fig. 11 presents snapshots of sine wave generation through the small physical model and times series of motor speed profile. In these snapshots, it is hard to see exact sine wave forms because the flume length is too short to avoid reflected wave. The time series of motor speed profile show similar sine wave forms. This means that the motor is accelerated and decelerated well to reach the targeted sine wave form. The possibility of system of HCW can be confirmed.

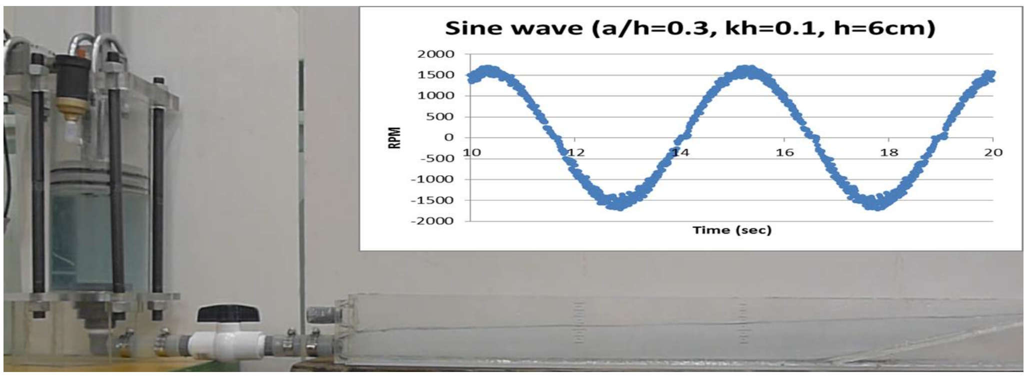
This small HCW system is transferred to a big flume(40 cm(W)*60 cm(H)*12m(L)) that we have had and sine wave with the maximum amplitude ration, a/h=0.013 is generated by using the small cylinder and the motor. The Fig. 12 shows a snapshot and time series of motor speed for generating sine wave with a/h=0.013 and kh=1. In the snapshot, more smooth sine wave form than in the small flume can be observed. The time series of motor speed profile shows a similar sine wave form and the maximum and minimum values are almost reach the maximum speed of motor, 5500RPM.

SUMMARY AND FUTURE WORK

A new method of wave generation by using HCW is performed through numerical analysis. The optimized design of HCW is suggested through sensitivity analyses with respect to baffle length, height, number and position. For verification, the numerical results from the optimized HCW are compared with analytical solutions. In the case of relative high wave amplitude, the phase lagged behind it in analytical solution, but most of results are good agreement with the analytical solutions. In practical, the small physical model with one baffle is developed and tested. The snapshots using the small-scale physical model of HCW and the time series of motor speed profiles are presented and the possibility of HCW system can be confirmed. For next work, a scale-up HCW system with three outflow baffles into the flume is being developed. Furthermore, the flow control system with one cylinder per baffle has finite volume problem, especially in the case



(a) Sine wave with a/h=0.3, kh=1



(b) Sine wave with a/h=0.3, kh=0.1

Figure 11: Snapshots and motion profiles of motor

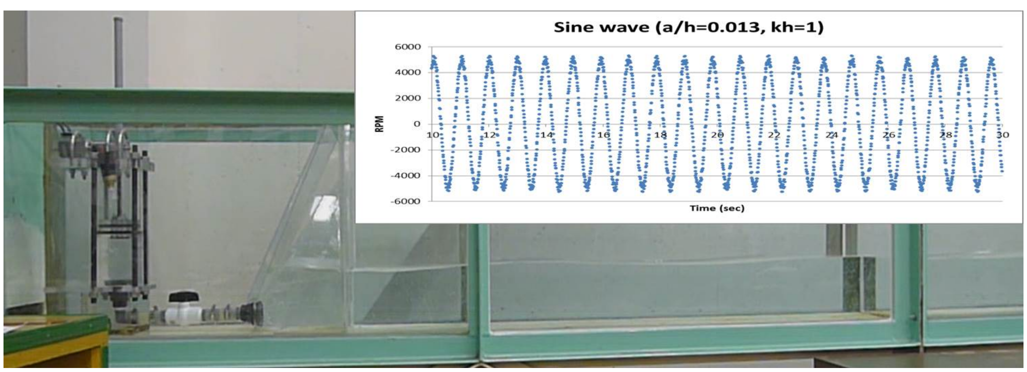


Figure 12: Snapshots and motion profiles of motor with big flume

of generating a combination of wave and current. To solve the limitation, A pair of cylinders connected to each baffle to achieve infinite flow into the flume is being challenged.

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