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Wave-current Interaction for Waves Propagating Against Currents

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This study investigates experimentally wave-current interaction and its mechanism and proposes a numerical method to simulate fluid motion under waves and currents in coexisting fields. Hydraulic model experiments were carried out in the open channel installed in a 3-dimensional wave basin to measure the wave height distributions and velocity fields in the channel. The experimental results indicated that the wave height increases initially due to the effects of the current, and then decreases gradually as the wave propagates upstream when its direction opposes the current. The incident wave period affected the decrease in wave height; in particular, a strong current resulted in spilling-type breakers. The results showed that waves also affect the current to weaken its velocity.

INTRODUCTION

As fundamental mechanisms associated with almost all problems related to coastal areas, the interactions of waves and currents are key concerns in ocean and coastal engineering. Wave-current interactions are particularly dominant near river mouths and in near-shore regions, and can characterize free-surface flows. The combination of wave and current can also create complicated fluid motions that are difficult to predict. Lalli and Bassanini (2004) noted that currents can be very much affected by waves, and that wave patterns can be significantly modified by currents as well. Further, the fluid motions created by wave and current interactions also act as a direct external force on sediment transport. In turn, sediment transport results in topographic changes. For effective and efficient countermeasures against coastal erosion, then, the fluid motions caused by waves, currents and their interactions must first be understood.

Because of the theoretical and numerical complexity of this problem, only a few studies have investigated the interactions between waves and currents in comparison with a study on wave or current mechanisms. Iwasaki and Sato (1970, 1971), using a hydraulic model test, indicated that the height of a wave traveling upstream against currents at the uniform water depth decreases at an exponential function due to the wave energy dissipation with the wave boundary layer near the bottom. Kemp and Simsons (1982) showed that mean velocity profiles of waves propagating with the current differ from those suggested by a linear superposition of wave and current velocities. Sakai and Saeki (1984) experimentally and theoretically investigated the transformation and breaking of waves affected by an opposing current on a sloping sea bed. They showed that wave height decay with an opposing current is greater than the decay without an opposing current, and that the wave height decay becomes milder as the slope becomes steeper. In addition to these studies, several others have also investigated how coexisting waves and currents interact, providing valuable information (Ronald et al., 1989; Mohiuddin et al., 1999, 2000; Kobayasi and Tanaka, 2002; Mizutani et al., 2002; Umeyama et al., 2003; Mase et al., 2004). Most studies, however, have focused on how a current deforms a wave, and few have examined how waves affect the currents. Plus, most previous research has examined the wave-current interaction in 2 dimensions, neglecting to investigate the 3-dimensional effects of wave-current interaction.

In recent years, with the improvement of computing environment, numerical methods capable of reducing the considerable effort and expense in hydraulic experiments are rapidly increasing in ocean and coastal engineering fields. However, numerical studies of the interactions between currents and waves have mainly been researched using analytical methods based on the linear or finite amplitude wave theory (Longuet-Higgins and Stewart, 1960; Jonsson, 1970; Thomas, 1981). However, analytical methods are not sufficient to solve exactly the characteristics of interactions between currents and waves because they are able to use only the appropriate approximations and consider the fluid to be an irrotational flow. Hedges and Lee (1992) introduced the concept of the "equivalent uniform current" when computing wave-current interaction for its simplicity. This current is defined as the uniform current that produces the same wave length as the actual depth-varying current for a particular observed wave height, period and water depth, i.e. it can be calculated by averaging the actual current velocities over a depth, the product of the wave length by a factor dependent mainly on the relative water depth divided by the wave length, from the water surface. However, in real sites, the vertical distribution of current velocity is not uniform, i.e. it varies with water depth. Further, interactions between waves and currents produce complex flows that are difficult to describe mathematically. Lalli and Bassanini (2004) studied 3-D wave-current interaction in shallow water, using the original time domain numerical method computed by means of the boundary integral formulation. However, these numerical models are generally based on the potential wave theory, which may not be sufficient to describe nonlinear wave-current interactions.

The goal of this study is to investigate how waves and current interact when wave direction opposes the current, based on the laboratory experiments. In order to achieve this purpose, 2 different, special open channels are used. One is a 2-D open channel with a uniform width (2-D experiment), and the other a 3-D open channel that gradually broadened toward the entrance of the open channel (3-D experiment).

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