DISTRIBUTIONS OF KINETIC ENERGY AND WAVE CELERITY IN INTERNAL WAVES PROPAGATING OVER A CONSTANT SLOPE

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1. INTRODUCTION

This investigation deals with spatial distributions of kinetic energy and wave celerity due to the propagation of internal waves along a uniform slope in two-layer density-stratified water. Using Particle Image Velocimetry (PIV), Umeyama et al. (2012) measured the instantaneous velocity for different thickness ratios and wave periods. Variation of kinetic energy during the runup event was computed after an analysis of velocity vectors. The kinetic energy along the slope was confirmed by the result computed from a two dimensional numerical model with Boussinesq approximation (Umeyama and Shintani, 2004). The wave celerity was simultaneously measured using an image processing technique and compared with the estimated results from the linear wave theory and the method of characteristics.

2. EXPERIMENTAL METHOD

Experiments were conducted in a 6-m-long, 0.15-m-wide, and 0.35-m-deep wave tank. A slide-type wave generator with a D-shaped wave paddle was placed at one end. A 1-cm-thick Plexiglas plate, which served as the plane seabed with slope 3 in 50, was fabricated between 100 and 600 m from the wavemaker. A density-stratified fluid consisting of fresh water in the upper layer and salt water in the lower layer was prepared for a series of experiments. The density of the salt water was 1,030 mg/cm^3, and the water depth was kept at 30 cm during the experiment. The upper and lower thickness ratio was chosen at h_I : h_{II} =15 cm : 15 cm, and 10 cm : 20 cm. The internal waves for two different periods (i.e. T = 5.0 s and 7.2 s) have been generated for each thickness ratio. A 1-cm laser sheet of uniform intensity was emitted from the upper side of the tank, and covered an area between the water surface and the sloping bed. The optical system included a high-definition digital video camera with a maximum resolution of 1920 x 1080 pixels. The water was seeded with DIAION whose grain size and specific gravity were 0.11 mm and 1.01, respectively.

3. RESULTS

Fig. 1 shows a comparison between the measured and computed kinetic energy distributions for T=7.2 s in the case of the thickness ratio of h_I : h_{II}=15 cm : 15 cm. These contour maps of kinetic energy were plotted at intervals of T/4 in one wave cycle. The dash line depicts the computed internal wave profile. The kinetic energy takes the maximum value in the lower layer while it decreases gradually toward the free surface in the upper layer. An internal wave travels along the slope, retaining high kinetic energy and forming an elliptic patch of it. Several energy patches appear under the crest or trough. As the wave runs up the slope, the elliptic patch decreases in its magnitude and spits into some smaller ones. This trend is very apparent in the range between 120 cm and 160 cm for the measured contour maps for t/T=0.0~0.5. The kinetic energy changes into the potential energy through the dissipation process associated with the breaking and friction losses. Finally, a turbulent bolus will be produced and advances slowly in the upper layer. The kinetic energy computed

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by the 2D numerical model shows relatively large value under the wave crest and trough although it is not conspicuous in its center of the patch. In the region between the elevation of z=5 cm and the bottom, the computed kinetic energy fairly agrees with measured data, especially in the positions of energy patches. However, the numerical prediction cannot give a detailed explanation of kinetic energy transfer.

Fig. 2 depicts the variations of the wave celerity along a slope in the case of h_I : h_{II}=15 cm : 15 cm for two different wave periods: (a) T=5.2 s; and (b) T=7.2 s. The measured data by an imaging technique is compared with the estimated results from the linear wave theory and the method of characteristics. The measured celerity is smaller than those predicted ones except in the upper slope region where most measured values exceed the predicted ones by the method of characteristics. It is noticed that near the origin, in the case of T=5.2 s the measured wave celerity increases while it should vanish as the theoretical distribution. The discrepancy between theoretical and experimental results might be some effects such as the interaction of incoming waves and return flow from the upper layer, internal wave set-up by breaking and so on.

(a) Measured (b) Computed

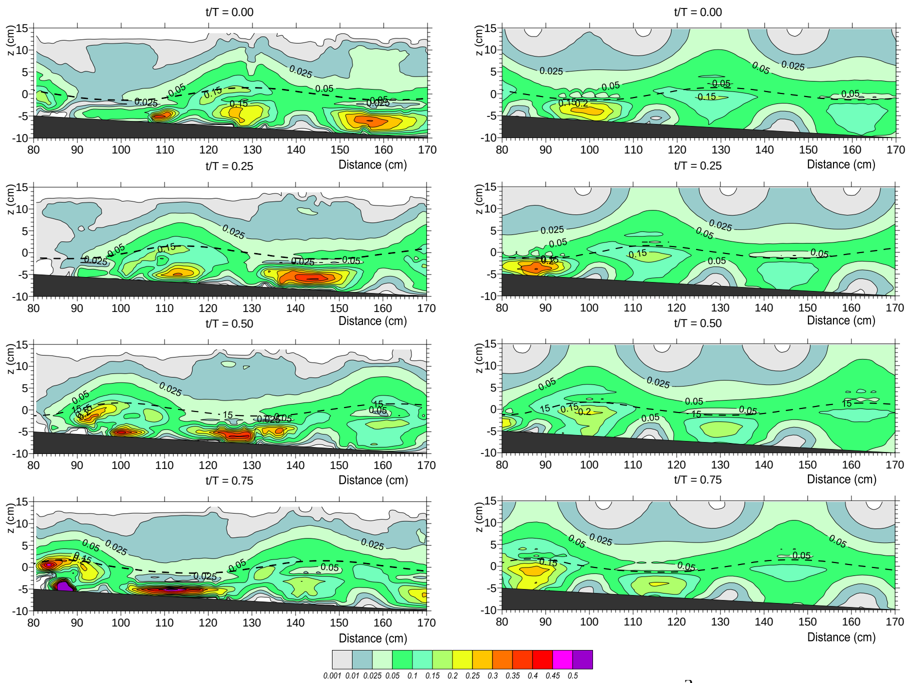

Fig. 1 Distributions of kinetic energy [J/m^3]
for h_I : h_{II}=15 cm : 15 cm, and T=7.2 s

(a) T=5.2 s

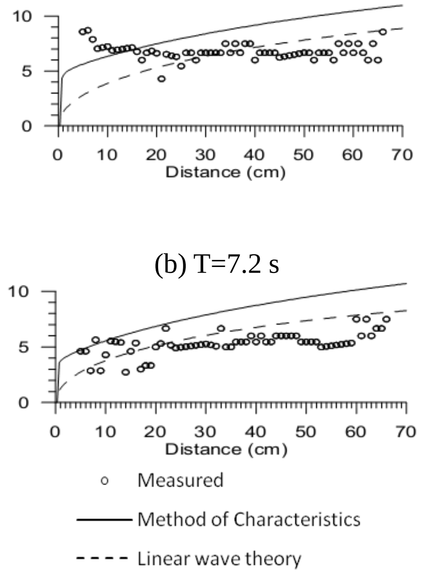

Fig. 2 Wave celerity
for h_I : h_{II}=15 cm : 15 cm

4. CONCLUSIONS

The physical aspects of internal waves were investigated to predict the spatial distributions of the kinetic energy and wave celerity along the sloping bottom. The measured kinetic energy showed the existence of intensive kinetic energy in the lower layer. The predicted variation by a 2D numerical model is shown to be in qualitative agreement with one obtained from the physical-model measurements. A comparison of theoretical and measured celerity variations indicates that the agreement with these values becomes poorer near the origin (x=0).

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