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学 位 論 文 要 旨

論文題名　Visualization and numerical analyses for mass transport due to internal waves propagating in the density-stratified water with a diffusive transition layer

（拡散遷移層を有する密度成層水域内を伝播する内部波の質量輸送に関する可視化および数値解析）

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（ 学位論文要旨 ）

Below the sea surface, generally, the water can be divided into three layers: (i) mixing layer, (ii) thermocline, and (iii) deep layer. Internal waves form at the bottom edge of a steep thermocline. These waves transport a considerable amount of energy and momentum horizontally and vertically. The study of internal waves in the density-stratified water is essential to the coastal environment because they cause the transport of planktonic larvae from the offshore to the coast and the mixing between subsurface water and bottom water. The shoaling and breaking of internal waves play important roles in the suspension, transport, and deposition of sediments in the ocean bottom. Knowing the water particle motion in an internal wave cycle is the key to solving the transport phenomenon. The subject may be of considerable importance for nearshore internal wave problems; however, the number of such investigations is still limited compared with those concerning nonlinear wave shapes. This is due to the inconvenience of describing the particle velocity and path experimentally under a wave motion in the Lagrangian system. Use of the recent imaging technique has made it possible to investigate the mechanism of internal waves in a wave tank. The latest developments in Particle Image Velocimetry (PIV) and Particle Tracking Velocimetry (PTV) have led to the visualization of velocity fields and particle paths.

Although the essential problems arising from the motion of internal waves approaching coastal areas are changes in wave characteristics and wave induced flows, the peculiar features of the mass transport in a shallow water region are still not understood. The objective of this study is to measure the physical quantities of internal waves over a uniform slope during a runup event using a video recording system and a PIV system. Interfacial displacement, celerity, setup, and particle velocity were measured in the cases with and without diffusive interfacial layer and a two-dimensional non-hydrostatic numerical model was used to examine these values.

This dissertation comprises seven chapters.

Chapter 1 gives a brief introduction to physical aspects of nonlinear internal waves that propagate in the density-stratified fluid layers. It also includes the motivation and objective of this study.

Chapter 2 reviews previous studies of the internal wave kinematics that include interfacial displacement, celerity, setup, water particle velocity and trajectory. The theoretical background on mass transport in the presence of internal waves is also presented for different stratifications.

Chapter 3 investigates experimentally the behavior of internal waves propagating along a uniform slope. Experiments were carried out in a wave tank having an overall length of 6.0 m and a cross section 0.15 m wide by 0.35 m deep. A slide-type wavemaker with a D-shaped wave paddle was placed at one end, and a Plexiglas plate with a slope 3 in 50, was fabricated between 1.0 and 6.0 m from the tip of the paddle. A density-stratified fluid consisting of fresh water and salt water with a density of 1,028 mg/cm^3 was prepared for a series of laboratory tests. The instantaneous water particle velocity in a wave motion was measured using a single-exposure PIV system that consists of a frequency-doubled Nd:YAG laser of 8-W energy at 532 nm, and two high-definition digital video cameras with a maximum resolution of 1920×1080 pixels. A cross-correlation method was performed to calculate the water particle displacement and local velocity in a Eulerian scheme by processing a pair of image frames. The PIV technique was applied to the computation of Lagrangian velocity and the prediction of Stokes drift. In addition to the PIV measurement, the spatial and temporal variations of the density interface, wave celerity, setup, and mass transport due to shoaling and breaking of internal waves were obtained using two imaging techniques. The first method used light-attenuation to mark the vertical motions of isopycnal layers and the second used dye-streak to visualize the water particle movement. Experiments were carried out in the fluid having different thickness ratios between two layers for some different wave periods using the first method, and in the fluid having a thin diffusive interfacial layer between two homogeneous layers.

Chapter 4 concerns numerical approach that is applied for the experimental setup. The theoretical aspect of the problem was based on a two dimensional numerical model. In formulating the model, the Boussinesq approximation was applied to the continuity and momentum equations. To solve these governing equations, an explicit finite difference technique with the fractional-step method was employed on staggered grids. The advective and diffusive terms were discretized using the ULTIMATE-QUICKEST scheme and the central difference scheme, respectively, and the velocity, trajectory and interface were computed in the whole flume with spatial resolutions. After the accuracy of the numerical model was confirmed by verification studies using experimental data, it was applied to several test results for various hydraulic and geometric conditions.

Chapter 5 investigates the effect of the thickness ratio on mass transport due to propagation of internal waves. Because boundary conditions are essential in the limited wave tank, first, the case of a horizontal bottom is considered to point out the various existing approximations given in the different models. For a uniform slope, the situation is more complicated and a two-dimensional non-hydrostatic numerical model was treated in a way that can be extended without much difficulty to the nonlinear problem. The mass transport velocity was estimated from the horizontal excursion of water particle. The water particle trajectory computed by the non-hydrostatic model was compared with PIV results from the wave tank. It was confirmed that the numerical model reasonably reproduces the measured mass transport velocity of the internal waves in various bottom conditions. A series of numerical experiments showed the dependency of mass transport on the layer thickness ratio and the internal wave height. The maximum mass transport velocity was the highest when the thickness ratio of upper and lower layers was unity and it became smaller when the lower layer thickness exceeded the upper layer thickness. For all thickness ratios, the mass transport velocity increased with an increase of the internal wave height.

Chapter 6 is concerned with a few aspects of nonlinear internal waves in a fluid system of two homogeneous layers separated by a thin diffusive transition layer. First the transport of water particles inside the interfacial layer and adjacent regions was investigated using a numerical model having very high resolution in the case of a flat bottom and subsequently, the horizontal mass transport in the case of a uniform slope is discussed.

Chapter 7 presents the conclusions and recommendations of this investigation. Conclusions are given to remark the fulfillment of the present work to the objective. Recommendations are made for further considerations on application of the proposed numerical method to predict velocity field, trajectory, and mass transport in homogeneous layers with a diffusive layer.

注意　２０００字程度、１２ポイントで記載

研究業績一覧

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研　究　業　績　一覧

＊印は，本論文に直接関係するものを示す

１．論文（フルペパー査読）

No.	論文名	掲載誌	巻，号，頁	発行年	著者名
1*	Effects of diffusive interface on mass transport by internal waves propagating in a two-layer fluid system	Journal of JSCE (A2) JSCE	Vol.69, No.2 Accepted	2013. 9	K.-C. Nguyen T. Shintani M. Umeyama
2*	Effect of thickness ratio on mass transport by internal waves propagating in two-layer system	Journal of JSCE (B1) JSCE	Vol.69, No.4, I_85-I_90	2013. 3	K.-C. Nguyen T. Shintani
3*	Water particle trajectory and mass transport of internal waves propagating over a constant slope	Journal of JSCE (A2) JSCE	Vol.68, No.2, I_653-I_660	2012. 9	K.-C. Nguyen M. Umeyama T. Shintani
4	Long-term morphological changes and hydrodynamics of tidal dominant coastal zone in the Hai Phong estuary, Vietnam	Journal of JSCE (B1) JSCE	Vol.68, No.4, I_85-I_90	2012. 3	K.-C. Nguyen M. Umeyama V. U. Dinh
5	Development of modeling system to simulate hydrodynamic and environmental quantities in the Hai Phong estuary, Vietnam	Proc. of World Congress IAHR	Vol.34 pp.3255 -3262	2011. 6	K.-C. Nguyen V. U. Dinh M. Umeyama
6*	Measurements of particle velocities and trajectories for internal waves propagating in a density-stratified two-layer fluid on a slope	Particle Image Velocimetry InTech	Ch.12 pp.321-344 ISBN 979-953 -51-0625-8.	2012. 5	M. Umeyama T. Shintani K.-C. Nguyen S. Matsuki

２．国際会議（アブストラクト査読）

No.	論文名	掲載誌	巻，号，頁	発行年	著者名
1*	Characteristics of internal waves propagating over a gentle slope in a two-layer density-stratified fluid	Proc. of 4th International Conference on Estuaries & Coasts	pp.65-73	2012. 10	K.-C. Nguyen M. Umeyama T. Shintani
2*	Velocity distribution and particle trajectories in internal wave propagating on an upper slope	Proc. of 18th IAHR-APD Conference IAHR	pp.92-94	2012. 8	K.-C. Nguyen M. Umeyama T. Shintani
3*	PIV measurements of particle velocities and trajectories for internal waves propagating in a two-layer fluid on a sloping boundary	Proc. of 33rd International Conference on Coastal Eng. ASCE	Vol.33 currents.54 13 pages	2012. 6	M. Umeyama K.-C. Nguyen
4	Investigation of shoreline and morphological changes, and simulation of the circulation in the Hai Phong estuary, Vietnam	Proc. of 34th International Symposium on Remote Sensing of Environments	CD-ROM 4 pages	2011. 4	K.-C. Nguyen V. U. Dinh M. Umeyama T. G. Nguyen H. Nguyen

３．口頭発表

No.	論文名	掲載誌	巻，号，頁	発行年	著者名
1	Numerical analysis of sediment transport in Hai Phong area with a coupled ROMS-SWAN model	Annual meeting 2013 JSFM	submitted	2013. 9	S. Motani K.-C. Nguyen T. Shintani M. Umeyama
2*	Distribution of kinetic energy and wave celerity in internal waves propagating over a constant slope	Proc. of 13th International Summer Symposium JSCE	Vol.13 pp.53-54	2012. 9	K.-C. Nguyen M. Umeyama T. Shintani
3	Numerical analysis on flow and tidal exchange characteristics in Ha Long Bay	Annual meeting 2011 JSFM	CD-ROM 6 pages	2011. 9	C. Nakaza K.-C. Nguyen T. Shintani M. Umeyama

４．研究レポート等

No.	論文名	掲載誌	巻，号，頁	発行年	著者名
1	Impacts of Sea Level Rise on Vietnam coastal cities and preparation for development assessment and strategic planning	Proc. of ISSUE TMU	pp.1-4	2012. 11	V. U. Dinh N. A. Tran T. G. Nguyen K.-C. Nguyen

上記のとおり相違ありません。

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※講演も記載すること。著者名は全員記載し、ご本人に下線を引いてください。
ご本人のローマ字入力のお名前も下線をお願いいたします。
主要論文に＊など印をつけてください。

様式５

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9	平成２２年　３月２９日	Centre for Space Science and Technology Education in Asia and the Pacific, India (Post graduate diploma) 卒業
10	平成２２年１０月　１日	首都大学東京大学院都市環境科学研究科博士後期課程 都市基盤環境学域入学
11	平成２５年　９月３０日	首都大学東京大学院都市環境科学研究科博士後期課程 都市基盤環境学域修了見込み

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