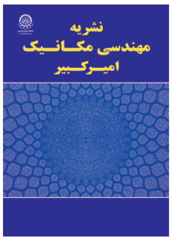

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Numerical Simulation of a Piston-Type Wavemaker using Lattice-Boltzmann Method with Moving Nested Grids

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ABSTRACT: Applications of the wavemaker mechanisms in the experimental investigations of wave-structure interactions have attracted various researchers' attention. Numerical simulations capable of wave generation in a water tank are appropriate substitutes for the expensive experimental studies. Due to the large values of the wave length to wave height ratio and also the water depth to wave height ratio, extremely fine grid points are generally required at the gas-liquid interface and this causes the numerical simulations to be very time consuming. In this study, a new method is proposed for numerical simulation of a piston-type wavemaker which is faster than the previous methods. The proposed method is a combination of a Lattice-Boltzmann method with multilayer moving nested grids and iWeno5 method for treating the kinematic free surface boundary condition. The numerical results of the proposed method are compared with the analytical and experimental data, where a good agreement is observed.

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1- Introduction

Producing a wave with desired characteristics is one of the main challenges for both the numerical and experimental investigations of water wave interactions with ocean structures. Most of the wavemaker mechanisms consist of a moving solid object that has a reciprocating linear or angular motion inside water, such as the piston or flap-type wavemakers.

Yet, several wave generation methods are introduced for effective wave generation inside a numerical wave tank which can be classified into three main categories [1]: analytical models, numerical models assuming an inviscid fluid, and numerical models considering a viscous fluid. The viscous wave generation methods are divided into two approaches: Internal wave generation methods [10, 21, 22, 23] and Volume Of Fluid (VOF)-Inflow methods [24-26]. Although these methods have been successful in producing desired waves, the numerical methods in the viscous numerical wave tanks are extremely time-consuming.

In this study, the Lattice-Boltzmann method is modified in order to simulate the dynamic motion of a piston-type wavemaker inside the water. A multi-layer moving grid technique in conjunction with the Weno method for treating the kinematic free surface boundary condition is employed which can greatly reduce the computational cost. For the validation purpose, the numerical results of the proposed method are compared with the available analytical and experimental data in the literature.

2- Governing Equations

The two-dimensional Navier-Stokes equations for the incompressible flow of a Newtonian fluid are as follows:

$$\nabla V = 0 \tag{1}$$

$$\frac{\partial V}{\partial t} + V \cdot \nabla V = -\frac{1}{\rho}\nabla p + \frac{1}{\rho}\nabla \cdot \vec{\tau} + g \tag{2}$$

where V, τ, p, ρ and g are the velocity vector, stress tensor, pressure, density and gravitational acceleration, respectively.

3- Numerical Method

In this study, the Lattice-Boltzmann method with the D2Q9 grid is incorporated for modeling the free surface wave propagations. In order to reduce the computational cost, a four-layer moving grid is used at the liquid-gas interface. The grid motions algorithm is explained in details in the paper, which has led to a significant reduction of the computational time.

4- Boundary Conditions

A schematic of the computational domain and the boundary conditions are depicted in Fig. 1. A rigid piston-type wavemaker is located inside the computational domain with moves horizontally back and forth. Two damping zones are located at the two ends of the computational domain to minimize the effects of the reflected waves.

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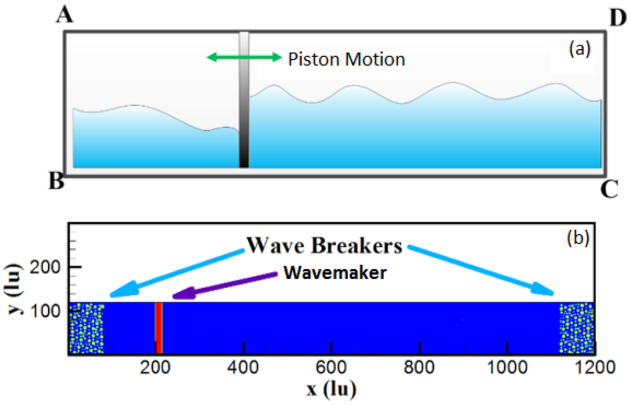

Figure 1. A schematic of the computational domain.

5- Results and discussion

In order to validate the proposed numerical method, first, a solitary wave is simulated. The transient motion of the wavemaker inside the water to generate a solitary wave with H=0.09 m inside a water depth of 0.3 m, are shown in Fig. 2. The velocity vector distributions beneath the generated solitary wave are also shown in Fig. 3. The solitary wave profile at various instances are compared with the Bousinesq analytical solution in Fig. 4. Wave train generation is also simulated for a piston stoke of 5.73 cm with a period of 0.96 sec, in a water depth of 0.2 m, and the results are depicted in Fig. 5.

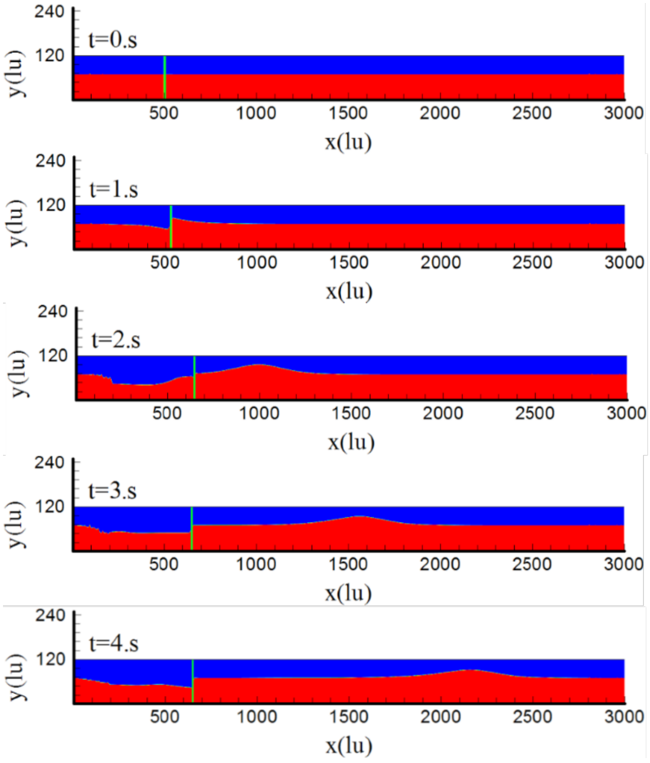

Figure 2. Transient contours of the fluid volume fraction, for the generation of a solitary wave

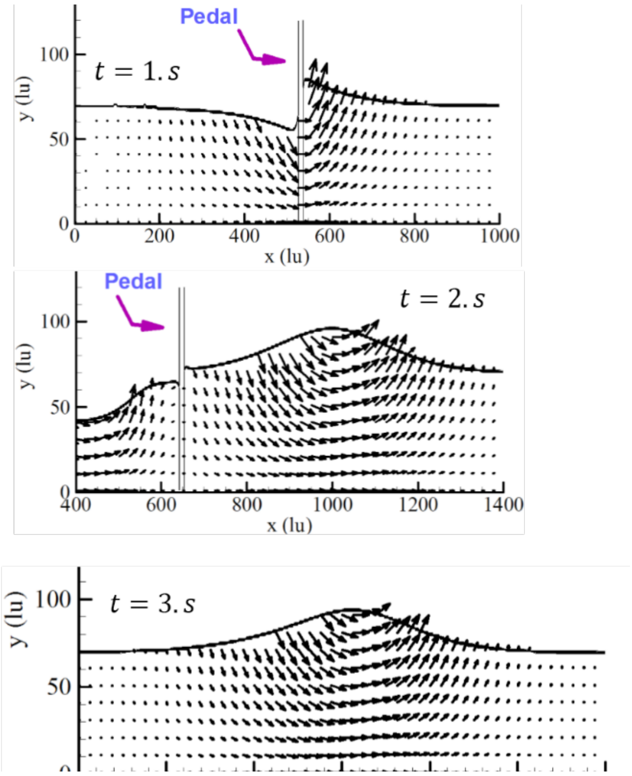

Figure 3. Velocity vectors distributions beneath a solitary wave.

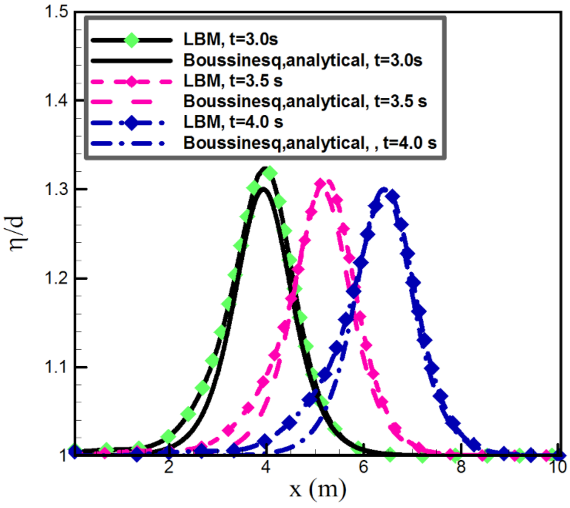

Figure 4. Instantaneous solitary wave profiles in comparison with the Bousinesq analytical solution

6- Conclusions

In this paper, a new numerical method is introduced to effectively generate viscous nonlinear waves inside a numerical wave tank. The method is based on the Lattice-Boltzmann method equipped with multi-layer nested cells and the iWeno5 method for applying the free surface kinematic boundary condition. The accuracy of the method is tested through several test cases such as a solitary wave and wave trains generated by a piston-type wavemaker. The comparisons made between the numerical results and those of the analytics and experiments showed a good agreement.

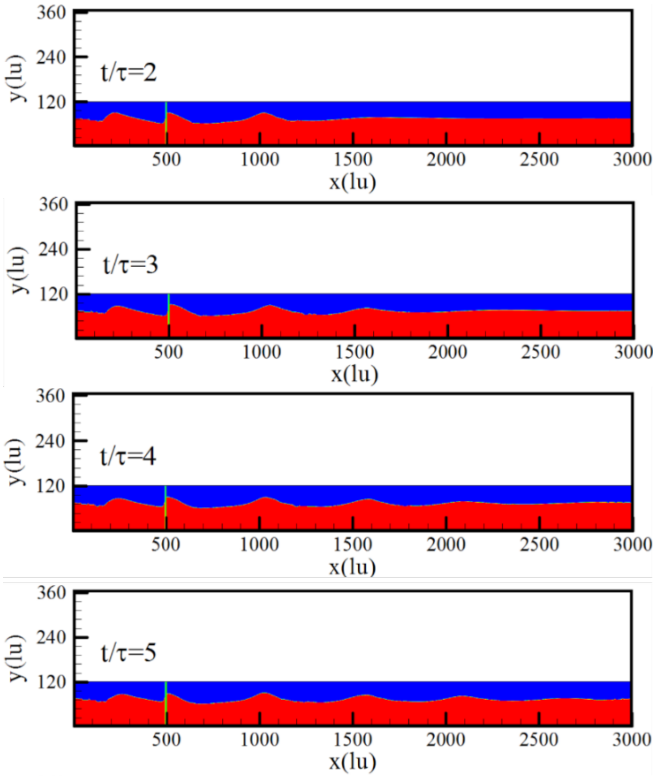

Figure 5. Transient evolution of the wave trains generated by the piston-type wavemaker.

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