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NUMERICAL SIMULATION OF FULLY NON-LINEAR IRREGULAR WAVE BY FLAP TYPE WAVE MAKER

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1. Introduction

Sea waves are usually irregular and of random nature. Therefore, no two waves are of the same wave height and period and move at different speeds. Investigating the effect of sea waves on offshore structures as well as absorbing energy from sea waves requires a thorough recognition of the waves and their features. Using numerical wave substrates being developed over the last two decades is an effective technique to simulate waves in different situations.

For the first time Havelock (1929) [1] and Hieu (1976) [2] assuming the non-viscous flow through using linear wave theory provided an analytical solution for flap and piston wave generators. However, Ursell (1960) [3], after conducting numerous experiments and examining waves with different sharpness, showed that the height of the waves generated by the piston wave generator is 10 percent less than the values obtained from analytical solutions based on the linear theory. Inability of analytical solutions for modeling waves in solid objects led high-order numerical models be presented based on the stream function wave theory to simulate the waves.

In one of the leading research studies conducted in 2008, Lee and Elanggovan [4] modeled linear regular waves by finite volume method. In 2015, Finnegan and Goggins [5], using the same method and Fast Fourier transformation, modeled linear irregular waves.

All afore-mentioned research studies used linear boundary conditions and problems are solved in a nonlinear form. Especially, in cases considering the wave contact with moving objects and absorbing their energy and when the drag force acting on the object cannot be ignored, linear boundary conditions will reduce the accuracy for the free surface. Thus, using non-linear theories to simulate waves and to track the free surface of the liquid is inevitable.

For the first time in 1965, Harlow and Welch [6] introduced marker and cell (MAC) method for free surface flows. In 1970, Chan and Street [7] improved this method at the Stanford University Modified Marker and Cell SUMMAC.

In 2005, Suea et al. [8], through solving the Navier-Stokes equations and boundary conditions by volume of fluid method, investigated the impact of non-linear waves on cubic structures submerged in the water.

For the actual mechanism of generating waves, height and wavelength are a function of range and course of the wave-generator motion as well as water depth. To this end, the linear wave-generating theory proposed by Dean and Darimpel [9] in 1984 and second-order wave-generating theory proposed by Madson [10] in 1971 were employed.

Accordingly, the development of a numerical model by assuming the viscous flow which models the actual conditions of the wave-generator seems necessary. In this study, Anbarsooz et al. numerical model [11] is used to model the real conditions of irregular nonlinear waves are produced flap wave generator.

2. The Governing Equations and Boundary Conditions

The schematic of the wave generation by flap type wave generator is shown in Figure 1.

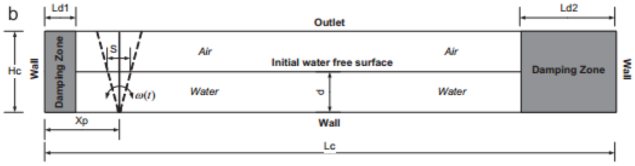

Figure 1. The area of the numerical solution and the boundary conditions

The equation governing the fluid flow is the Navier-Stokes' equation is two-dimensional with laminar, incompressible, and Newtonic flow:

$$\nabla.\vec{V} = 0 \qquad (1)$$

$$\frac{\partial \vec{V}}{\partial t} + \vec{V}.\nabla\vec{V} = -\frac{1}{\rho}\nabla P + \frac{1}{\rho}\nabla.\vec{\tau} + \vec{g} + \frac{1}{\rho}\vec{F}_b \qquad (2)$$

$$\vec{\tau} = \mu\left[\left(\nabla\vec{V}\right) + \left(\nabla\vec{V}\right)^T\right] \qquad (3)$$

Where, $\vec{V}$ is the velocity vector, ρ density, μ the dynamic viscosity, p the pressure, $\vec{\tau}$ stress tensor and $\overrightarrow{F_b}$ external forces applied on the fluid. To track the free surface of fluid, the volume of fluid method is used and defined as follows:

$$F = \begin{cases} 0 & \text{in the gas phase} \\ 0 <, < 1 & \text{in the liquid} - \text{gas interface} \\ 1 & \text{in the liquid phase} \end{cases} \qquad (4)$$

In this method, the solid in the solution is specified by using the scalar quantity below:

$$\emptyset = \left[\begin{array}{cc} 0 & \text{Out of the solid} \\ 0 <, < 1 & \text{Solid boundary} \\ 1 & \text{within the solid} \end{array}\right. \qquad (5)$$

3. Numerical Solution Method

To discretize the governing equations, the three-stage analysis method is used for the equations of continuity and momentum proposed in 2012 Mirzaii and Passandideh-Fard [12]. This method can be used for the Euler's constant networking in the simulation of free surface flows with surface tension. The momentum equation (2) is rewritten as follows.

$$\frac{\vec{V}^{n+1} - \vec{V}^{n}}{\Delta t} = -\left(\vec{V}.\vec{\nabla}\vec{V}\right)^{n} - \frac{1}{\rho^{n}}\nabla p^{n+1} + \frac{1}{\rho^{n}}\vec{\nabla}.\vec{\tau} + \vec{g}^{n} + \frac{1}{\rho^{n}}\vec{F}_{b}^{n} \qquad (6)$$

4. Results

In this section, the capabilities of the method presented in this study to model non-linear irregular waves through comparing the numerical results with experimental and numerical results obtained by other researchers are discussed.

According to what mentioned earlier, in order to generate the wave in the developed context of numerical wave, the height and the courses of wave-generating movement are only required and other parameters and related phenomena are obtained by solving the Navier-Stokes equation. To this end, using Fast Fourier transformation method, harmonic waves of the experimental and numerical wave proposed by Liang et al. [13]. This numerical wave possesses 20 harmonics and 10 of its main harmonics are used for numerical modeling.

The periodicity of flap type wave-generating motion is equivalent to the periodicity of the harmonic waves and its motion course is calculated by using the following equation:

$$\theta(t) = \frac{\Delta\theta}{2}\cos\left(\frac{2\pi}{T}t\right) \qquad (7)$$

$$S = 2d \times \tan\left(\frac{\Delta\theta}{2}\right) \qquad (8)$$

To avoid sudden wave-generating movement at the beginning of the resolution and sharp waves, the ramp function is used for the first second. Figure 2 shows the process of forming waves by flap type wave generator. Figure 3 shows the changes in water level or the length of the waves generated in 2 m distance from wave generator. As it can be seen, the results of the model presented in this study are pretty much consistent with experimental and analytical results extracted from the study conducted by Liang et al. [19]. Accuracy of the results has provided conditions for investigating different waves with various H/L ratios and different sharpness and provides the opportunity for modeling solid objects and investigating the interaction of waves with these objects.

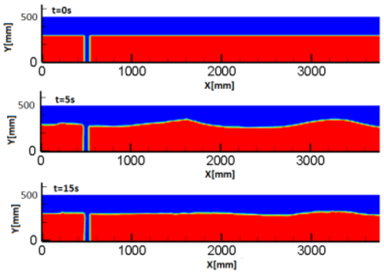

Figure 2. Latitude changes and periodicity of irregular wave generated by the finned wave-generator

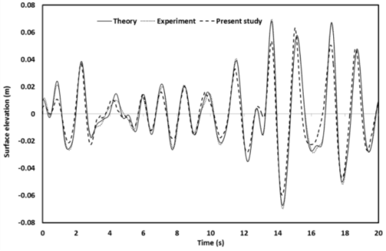

Figure 3. Changes in the water level at x = 2 m

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