ENERGY ABSORPTION OF FULLY NON-LINEAR IRREGULAR WAVE BY BRISTOL CYLINDER WAVE ENERGY CONVERTER

Saadati-Nasab .Mehran[1], Passandideh-Fard. Mohammad[2] and Anbarsooz. Morteza[3]

1) Mechanical Engineering, Ferdowsi of Mashhad, Mashhad, Iran, saadati.mehran@gmail.com
2) Mechanical Engineering, Ferdowsi of Mashhad, Mashhad, Iran, mpfard@um.ac.ir
3) Mechanical Engineering, Advanced Technologies Engineering, Quchan, Iran, m.anbarsooz@gmail.com

1. Introduction

Various types of wave energy absorption equipment work based on a swing or a submerged buoy to a fixed reference. The efficiency of this equipment can vary based on the depth of water in which they are installed. One of the equipment that can effectively use both components of wave forces in x and y direction is Bristol cylinder which was first introduced by Evans from the University of Bristol in 1976 [1].

Evans provided a linear theory to predict the performance of this group of wave energy absorption equipment and indicated that, in theory, there is a possibility of 100% absorption for wave energy using the cylinder [1]. He also showed that passing waves can be eliminated and the total wave energy can be absorbed for certain values of the spring constant and damping factor in each frequency of incident wave. Recently, Heikkinen et al. [2], through providing a theoretical analysis based on potential flow theory, investigated the effect of various parameters such as height, wave periodicity, and the cylinder diameter on the cylindrical Bristol efficiency.

Evans [3] and Davis [4] experimentally showed that linear theory quite loses its accuracy in calculating the Bristol cylindrical efficiency for waves with high sharpness. This is due to limiting assumptions of linear theory which ignore the effects of viscosity and assumes the non-rotating flow and linear waves.

A common method for considering the effects of viscosity in non-viscous fluid simulations is adding a sentence of similar force with the drag force in the well-known Morison's equation [5]. This method has been used by many researchers, including Davis [4] and Babarit et al. [6]. Regarding the Bristol cylinder, Davis [4] showed that the use of this method for predicting efficiency does not provide acceptable results. In fact, because of the cylinder movement, the drag coefficient is different at any given moment and considering a fixed amount for the drag coefficient cannot accurately predict wave forces.

Hence, providing a method for predicting the performance of the Bristol cylinder in various conditions, including against irregular non-linear waves, seems essential. In this study, using a method based on the unmatched and fixed networking (fast fictitious domain method), the performance of this wave energy absorbent in different conditions is simulated.

2. The Governing Equations and Boundary Conditions

The schematic of the wave energy absorption mechanism by the Bristol cylinder is shown in Figure 1.

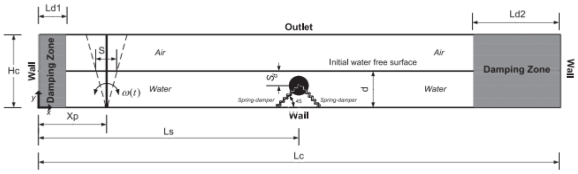

Figure 1. The area of the numerical solution and the boundary conditions

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

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

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

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

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:

$$F = \begin{bmatrix} 0 & \text{in the gas phase} \\ 0 <, < 1 & \text{in the liquid} - \text{gas interface} \\ 1 & \text{in the liquid phase} \end{bmatrix} \tag{4}$$

In the taken computational steps, after calculating the velocity based on the momentum equation, F values are replaced based on the following transfer equation in the solution area:

$$\frac{\mathrm{dF}}{\mathrm{dt}} = \frac{\partial \mathrm{F}}{\partial \mathrm{t}} + \vec{\mathrm{V}}.\nabla\mathrm{F} = 0 \tag{5}$$

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

$$\emptyset = \begin{cases} 0 & \text{Out of the solid} \\ 0 <, < 1 & \text{Solid boundary} \\ 1 & \text{within the solid} \end{cases} \qquad (6)$$

3. Efficiency of Energy Absorption

The overall force applied on the cylinder, in addition to wave forces, includes external forces (spring and damper forces) as well as the buoyancy force. According to Newton's second law:

$$\vec{F}_{tot}(t) = \vec{F}_{spring}(t) + \vec{F}_{damper}(t) + \vec{F}_{bouyancy}(t) + \vec{F}_{wave}(t) = M_s \frac{d\,\vec{V}_s(t)}{dt} \qquad (7)$$

The energy absorption efficiency which is defined as the ratio of the average power absorbed, $\bar{P}_{abs}$, to the average total energy of the wave, $\bar{P}_w$, can be introduced by using the following equation [7]:

$$\eta = \frac{\frac{1}{T}\left[\int_t^{t+T} -\vec{F}_{damper}(t).\vec{V}_s dt\right]}{\frac{1}{T}\left[\int_t^{t+T}\int_{-h}^{\gamma} P_D.udzdt\right]} \qquad (8)$$

4. 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 Passandideh-Fard and Mirzaii [8]. 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.

$$\frac{\vec{V}^{n+1} - \vec{V}^n}{\Delta t} = -\left(\vec{V}.\vec{\nabla}\vec{V}\right)^n - \frac{1}{\rho^n}\nabla p^{n+1} + \frac{1}{\rho^n}\vec{\nabla}.\vec{\tau} + \vec{g}^n + \frac{1}{\rho^n}\vec{F}_b^n \qquad (9)$$

5. Results

Potentials of the method proposed in this research are indicated in this section for Bristol cylinder modeling and absorption of energy from sea waves.

Figure (2) shows the Bristol cylinder in the solution domain. Spatial displacements of the cylinder and wave maker are clearly depicted in the latter figure over time. To absorb energy from the cylinder deep in water a spring with a constant of 826 N/m and a damper with a damping factor of 20 Ns/m were used. The free spring length is 30 cm and the cylinder is static when the solution begins. As the wave travels over the cylinder with irregular movements, part of the wave energy is dissipated by the cylinder and damper.

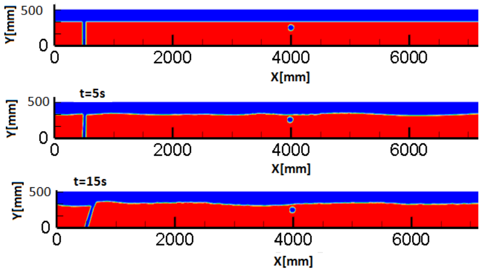

Figure (2): Spatial displacements

Due to the absorption of wave energy by the cylinder in the x and y directions, the amount of energy absorbed by the cylinder in the aforementioned two directions is depicted in Figure (3). The energy absorbed by the cylinder is insignificant and varies in the 0.1-0.45 W/m range because of irregularity of waves hitting the cylinder. As seen in figure (4), efficiency of energy absorption by the cylinder varies from 20 to 60%. Therefore, the cylinder should be optimized for maximum absorption of energy, and this could be the subject of future research.

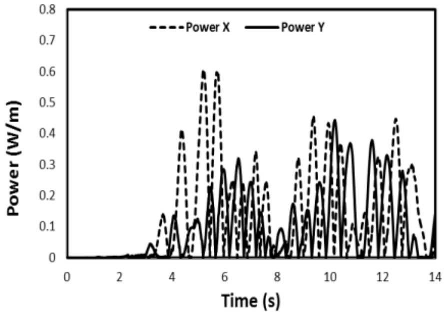

Figure (3): Power absorbed by cylinder

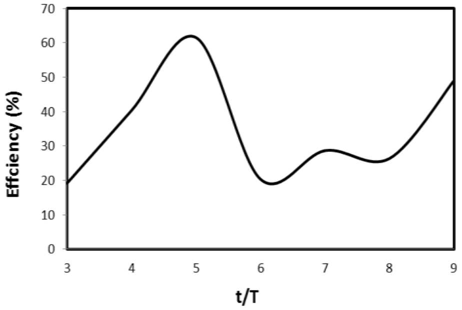

Figure (4): Variations of efficiency of energy absorption by the Bristol cylinder

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