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Research paper

Study on Wave Energy Generation of Multi-Floating Bodies for Energy Absorption by CFD

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Abstract : In order to design a wave energy generating system, a 6-DOF analysis technique is applied to CFD analysis on of a floating body and the behavior is interpreted according to the nature of the incoming waves. A spring constant is adopted to control the motion of multi floating bodies and to calculate the total average power absorption. Three cases of different wavelengths namely 20D, 30D and 40D have been modeled to analyze the total average power absorption. The average power absorption not only varies with the position of the floating body but also varies with wavelength. From the results obtained, it is concluded that the maximum total average power absorption is 9W approximately in wavelength 30D and the minimum total average power absorption is 4.3W approximately in wavelength 40D.

Key Words : Multi-floating Bodies, Spring Constant, Wave Energy, Power Absorption, CFD Magnetic

— Nomenclature —

A : Wave amplitude [m]
E : Energy absorption [J]
F : Force [N]
g : Gravity $[m/s^2]$
h : Water depth [m]
k : Wave number [rad/m]
k_{Rotate} : Rotational spring constant [N m/rad]
k_{Spring} : Linear spring constant [N/m]
L : Floater length [m]
M : Torque [N m]
m : Mass [kg]
P : Power [W]
p : Pressure [Pa]
r : Floater radius [m]
S_M : Source term
U : Velocity [m/s]
u_i : u velocity component [m/s]
v_i : v velocity component [m/s]
y : Water height [m]

Greek Symbols

ρ : Density $[kg/m^3]$
τ : Shearing stress [Pa]
ω : Circular frequency [rad/s]
θ : Angle [rad]

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1. Introduction

The demand for renewable energy sources in the world are growing with the depletion of fossil fuel supply as well as the environmental concerns of global warming. Renewable energy sources are of different kinds and ocean wave energy sources are one among them. The earth is covered with two thirds of water and therefore this energy source is considered as a permanent source. It has a tremendous amount of untapped energy left in it.

The global theoretical energy from waves corresponds to 8×10^6 TWh/year, which is about 100 times the total hydroelectricity generation of the whole planet[1]. Energy can be extracted from the oceans in the form of a Wave Energy Converter (WEC), and among the converters proposed, the Pelamis WEC is a notable one[2]. It is a long elongated body of cylindrical sections joined by hinges, which, when in motion with the waves drives a hydraulic motor. These motors drive the electrical generators, thus producing electricity. Different from other WEC converters, the Pelamis is designed to collect the wave kinetic energy horizontally (sidewise) and vertically (up and down). The kinetic energy of pitch and yaw motions are the most important variables in designing floating type systems to generate electricity.

In order to design a large-scale system like the Pelamis type in the ocean, we need to study the motion of a floater, which is effected by wave characteristics, as well as to study how much energy can be captured by the floater, thus, necessitating for an optimal design of the floating type WEC. In this paper, we focus on multi floating bodies to analyze the energy absorption capabilities of each floating bodies separately based on the research of Li etc.[3-5]. It is modeled as shown in Fig. 1. Four long floating bodies are connected by three hinges (Close-up picture) in order to describe the power generation process.

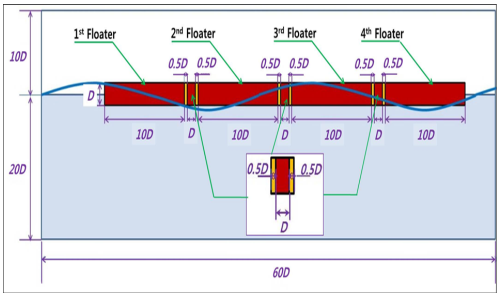


Fig. 1 Modeling of multi floating bodies.

2. Numerical analysis

2.1 Governing equation

The governing equations are given by equations (1) and (2). A description about them can be had from[6].

Continuity Equation:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho U) = 0 \tag{1}$$

Momentum Equation:

$$\frac{\partial (\rho U)}{\partial t} + \nabla \cdot (\rho U \otimes U) = -\nabla p + \nabla \cdot \tau + S_M \tag{2}$$

2.2 Rigid body equation

The translational equation of motion 6) is given by

$$m\ddot{x} = F \tag{3}$$

where m is the mass and F represents the sum of all forces which include aerodynamic forces, weight of the rigid body, spring and/or explicit external force.

$$F = F_{Aero} + mg - k_{Spring}(x - x_0) + F_{Ext} \tag{4}$$

where, F_{Aero} is the aerodynamic force, g is the gravity, k_{Spring} is the linear spring constant and F_{Ext} is all other external forces acting on the body. The rotational equation of motion [6)] is given by

$$\dot{\theta}\times\dot{\theta}+\dot{I}\dot{\theta}=M \qquad (5)$$

where I is mass moment of inertia matrix.

$$M=M_{Aero}-k_{Rotate}(\theta-\theta_{SO})+M_{Ext} \qquad (6)$$

where M_{Aero} is the aerodynamic torque, k_{Rotate} is the rotational spring constant and M_{Ext} is all the other external torques acting on the body.

3. Boundary and analysis conditions

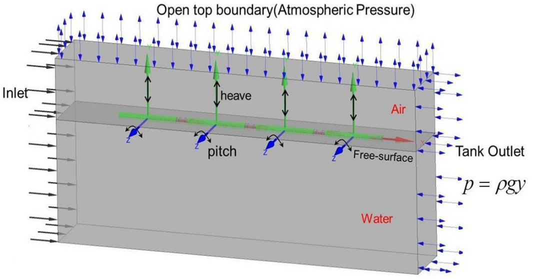


Fig. 2 Computational domain and boundary conditions

Fig. 2 shows the computational domain of a model tank. The top is left open which is considered as atmospheric pressure. The outlet static pressure in water depth is $p=\rho gy$. The bottom is considered as a wall with no-slip conditions and the side walls are considered as free slip conditions.

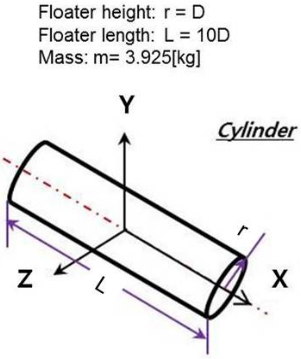
The velocity components are considered as inlet in the left wall which is given by equations (7) and (8)[7)].

$$u_i=\frac{gAk}{\omega}\frac{\cosh(k(y+h))}{\cosh(kh)}\cos(kx-\omega t) \qquad (7)$$

$$v_i=\frac{gAk}{\omega}\frac{\sinh(k(y+h))}{\sinh(kh)}\sin(kx-\omega t) \qquad (8)$$

where, g is gravity, A is wave amplitude, ω is circular frequency, k is the wave number, h is water depth, y is the water height, and $\omega=\sqrt{gk\tanh(kh)}$ is the dispersion relation.

The four floaters constitute a long floating body, one such is shown in Fig. 3.



$$I_z=\frac{m(L^2+3r^2)}{12}$$

Fig. 3 Rigid Body definition

4. Results and discussion

The linear spring constant k_{Spring} (Eq. (9)) and rotational spring constant k_{Rotate} (Eq.(10)) [6, 8)] are adopted to control the heave and pitch motions, where ρ_w is water density, g is gravity, L is floater length and r is the radius.

$$k_{Spring}=2\rho_w gLr \qquad (9)$$

$$k_{Rotate}=\rho_w gr\frac{L^3}{6} \qquad (10)$$

Energy absorption due to pitch motion of the floating body stored in a torsion spring is given by [8)]

$$E=\frac{1}{2}k_\theta\theta^2 \qquad (11)$$

where, θ is the angle of twist from its equilibrium position in radians.

Then, the power absorption is

$$P = \lim_{\Delta t \to 0} P_{avg} = \lim_{\Delta t \to 0} \frac{\Delta E}{\Delta t} = \frac{dE}{dt} \tag{12}$$

Here, three cases of different dimensionless wavelengths of 20D (D=0.1m), 30D and 40D and a wave height of 0.2D were simulated using CFD. Since the wave power density is relatively small in shorter wave lengths, the cases of wavelength less than 20D were not considered. When the wavelengths become larger, the energy density also becomes larger which takes a relatively longer period of wave propagation. This reduces the power generating efficiency for floating bodies. Hence the range between 20D and 40D was chosen as a reasonable range.

An example of the motion of multi floating bodies in waves is shown for the case of wavelength 20D in Fig. 4. It also can be seen from Fig. 5 that the motion of multi floating body changes with time step.

Fig. 6 shows that the rotational power absorption in time step when wavelength is 20D. It can be seen that minimum power absorption is approximately 0.06W for the 3rd floating body, and the maximum power absorption is approximately 0.3W for the 4th floating body.

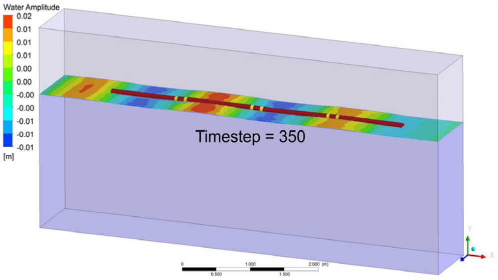


Fig. 4 An example of multi floating body motion in 350th time step (wavelength = 20D)

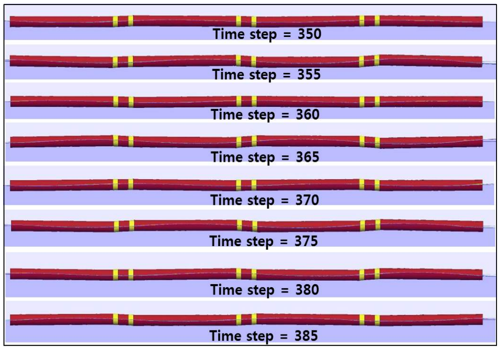


Fig. 5 Motion of Multi floating bodies in time step for wavelength of 20D

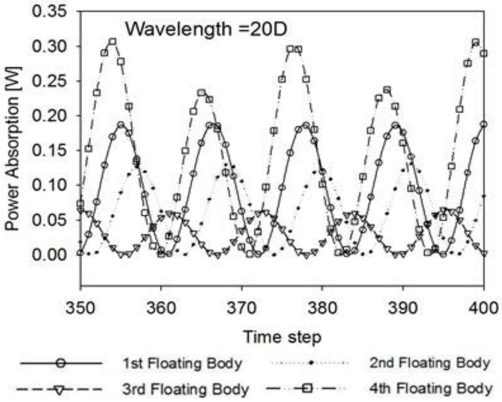


Fig. 6 Power absorption in time step

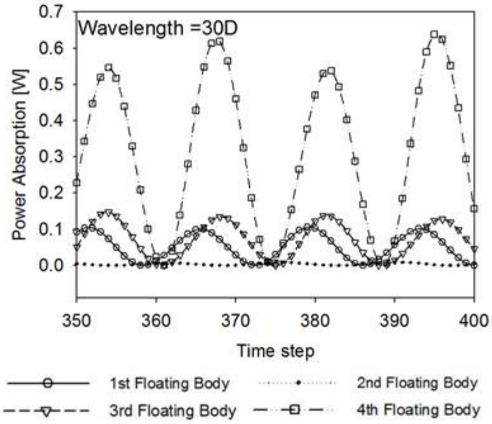


Fig. 7 Power absorption in time step

Fig. 7 shows that the rotational power absorption in time step when wavelength is 30D.

It can be seen that minimum power absorption is approximately 0.01W for 2nd floating body, and the maximum power absorption is approximately 0.6W for the 4th floating body.

Fig. 8 shows that the rotational power absorption in time step when wavelength is 40D. It can be seen that minimum power absorption is approximately 0.01W for the 1st floating body, and the maximum power absorption is approximately 0.25W for the 2nd floating body.

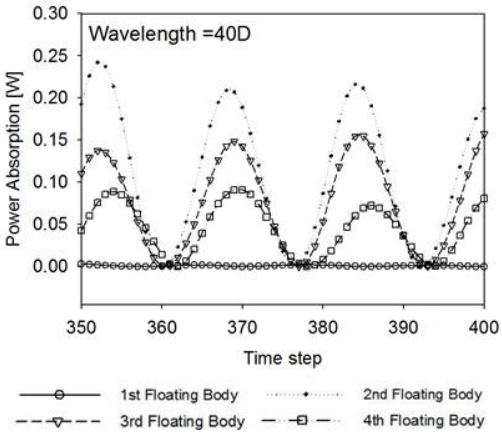


Fig. 8 Power absorption in time step

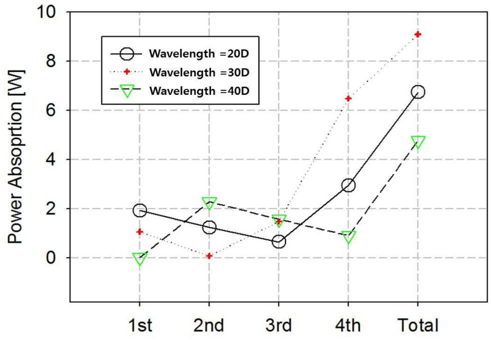


Fig. 9 Power absorption comparison in wavelength of 20D, 30D and 40D for each floating body and total average power absorption

Fig. 9 shows the comparison of the total and average power absorption for each floating bodies in the three wavelengths. For the 1st floating body, the highest average power absorption is approximately 2W when the wavelength is 20D and is the lowest when wavelength is 40D. For the 2nd floating body, the highest average power absorption is approximately 2.1W when the wavelength is 40D and is the lowest when wavelength is 30D. For the 3rd floating body, the highest average power absorption is approximately 1.9W when the wavelength is 30 and 40D and is the lowest when wavelength is 20D. For the 4th floating body, the highest average power absorption is approximately 6.2W when the wavelength is 30D and is the lowest when wavelength is 40D.

The highest total power absorption for multi floating body is approximately 9W when the wavelength is 30D, and the lowest total power absorption is approximately 4.3W when the wavelength is 40D.

5. Conclusions

Spring constant is adopted to control the motion of multi floating bodies and to calculate the total average power absorption. Three dimensionless wavelengths of 20D, 30D and 40D have been modeled to analyze the total average power absorption. The average power absorption varies with both the position of floating body and wavelength. The results obtained shows that the maximum and minimum total average power absorption is 9W and 4.3W approximately in wavelength 30D and 40D respectively.

Acknowledgement

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