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Numerical Modeling of Regular Wave Tank

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Abstract**: *Wave energy is the potential source for the generation of electricity for the Industrial, Irrigational and Domestic needs. Wave energy converters (WEC's) transform the tidal energy into electrical energy. Optimum design of WEC's depends on the wave hydrodynamic characteristics acting on it. In this paper, a 2D numerical wave flume is developed using linear wave theory. Simulation of a regular wave is carried to understand the wave parameters along the flume length due to artificial beach treatment. The equation of continuity and momentum are the governing equations for incompressible fluid motion, the standard k-ε model is considered for solving the turbulence of RANS equations. A two-phase model (VOF) is applied for determining the surface containing 50% of water. Validation of the model is done by using the analytical theory. Generation of linear waves is in good agreement with the analytical results.***

Index Terms**: *k-ε model, Multiphase model (VOF), Numerical wave tank, Regular waves***

I. INTRODUCTION

Recent papers have called for improving the efficiency of tidal current energy development all over the world [1]. Tidal energy converts into mechanical energy and thereby to electrical energy without the emission of greenhouse gases [2]. Physical model tests in marine laboratories have their own problems such as lack of equipment, expensive instrument and also a time-consuming process [3]. For the reliability of model performance of wave energy converter, wave hydrodynamics and the wave-structure interaction studies are to be compared with laboratory and analytical results [4]. Numerical wave tank is an essential part of studying wave structure interaction and recently have been used especially in modeling wave energy converters [5]. Predicting wave energy converters efficiency and their response to wave loads are strictly dependent on good modeling of wave behavior and its hydrodynamic characteristics [6]. Based on the unsteady two-dimensional RANS, different incident waves are generated [7].

The Volume of Fluid technique can capture the free surface containing 0 to 100 % of water present in the cells [8]. In simulation to absorb the reflected wave from the exit boundary, coefficients in the damping functions must be adjusted to the wave parameters. In this paper, simulation of regular waves is done by linear theory [9] for constant water depth, horizontal seabed, 3 wave heights and 4 wave periods. The multiphase model VOF is used for tracking the free surface. Dissipation of incident waves reaching the outlet has been reduced by using coefficients in beach treatment. Regular waves are calculated and validation of the model is done using analytical theory in MATLAB. From the observations, the calculated wave heights and velocity profiles observed from the simulation are in good agreement with the analytical values.

II. METHODOLOGY

The governing equations used are the vertical two-dimensional equations describing the conservation of mass and momentum. The standard k-ε model is used for turbulence closure of Reynolds Averaged Navier Stokes (RANS) equations

The equation of continuity is represented as,

$$\frac{\partial u_i}{\partial x_i} = 0$$

The equation of momentum as shown below

$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = g_i - \frac{1}{\rho}\frac{\partial p}{\partial x_i} + \frac{\partial \tau_{ij}}{\partial x_j} \quad (2)$$

And the k-ε equations are represented as,

$$\frac{\partial k}{\partial t} + u_j \frac{\partial k}{\partial x_j} = \frac{\partial}{\partial x_j}\left[\left(\frac{\upsilon_t}{\sigma_k} + \upsilon\right)\frac{\partial k}{\partial x_j}\right] - G - \varepsilon + \eta_k F_i u_i$$

$$\frac{\partial \varepsilon}{\partial t} + u_j \frac{\partial \varepsilon}{\partial x_j} = \frac{\partial}{\partial x_j}\left[\left(\frac{\upsilon_t}{\sigma_\varepsilon} + \upsilon\right)\frac{\partial \varepsilon}{\partial x_j}\right] -$$

$$C_{1\varepsilon}\frac{\varepsilon}{k}G - C_{2\varepsilon}\frac{\varepsilon^2}{k} + C_{1\varepsilon}\frac{\varepsilon}{k}\eta_k F_i u_i$$

$$\tau_{ij} = 2(\upsilon + \upsilon_t)\sigma_{ij} - \frac{2}{3}k\sigma_{ij}$$

$$\upsilon_t = C_\mu \frac{k^2}{\varepsilon}$$

$$G = 2\upsilon_t \sigma_{ij}\frac{\partial u_i}{\partial x_j}$$

$$\sigma_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)$$

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$$\frac{\partial(F)}{\partial t}+\frac{\partial(u\ F)}{\partial x_i}=0$$

Where, i = 1, 2; j = 1, 2

A function F is introduced which indicates the fraction of a mesh cell that is filled with water. The function of F is governed by equation (9). If F=1, the cell is full of water; F=0 the cell is full of air and if F is in between 0 and 1, the cell must be surface cell.

The governing equations are discretized using finite difference scheme. For solving convection terms hybrid difference scheme i.e., combination of 2nd order centered difference scheme with 1st order upwind difference scheme is used. Viscosity and diffusion terms are solved using 2nd centered order difference scheme. A pressure-velocity coupling method PISO is used. A computation domain of x= 45 m, y= 1.2 m, mesh size of *dx* = 0.04 m and *dy* =0.04 m with time step size of 0.01 s and simulation period of 20 seconds is considered for all the cases. For convergence of the solution the value of order 10-6 is considered. For wave simulation, boundary conditions considered on the left side of the domain is velocity inlet condition (Table1), for avoiding reflections from the right side exit boundary beach treatment is provided to damp the waves. At the top of the domain pressure outlet condition and bottom of the domain no-slip wall condition is considered and represented in Fig.1

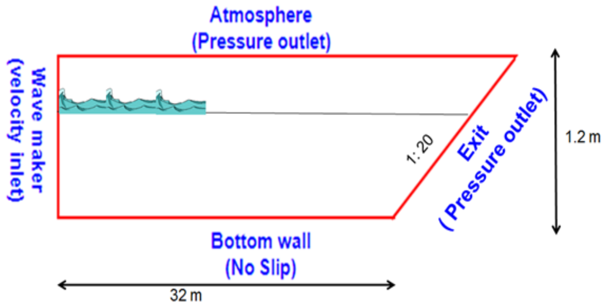

Fig.1 Two Dimensional Computation Domain

Table 1: Input Values in Velocity Inlet Condition

Water depth (d) (m)	*Wave height (H) (m)*	*Time period (T) (s)*
0.5	0.05	1.5
0.5	0.05	2.0
0.5	0.05	2.5
0.5	0.05	3.0
0.5	0.1	1.5
0.5	0.1	2.0
0.5	0.1	2.5
0.5	0.1	3.0
0.5	0.15	1.5
0.5	0.15	2.0
0.5	0.15	2.5
0.5	0.15	3.0

III. RESULTS

(7)

Water surface elevations (η)

The numerical model is verified with the analytical theory. Coding of the free surface profile of airy theory is done in MATLAB. The wave profile generated at the wave maker end is validated with the analytical theory. Reflections from the outlet are dissipated by using the beach treatment and the model is free from the reflection of an incident wave. Fig.2 shows the wave profiles of the model and analytical theory for different wave heights (H=0.05, 0.1 and 0.15 m) and a time period of 3 seconds. The water surface elevations measured at 7.2 m from the left side of the domain are as shown in the Fig.3. H5T1.5MOD represents a wave height of 0.05 m with awave period of 1.5 s model results, similarly for 0.10 m and 0.15 m.

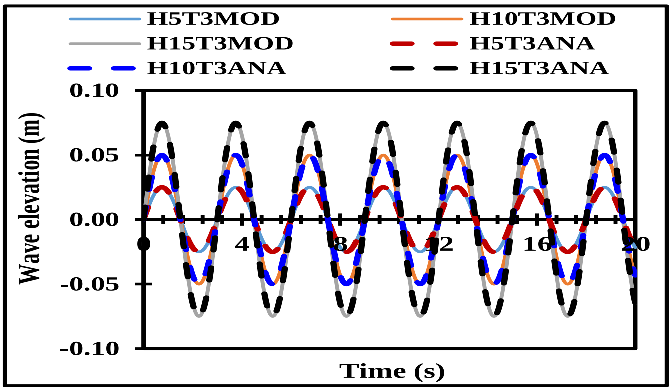

Fig.2 Wave profiles for different wave heights (H=0.05, 0.1 and 0.15 meters) & T= 3 seconds.

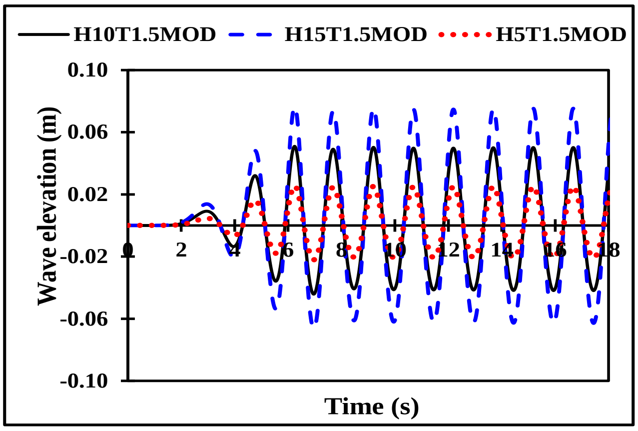

Fig.3Wave profiles for different wave heights (H=0.05, 0.1 and 0.15 meters) & T= 1.5 seconds.

A. Velocity profiles

The velocity profile obtained from the model is validated with the analytical theory. The velocity profiles are taken at 7.2 m at 20 seconds as shown in the following figures. Fig.4 shows the velocity profiles for different wave heights (H=0.05 m, 0.10 m, 0.15 m) and a wave period of 1.5 seconds. H5T1.5ANA represents a wave height of 0.05 m with a wave period of 1.5 s analytical results. H5T1.5MOD represents a wave height of 0.05 m with a wave period of 1.5 s model values.

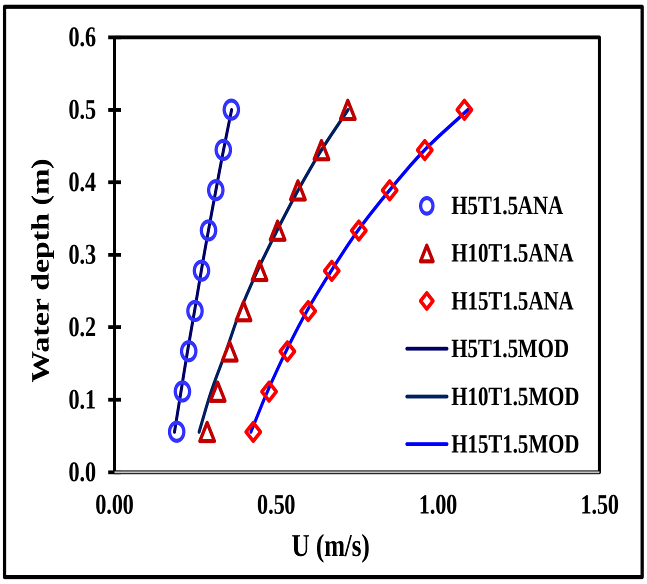

Fig.4: Velocity profiles for different wave heights (H=0.05, 0.1 and 0.15 meters) & T= 1.5 seconds.

IV. CONCLUSION

Regular waves were analyzed using linear wave theory in a numerical wave flume of length 45m, depth of 1.2 m for three wave heights i.e., 0.05 m,0.10 m, 0.15 m and four-wave periods (1.5 s, 2 s, 2.5 s, 3 s) with horizontal seabed condition. Time series of free surface levels are taken at every 5 m interval and compared with analytical values. Water surface elevations measured are in good agreement with the analytical data. Therefore this model is capable of producing regular waves of required wavelength and wave period. Velocity profile pattern of the model shows the logarithmic distribution and is in good agreement with the analytical data. Therefore this model is capable of flow simulation. Based on the observations this model can be used to do computational modeling for regular wave-structure interaction where it is needed to generate regular waves of required wave height and wave period

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