Scholar Publishing Group
Frontiers in Ocean Engineering
https://doi.org/10.38007/FOE.2020.010204
ISSN 2790-2706 Vol. 1, Issue 2: 25-32

Monitoring of Marine Engineering Hydrodynamic Environment Based on Numerical Simulation

Rizenwan Jalali*

Bangladesh University of Engineering and Technology, Bangladesh

**corresponding author*

Keywords: Numerical Simulation, Ocean Engineering, Hydrodynamic Force, MIKE 21

Abstract: Hydrodynamic problems exist widely in offshore and offshore engineering, which is one of the important factors affecting the safety of people's life and property and production facilities. However, the complexity and variability of the actual engineering sea state bring great difficulties to the study of the related hydrodynamic problems. This paper first analyzes the basic principle of hydrodynamic module. MIKE21 platform was used to establish the small-scale component structure and large-scale panel structure, and a reasonable numerical model was established. The simulation results SHOW THAT THE HYDRODYNAMIC characteristics OF tidal flat area change obviously under the action of ocean engineering, and the influence of ocean engineering on hydrodynamic conditions is closely related to wind direction.

1. Introduction

Hydrodynamic problems are closely related to human life, such as the influence of engineering structures on flow fields and the interaction between waves and breakwaters [1]. In recent years, as the number of cross-sea Bridges, undersea tunnels and ports and wharfs increases year by year, the construction conditions of offshore projects are more complex, so the importance of research on hydrodynamic problems is becoming increasingly prominent [2-3]. In order to solve this kind of problems, there are mainly theoretical research, experimental simulation and numerical simulation. Among them, theoretical research often has many simplifications and assumptions, which makes it difficult to deal with complex hydrodynamic problems, while experimental simulation is often limited by sites and equipment, and requires high economic costs, as well as more complex setup and operation [4-5]. In recent decades, with the progress of partial differential equation solving algorithms and the development of computer performance, relatively low-cost numerical simulation has become a widely used research method [6].

Numerical simulation of shallow water dynamics can be traced back to the middle and late 19th century. In the 21st century, some scholars established a two-dimensional numerical model of the Gironde Estuary in France, in which the optimized finite element numerical calculation was used to simulate the tidal evolution within 10cm of the predicted water level accuracy [7]. The research and application of two-dimensional hydrodynamic models have successfully solved many practical problems, and also developed from simple simulation of water flow movement to simulation of pollutant diffusion, transport and seawater intrusion. In China, the numerical simulation of estuarine nearshore hydrodynamic forces began in the 1970s. Because the electronic computer has the characteristics of large storage capacity, high computing speed and high accuracy and the constant development of estuary dynamics, the trend of mathematical models for numerical simulations of estuary and coastal hydrodynamics has become more and more common in our country, and is gradually trusted in engineering [8]. On the whole, in the 1970s, the calculation of estuarine tidal current was mainly based on one-dimensional model [9]. In the 1980s, while one-dimensional power flow calculation was widely applied, two-dimensional power flow mathematical model was also mostly adopted [10]. In addition, according to the needs of different regions, the transport modules of sediment, pollutants, warm salt and other substances are also added into the hydrodynamic simulation [11]. 3D models have also been gradually applied, and some very valuable research results have been achieved [12].

In this paper, related research is carried out based on numerical simulation, and different types of hydrodynamic problems are solved quickly, and the calculation results are compared and analyzed with the corresponding experimental results. This paper aims to expand the application of numerical simulation in offshore engineering, provide new ideas and methods for solving traditional hydrodynamic problems, and realize real-time prediction of hydrodynamic characteristics, which has relatively important research significance.

2. Numerical Simulation of Hydrodynamics in Marine Engineering by MIKE 21

2.1. Basic Principle of Hydrodynamic Module

The most commonly used governing equation for hydrodynamic models is the Reynolds mean Navier-Stokes equation (RANS equation) [13]. The original RANS equation was three dimensional. Due to the limitation of computer technology, the original 3D RANS equation is difficult to solve. In order to effectively simplify the original RANS equation, one-dimensional, planar, vertical two-dimensional and three-dimensional hydrodynamic models are established [14]. It is usually realized by dimensional analysis under the assumption of engineering practice and theoretical research. Compared with the hydrodynamic model established by solving the three-dimensional problem, the computation amount of one-dimensional equations is greatly reduced [15]. However, the one-dimensional and two-dimensional models are only applicable to flood waves and tidal waves in rivers and narrow channels [16].

The influencing factors of the hydrodynamic model mainly include the determination of bed roughness, the definition of dry and wet water depth, the assignment of density, eddy viscosity coefficient, Coriolis force, and the formulation of initial and boundary conditions [17]. The factors are described as follows:

(1) Dry and wet water depth

The MIKE 21 model adopts the dynamic boundary treatment method to solve the problem of continuous outcropping. The water depth value of each unit is calculated by the model, and according to the calculated water depth, each unit is divided into three types: dry unit, semi-dry and semi-wet unit, and wet unit. Then the water boundary is determined and calculated based on the distribution of semi-dry and semi-wet unit [18].

(2) Density

The variation of water density in the model depends on the temperature and salinity of the water body. Under the positive pressure model, the temperature and salinity of the water body are constant, and its density is generally assumed to remain constant during the model operation. In baroclinic mode, the temperature and salinity of water body will change, and its density can be defined as a function of salinity and temperature in the process of model operation. Among them, water temperature can interact with atmospheric temperature through heat exchange. The calculation of heat exchange process mainly considers latent heat, sensible heat, short wave radiation and long wave radiation. Latent heat is the heat exchange caused by evaporation of water, which is calculated by Dalton's evaporation theorem. Sensible heat process includes convective heat transfer between water and air, which requires setting atmospheric temperature and humidity conditions. Both short-wave and long-wave radiation are important branches of solar radiation, which are generally calculated by empirical formula in MIKE 21 model.

(3) Eddy viscosity coefficient

The eddy viscosity coefficient describes the physical process of uncertainty in time and space, and the relevant predictor variables are decomposed into an average term and a turbulent term. When the definition of vortex-viscosity coefficient is introduced, these physical processes can be reflected by the gradient of vortex-viscosity coefficient and the mean term.

Generally, the horizontal eddy viscosity coefficient has three assumed forms: no vortex, time-invariant eddy viscosity formula and Smagorinsky formula. Among them, Smagorinsky's formula is:

$$A = C_s^2 l^2 \sqrt{2S_{ij}S_{ij}} \tag{1}$$

$$S_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)(i, j = 1,2) \tag{2}$$

Where, A is the eddy viscosity coefficient; Cs is the eddy viscosity constant; L is the characteristic length; Sij is the deformation length.

(4) Roughness of bed bottom

According to the four-part law of friction, the friction at the bottom of the bed can be expressed as:

$$\tau_b = c_f \bar{u}_b \,|\, \bar{u}_b \,|\, \rho_o \tag{3}$$

Where, τb is the bottom bed friction force; Cf is the drag force, which can be determined by Xie CAI coefficient or sum Manning coefficient; Ub is the average depth velocity; ρ0 is the density of water.

(5) Cor force

Coriolis force in the model mainly refers to the linear motion offset of water body due to inertia caused by the rotation of the earth. The calculation formula is as follows:

$$F = -2m\omega \times V \tag{4}$$

Where, F is Coriolis force; M is the mass of the particle; V is the motion velocity of the particle in the relative rotating reference frame, ω is the angular velocity (vector) of the rotating system; X is the sign of the cross product of two vectors.

(6) Initial conditions

When the model starts to calculate, the water level and the flow field need to coordinate with each other. In order to avoid the instability of calculation, the measured data are generally taken as the initial value. The initial conditions of the model include: the initial water level of the calculation area, the flow rate of the water body, etc.

(7) Boundary conditions

In the hydrodynamic module, the boundary conditions are divided into land boundary and open boundary. The land boundary also includes the land boundary with zero vertical velocity but slip, and the land boundary with zero velocity and non-slip in all directions of the boundary. The open boundary includes four types: velocity boundary, flux boundary, water level boundary and discharge boundary.

2.2. Construction of Hydrodynamic Model for Wind Farm

MIKE21 software is a hydrodynamics and water quality simulation software developed by the Danish Hydrodynamic Research Institute (DHI). Due to its simple interface, wide application, mature data processing system and environmental assessment platform, it has been favored by more and more scholars and companies. At present, the software is mainly used to simulate the water environment in estuaries, bays and coastal areas of the ocean. It can also be used to simulate the hydrodynamic characteristics of tides, wind/wave generated current, secondary circulation, channel, dam break, port engineering, tsunami and other aspects. On the basis of simulating two-dimensional unsteady flow, it can also be coupled with wet and dry change, density change, underwater topography, tidal change and other influencing factors of meteorological conditions. MIKE21 software uses finite volume method to solve the original governing equations. This method combines the advantages of finite element method to deal with complex boundary with the advantages of finite difference method to achieve high computational efficiency, which ensures that the conservation of mass can be met simultaneously in a single grid and the whole computational area. The dry and wet grid discriminating technique is used for the moving boundary condition, which can well adapt to the dynamic boundary problem of tidal fluctuation in the estuary.

The far point of the coordinate system selected in this paper is located at the sea level, and the Z-axis is vertically upward, which coincides with the center of the tower. The XY plane coincides with the sea level, and the coordinate origin is located at the central column of the cage.

(1) Model modeling method

The numerical model tool used for the study is MIKE 21, which is mainly used for the analysis of the hydrodynamic and wind loads of the platform structure. Wind power fishery comprehensive platform facilities include two kinds of structures, one is small component structure, the other is large panel structure. Based on Morison equation, the wave load is simplified to drag force and inertia force acting on the structure. In addition, the boundary element method based on potential flow theory is applied to large plate structures. The combination of these two different scale structures, the small-scale component structure and the large-scale panel structure, allows the simulation and analysis of the hydrodynamic response of a semi-submersible aquaculture facility. This method avoids a large number of calculations using only unified surface elements, and the results of calculations using only Morison cells are not accurate.

(2) Grid division

Considering the topographic map accuracy, simulation calculation time, and the actual boundary of reed land, village and Amylan district, this study adopts triangular mesh to divide the calculation domain through the grid generator provided by MIKE software. The terrain fluctuation of the region is relatively gentle. Considering the wide simulation area of this study, the comprehensive simulation accuracy, calculation time, software performance and other factors, it is determined that the grid side length is controlled within 150m and the area is controlled within 22,000 m2. After multi-level encryption, the mesh side length is controlled within 30m and the area is controlled within 400m2. After encryption, there are 32,358 grid units and 18,641 grid nodes. In order to improve the calculation speed, the mesh is smoothed and the mesh Angle is optimized.

(3) Environmental parameters

The simulated water depth was 2m, and the water density and gravity acceleration were 1032kg/m ^{3} and 9.4m/ S2, respectively. The wave direction ranges from -180 ° to 180 ° with 60 ° intervals. At the same time, it is established according to the size of the test model. The draft of the model is 38cm. The design conditions are shown in Table 1:

Table 1. Numerical model test design condition

Serial number	Wave height(m)	Cycle(s)
1	0.2	1.1
2	0.2	1.3
3	0.2	1.5
4	0.2	1.7

3. Algorithm Simulation Experiment

In this paper, MIKE21 hydrodynamic model was used to simulate and analyze the variation law of water flow in wetland area under the action of wind farm near the coast. Wetland tidal flat area tidal ditch crisscross distribution, the terrain is very complex. In order to achieve more accurate simulation effect, the grid of tidal flat area is encrypted. The encrypted calculation domain of the Liaohe estuary model includes 22015 triangular elements, the number of grid nodes is 10942, and the minimum space step of the grid in the tidal flat area is 100 meters.

In order to determine the rationality of the model parameters, the validity of the model is verified by comparing the simulated data with the measured data. In this simulation, two stations were selected to verify the model. Point 1 was used to verify the flow rate and water depth, and point 2 was used to verify the water depth.

4. Analysis of Experimental Results

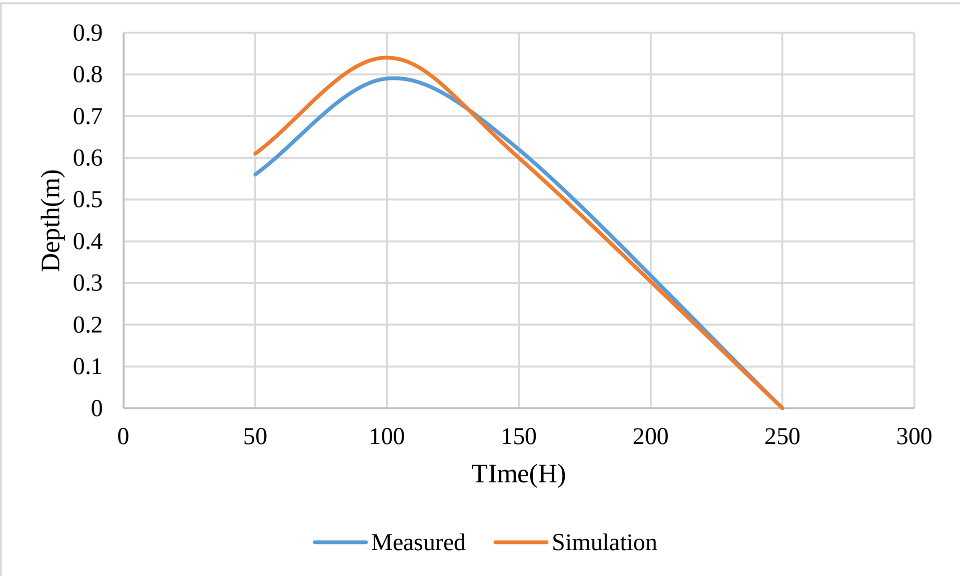

Figure 1. Comparison of water depth simulation and measurement at site 1

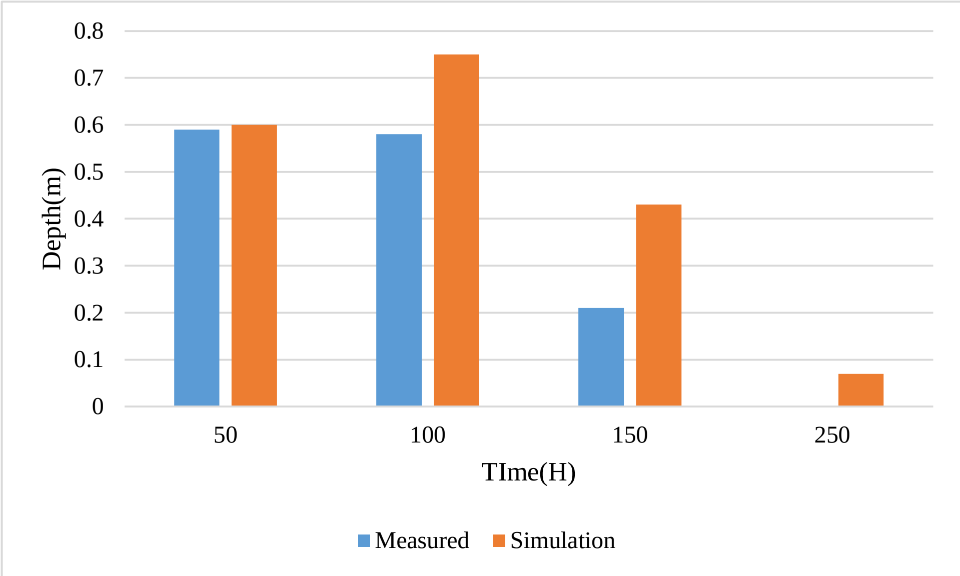

Figure 2. Comparison of measured and simulated data at site 2

As shown in Figure 1 and Figure 2, in order to verify the comparison between simulated and measured water depth data, it can be seen from the figure that the simulated water depth data at point 1 is about 0.05m smaller than the measured data. The simulated data of water depth at point 2 is slightly larger than the measured data, with an error of about 0.21m.

Table 2. Comparison of velocity simulation and measurement

	20(min)	60(min)	120(min)	180(min)
Measured	0.16	0.07	0.13	0.12
Simulation	0.12	0.09	0.14	0.11

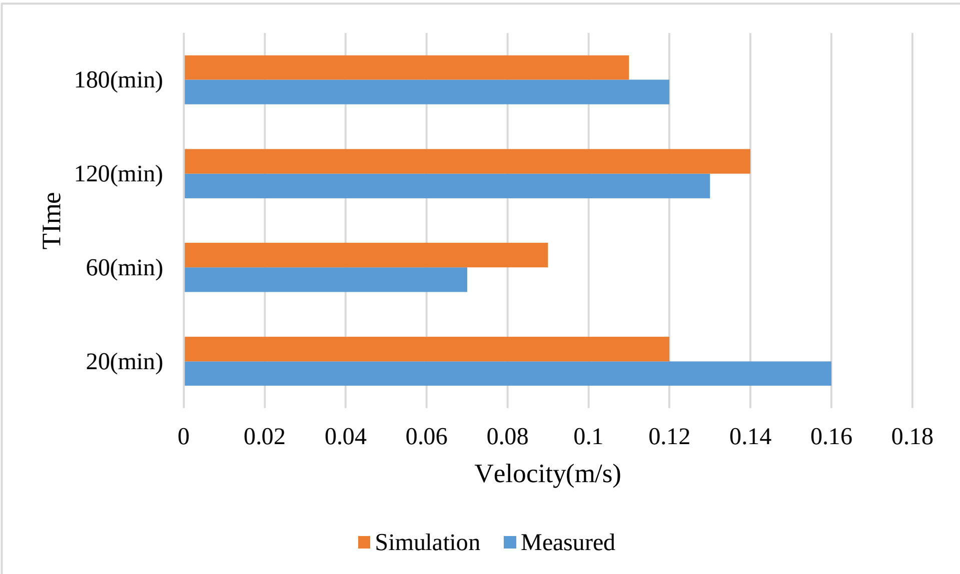

Figure 3. Schematic diagram of comparison between velocity simulation and measurement at point 1

As shown in Table 2 and Figure 3, the simulation and measured data of validated flow velocity are compared. It can be seen from the data in the chart that the velocity data are consistent with each other, with only an error of about 0.04m/s. Through analysis, it is found that the error between the numerical simulation and the measured values is caused by the fact that the measured points are close to the coast, and the terrain given in the model calculation is not accurate enough. In addition, the accuracy of open boundary extraction data may be insufficient and the complex water environment of the estuary may also cause errors.

5. Conclusion

With the rapid development and large-scale application of numerical simulation technology, the demand of numerical simulation system integrating modeling, numerical calculation and visual analysis becomes increasingly strong. The Marine wind power farm construction project is a huge project, and the Marine hydrodynamic environment will be affected to some extent after the Marine pile foundation is laid. In the environmental impact assessment of the project, the researchers need to analyze the hydrodynamic field of the project area, and further analyze the impact of the project construction on the study sea area. In this paper, MIKE21 numerical simulation software was used to carry out numerical simulation of the hydrodynamic field before and after the construction of offshore wind power project.

Funding

This article is not supported by any foundation.

Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of Interest

The author states that this article has no conflict of interest.

References

[1] Hnel E , Ziegler F . Analytical approach and numerical simulation of hydrodynamic forces in immersion optics. Journal of Applied Physics, 2020, 128(4):044502. https://doi.org/10.1063/5.0013381

[2] Melnikova V G , Kotsur O S , Shcheglov G A . Numerical simulation of the flow rate regulator valve using OpenFOAM. Proceedings of the Institute for System Programming of RAS, 2017, 29(1):53-70. https://doi.org/10.15514/ISPRAS-2017-29(1)-4

[3] Lee C A , Kong Q , Paeng D G . Depletion-model-based numerical simulation of the kinetics of red blood cell aggregation under sinusoidal pulsatile flow. Biorheology, 2018, 1(1):1-13. https://doi.org/10.3233/BIR-170147

[4] Ong M C , Kamath A , Bihs H , et al. Numerical simulation of free-surface waves past two semi-submerged horizontal circular cylinders in tandem. Marine Structures, 2017, 52(mar.):1-14. https://doi.org/10.1016/j.marstruc.2016.11.002

[5] Ali, Nasrollahi, Ali, et al. Numerical simulation of incipient particle motion. International Journal of Sediment Research, 2020, v.35(01):5-18. https://doi.org/10.1016/j.ijsrc.2019.07.006

[6] Ouchene R . Numerical simulation and modeling of the hydrodynamic forces and torque acting

on individual oblate spheroids. Physics of Fluids, 2020, 32(7):073303. https://doi.org/10.1063/5.0011618

[7] Najafi S , Abbaspoor M . Numerical investigation of flow pattern and hydrodynamic forces of submerged marine propellers using unsteady boundary element method:. Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment, 2019, 233(1):67-79. https://doi.org/10.1177/1475090217717174

[8] Boghi A , Russo F , Gori F . Numerical simulation of magnetic nano drug targeting in a patient-specific coeliac trunk. Journal of Magnetism & Magnetic Materials, 2017, 437(sep.):86-97. https://doi.org/10.1016/j.jmmm.2017.04.055

[9] Gontijo R G , Cunha F R . Numerical simulations of magnetic suspensions with hydrodynamic and dipole-dipole magnetic interactions. Physics of Fluids, 2017, 29(6):141-157. https://doi.org/10.1063/1.4986083

[10] Suzuki R , Ueno M , Tsukada Y . Numerical simulation of 6-degrees-of-freedom motions for a manoeuvring ship in regular waves. Applied Ocean Research, 2020, 113(17–18):102732.

[11] Kermani M S , Jafari S , Rahnama M , et al. Direct pore scale numerical simulation of colloid transport and retention. Part I: Fluid flow velocity, colloid size, and pore structure effects. Advances in Water Resources, 2020, 144(1):103694. https://doi.org/10.1016/j.advwatres.2020.103694

[12] Javid K , Ali N , Asghar Z . Numerical Simulation Of The Peristaltic Motion Of A Viscous Fluid Through A Complex Wavy Non-Uniform Channel With The Magneto-Hydrodynamic Effects. Physica Scripta, 2019, 94(11):115226. https://doi.org/10.1088/1402-4896/ab2efb

[13] Pawar R , Bhar A , Dhavalikar S S . Numerical prediction of hydrodynamic forces on a moored ship due to a passing ship. Proceedings of the Institution of Mechanical Engineers Part M Journal of Engineering for the Maritime Environment, 2018(4):147509021877003. https://doi.org/10.1177/1475090218770039

[14] Sheikholeslami M , Zeeshan A . Numerical simulation of Fe_30_4-water nanofluid flow in a non-Darcy porous media. International journal of numerical methods for heat & fluid flow, 2018, 28(3):641-660. https://doi.org/10.1108/HFF-04-2017-0160

[15] Mottahedi H R , Anbarsooz M , Passandideh-Fard M . Application of a fictitious domain method in numerical simulation of an oscillating wave surge converter. Renewable Energy, 2018, 121(JUN.):133-145. https://doi.org/10.1016/j.renene.2018.01.021

[16] Chillcce G , Moctar O E . A numerical method for manoeuvring simulation in regular waves. Ocean Engineering, 2018, 170(DEC.15):434-444. https://doi.org/10.1016/j.oceaneng.2018.09.047

[17] Vijayanandh R , Venkatesan K , Kumar R R , et al. Theoretical and Numerical Analyses on Propulsive Efficiency of Unmanned Aquatic Vehicle Propeller. Journal of Physics: Conference Series, 2020, 1504(1):012004 (10pp). https://doi.org/10.1088/1742-6596/1504/1/012004

[18] Shin, Usune, Taro, et al. Numerical Simulation of Structure Formation of Surface-Modified Nanoparticles during Solvent Evaporation. Journal Of Chemical Engineering Of Japan, 2019, 52(8):680-693. https://doi.org/10.1252/jcej.19we012