Numerical Simulation of Wave of Oil Storage Platform for Large Concrete Foundation

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Abstract. In this paper, the hydrodynamic characteristics of a large concrete foundation oil storage platform under wave action are simulated by using the three dimensional wave sink IHFOAM developed by OpenFOAM. It mainly simulates the wave high, the envelope diagram of the maximum pressure value, and the force characteristics of the platform such as the combined force and bending moment under two working conditions. And draw relevant conclusions, provide optimization suggestions for the design layout scheme, and provide reference for other similar structure calculations.

Keywords: large concrete foundation, oil storage platform, wave, numerical simulation.

1. Introduction

The offshore platform refers to the offshore building which carries on the oil drilling, the exploitation, the production and so on in the ocean, according to its installation way in the sea can be divided into two categories: fixed type and mobile type. Fixed oil production platform is generally fixed platform cannot move as a whole, but also can be divided into gravity type and pile foundation type. Gravity platforms are generally reinforced concrete structures used as large multi-purpose platforms for oil recovery, storage and disposal [1].

The project is to build a large concrete foundation production oil storage platform, the platform needs to have oil and gas production, treatment, storage, external transportation, drilling and repair wells and living power, parking and other functions, the lower part of a large concrete foundation oil storage platform, the upper part of the steel process tank. Through the establishment of mathematical model, the hydrodynamic characteristics around the foundation of the engineering platform are studied, the wave force of the platform under each wave condition is calculated, and the plane layout scheme is optimized. To provide scientific basis and technical support for engineering design and implementation.
2. Platform scheme and simulation conditions

2.1. Platform programme

The lower part of the project is a large concrete foundation oil storage platform, and the upper part is the steel process tank. The platform is caisson structure, the middle part of the platform structure is equipped with crude oil tank, the plane size is 40 meters × 30 meters. As a qualified crude oil storage tank after treatment, the key technologies of anti-leakage, anti-cracking and anti-corrosion should be considered. In addition, in order to ensure the normal use of the structure and environmental protection requirements, the crude oil tank should also consider the protection (anti-collision) design. According to the preliminary overall scheme, the position of the crude oil tank is near the sea surface, and the passing ship may cause impact on the cabin body. In order to ensure the safety of the structure, it is proposed to consider setting the ballast tank of equal height outside the crude oil tank.

After preliminary analysis, the main parameters of caisson foundation are as follows:

Size of caisson : 70 m × 56 m × 21 m
Tank size : 40 m × 30 m × 11.9 m

The schematic diagram of the platform scheme is shown in figure 1-1, 1-2, and 1-3.

![Figure 1-1 Three-dimensional diagram of platform caisson](image1)

![Figure 1-2 Plan of platform caisson](image2)

![Figure 1-3 Section of platform caisson](image3)

2.2. Simulated operating conditions

This paper mainly simulates and analyzes the interaction between waves and platforms under two kinds of wave conditions: working condition 1 and working condition 2. Both conditions correspond to 100 years of wave conditions under extreme high water level conditions, which are W and SW incident waves, respectively. The specific calculation parameters of the two working conditions are shown in Table 1-1, and the relationship between the action angle of the wave and the platform is shown in Fig. 1-4 and Fig. 1-5, respectively, corresponding to the forward incidence and the oblique 45-degree angle incidence.
Table 1-1 Two operating condition parameter tables

| Parameters         | Depth of water (m) | Wave height (m) | Cycle (s) | Wave direction |
|--------------------|--------------------|-----------------|-----------|----------------|
| Working condition1 | 21.8               | 8.7             | 12.84     | W              |
| Working condition2 | 21.8               | 9.1             | 13.10     | SW             |

3. Wave numerical model

This model adopts a three-dimensional numerical wave flume based on OpenFOAM development IHFOAM, which can be used to simulate the interaction between waves and buildings in ocean and water conservancy projects. IHFOAM has more reasonable boundary conditions in wave research, which can produce waves and actively absorb the wave reflection produced by buildings [2] [3]

3.1. Governing equations

This paper uses the two-phase flow model in OpenFOAM to simulate the motion of water and air two-phase incompressible fluid by solving the RANS equation. The RANS equation includes continuity equation (2-1) and momentum conservation equation (2-2). The VOF method is used to capture the free liquid level. Formula (2-3) is the convection equation of volume function solved by VOF method.

\[ \nabla \cdot \mathbf{U} = 0 \]  
\[ \frac{\partial \mathbf{U}}{\partial t} + \nabla \cdot (\rho \mathbf{U} \mathbf{U}) = -\nabla p_{\text{rgh}} - g \cdot \mathbf{X} \rho + \sigma \mathbf{U} \]  
\[ \frac{\partial \gamma}{\partial t} + \nabla \cdot (\mathbf{U} \gamma) + \nabla \mathbf{U} \cdot \mathbf{c}_\gamma (1 - \gamma) = 0 \]

In the formula, \( \mathbf{U} \) is the velocity vector, \( \rho \) is the fluid density, \( \mu_{\text{eff}} \) is the vortex viscosity coefficient considering the molecular dynamic viscosity and turbulent flow, \( \mu_{\text{eff}} = \mu + \rho \nu_{\text{turb}} \), \( \nu_{\text{turb}} \) is the turbulent viscosity coefficient, \( \nu_{\text{turb}} = C_k k^2 / \epsilon \), \( p_{\text{rgh}} \) is the modified pressure, \( p_{\text{rgh}} = p - \rho g \cdot \mathbf{X} \), \( \mathbf{X} \) is the position vector, \( \gamma \) is a fluid volume function.

3.2. VOF tracing free surface

VOF (volume of fluid method) is a commonly used free surface tracking method. Its principle is to solve the ratio of fluid volume to grid volume \( \gamma \) to determine the position of free surface, which is a scalar defined in the center of the element. Between 0~1,0 means that the unit is all water, and between 0 and 1, the unit is a mixture of air and water, that is, the unit where the free surface is located. A more accurate position of the free surface can be obtained by integrating the \( \gamma \) function along the water depth, as shown in figure 2-1. At the same time, in the calculation of two-phase flow, the physical properties of the fluid are considered as a whole, which is obtained by weighting the volume
fraction of water and the volume fraction of air, that is, the density and effective viscosity coefficient of the fluid in the unit can be expressed as follows:

\[ \rho = \rho_l \gamma + \rho_g (1 - \gamma) \]  
\[ \mu_{\text{eff}} = \mu_{\text{eff}} \gamma + \mu_{\text{eff}} (1 - \gamma) \]

(2-4)

(2-5)

VOF method, the volume function needs to satisfy the convection equation:

\[ \frac{\partial \gamma}{\partial t} + \nabla \cdot (\mathbf{U} \gamma) + \nabla \cdot \left[ \mathbf{U} \gamma (1 - \gamma) \right] = 0 \]

(2-6)

In the third term on the left of the above equation, the area of \( \gamma = 0 \) and \( \gamma = 1 \) (that is all air or all water) is 0, and only \( \gamma = 0 \sim 1 \) is valid. By this method, the position of the free surface can be determined.

Figure 2-1 VOF Capturing free surface  
Figure 2-2 Numerical Wave Flume Boundary

3.3. Boundary conditions

The definition of each boundary of pure flume is shown in figure 2-2 below. The bottom surface is the bottom boundary, the front and back are the side wall boundary, the upper part is the atmospheric boundary, and the left and right sides are the solid wall boundary.

4. Establishment of Engineering Mathematical Model

In order to fully reflect the impact of waves on marine platforms, first of all, it is necessary to establish a suitable numerical wave pool, Generate target waves. 790 m, of 3-D numerical pool 400 m, wide 48 m. higher X direction and Y direction mesh size L/100=1.3 Z take H/150.6m, in the wave height region Local encryption of the grid near the platform, Grid size about 0.3 m. Figure 3-1 and figure 3-1 are the computational and local grid diagrams of the three-dimensional numerical wave pool.

Figure 3-1 Schematic illustration of the grid of 3D numerical wave pool (left)  
Figure 3-2 Schematic illustration of the local grid of 3D numerical wave pool (right)
5. Calculation and Analysis of the Interaction between Wave and Platform

5.1. Calculation grid
Considering that the truss in the superstructure of the offshore platform has little influence on the hydrodynamic characteristics near the platform, in order to simplify the calculation, the function of the truss is not considered. Figure 4-1 shows a grid diagram of the structure of the offshore platform with an overall height of 41.5 m, with a caisson height of 21 m. Figure 4 Grid local encryption near the project, minimum mesh size of 0.3 m.

5.2. Calculation of Wave and Platform Interaction

5.2.1. Calculation results of wave field in working condition 1. Figure 4-3 shows the wave field diagram of the offshore platform at the peak of the wave under the condition of working condition, and figure 4-2 shows the schematic diagram of the measuring point of the offshore platform. The water level diachronic curve of each measuring point is simulated.

The simulation results show that, Under operating conditions, W waves act on ocean platforms, Being blocked by the platform, To create a reflection wave, The wave height on the west side of the platform reaches 14.8 m (i.e. G4 measuring point), Maximum crest height up to 11.5 m. above hydrostatic surface From the results of the G1 test points, Climb up to 42.07 m, on the west side of the impact craft module About 20.27 m above the surface, At extreme conditions, waves cross the top of the craft hatch (41.5 m). A wave of up to 42.5 m, is generated when the wave impacts the craft chamber the maximum elevation reached by spray sputtering is higher than that of wave climbing along the wall.
5.2.2. Calculation results of two wave wave field in working condition 2. Figure 4-4 shows the wave field diagram of the offshore platform at peak under working condition 2. The water level diachronic curve of each measuring point is simulated (the position of the second measuring point is the same as that of the first working condition).

The simulation results show that, under condition two, SW waves act on ocean platforms, being blocked by the platform, the water level on the west and south sides of the platform is high. Among them G2 the measuring point is located at the corner of the wave side of the craft cabin, climb up to 33.58 m, here but the maximum wave climb is near G1 point, climb up to 40.8 m, wall the waves are in danger of crossing the roof. G3 point is located at the corner of the caisson's side, As the waves reflect, 29.8 m, maximum water level Up to 31.6 m. at G4 points

5.3. Analysis of Dynamic Water Pressure Results

5.3.1. Analysis of the Results of Working Condition 1. Figure 4-5 shows the maximum hydrodynamic pressure envelope cloud map in the southwest under working conditions. In addition, the cloud map of maximum hydrodynamic pressure envelope in northeast direction, the layout diagram of maximum hydrodynamic pressure profile, the distribution map of maximum hydrodynamic pressure envelope of each section and the pressure distribution of each section at wave peak and trough time are simulated. Simulation results show that due to the impact of wave on the process tank, there will be a large dynamic water pressure at the bottom of the process tank, up to 172.75 kPa. Because the wave is incident positively, the dynamic water pressure on the north and south sides of the offshore platform is symmetrically distributed, and the area with large dynamic water pressure is also concentrated at the bottom of the process tank.

![Figure 4-5](image1) Maximum hydrodynamic pressure envelope cloud map in southwest in working condition 1 (unit: Pa) (left)

![Figure 4-6](image2) Maximum hydrodynamic pressure envelope cloud map in southwest in working condition 2 (unit: Pa) (Unit: Pa) (right)

5.3.2. Analysis of Two Dynamic Pressure in Working Condition 2. Figure 4-6 shows the maximum hydrodynamic pressure envelope cloud map in the southwest under working conditions. In addition, the cloud map of maximum hydrodynamic pressure envelope in northeast direction, the layout diagram of maximum hydrodynamic pressure profile, the distribution map of maximum hydrodynamic pressure envelope of each section and the pressure distribution of each section at wave peak and trough time are simulated. According to the simulation results, the dynamic water pressure at the corner of the lower part of the craft cabin is the largest, which can reach about 162.39 KPa.

5.4. Platform force calculation results (including hydrostatic pressure)

5.4.1. Calculation results of stress on a platform under working condition 1. Figure 4-7 shows the duration curve of each side of the caisson under working condition (including hydrostatic pressure), and figure 4-8 shows the duration curve of each side of the process tank under working condition (including hydrostatic pressure). In addition, the moment diachronic curves of caisson and process tank are simulated (including hydrostatic pressure).
Simulation results show that under the condition of W wave, the load on the west side of the offshore platform is obviously larger than that on the east side, and the range of load variation is great. The maximum force on the west side of the caisson is about $1.9510^8$N, maximum resultant force on the west side of N·m, craft module $2.4810^7$N, maximum bending moment is about $610^8$N·m. The minimum resultant force on the west side of the caisson is $8.910^7$N, minimum bending moment is about $510^8$N·m, and the process cabin is basically not subjected to wave load.

Working condition 1 caisson overall east-west maximum force $6.6810^7$N, direction from west to east; maximum stress from east to west $x7$N, direction is from west to east.

5.4.2. Calculation results of the force on the second platform under working condition 2. Figure 4-9 shows the duration curve of each side of the caisson under working condition 2(including hydrostatic pressure), and figure 4-10 shows the duration curve of each side of the process tank under working condition 2(including hydrostatic pressure). In addition, the moment diachronic curves of caisson and process tank are simulated (including hydrostatic pressure).

Simulation results show that under the second condition, that is, when the SW wave acts, the south and west sides of the offshore platform are both facing waves. Under the influence of wave load, the load on the south and west sides of the offshore platform is obviously larger than that on the north and east sides. And the range of load variation is great. The maximum force on the south side of the caisson is about $2.3210^8$N, maximum resultant force on the west side of the caisson is about $1.910^8$N, maximum force on the south side of the craft module $2.210^7$N, maximum resultant force on the west side of N, craft module $1.6610^7$N.

Maximum force in the east-west direction of the secondary settling box under working conditions $7.810^7$N, direction is from west to east, caisson north-south maximum force $7.7610^7$N, direction from south to north; maximum force on east and west of craft cabin $1.410^7$N, direction is from west to east, the maximum force between north and south of craft cabin is $2.210^7$N, direction is from south to north.
6. Conclusions and recommendations

In this paper, three-dimensional wave mathematical model is established, and the rationality of the model is verified by pure numerical pool wave making. The model is used to calculate the interaction between wave and ocean platform under the action of different wave elements.

The comparison between the calculated results and the target wave height shows that the three-dimensional numerical wave pool model can better reflect the wave conditions in the sea area near the engineering area.

Under the working condition 1, that is, when the W wave acts, the load on the west side of the offshore platform is obviously larger than that on the east side, and the range of load change is great. Under the working condition 2, that is, when the SW wave acts, the south and west sides of the offshore platform are both facing waves. Under the influence of wave load, the load on the south and west sides of the offshore platform is obviously larger than that on the north and east sides, and the range of load variation is great.

Suggestions based on simulation results: under the wave condition of two working conditions, the wave climbing height exceeds the top of the process tank, and whether the process tank needs to be raised should be considered in combination with the operation situation.

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