Flow Field Simulation When Waves Impact on Beam-plate Structures

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Abstract. To discuss the characteristics of flow field during wave impact, based on the software FLUENT, two-dimensional regular wave numerical models were adopted. The models could reproduce the wave impact of several typical beam slab structures, and compared with the experimental data, which verified the correctness of the model and showed the wave impact process intuitively. With simulation, the influences of wave steepness, relative clearance and relative structure width on flow field in impacting were analysed. The computational relations between the impact pressures and corresponding vertical velocities were analysed. The works are useful for mastering more mechanism of wave impact.

1. Introduction

Experiment is a main method for wave slamming problems [1]. While the test equipment and conditions now still have some problems so as to obtain the exact peak values of wave action difficulty [2]. Test results should be verified and improved by other methods. Numerical simulation has some advantages, which overcomes some limitations of experiment and becomes a useful method for slamming problems. The physical model test method and numerical simulation method can be verified and complemented each other [3]. Superiorities of simulation method should be full used to obtain more understanding about the flow field during wave slamming on structures.

This thesis mainly used the numerical simulation method, and combined with the experiment results of Chen et al. (2009) in the analysis [4]. Based on the software FLUENT two-dimensional regular wave numerical models were adopted. With the models some cases of wave slamming on beam-plate structures were reproduced, compared with the experimental data the models were verified. By calculations, the influences of wave steepness, relative clearance and relative structure width on flow field in impacting were analysed. The computational relations between the impact pressures and corresponding vertical velocities were analysed. The works are useful for getting more information about wave slamming.

2. Mathematical model and its validation

2.1. Governing equations
The wave is in turbulent motion in the process of wave impact, so the Reynolds equations are used to solve the mean fluid flow, the $k-\varepsilon$ model closes the Reynolds equations and the VOF method tracks the free surface. The relevant governing equations can be found in the author's paper (2017) [5].

2.2. Boundary conditions
Wave generation uses the setting wave-generating boundary and wave absorbing adopts the porous media model [5].

The tank parameters of numerical model are consistent with the physical model test in Chen et al. (2009) [4]. The water tank diagram is showed in Fig. 1. The wave absorbing zone is 10m, the plate thickness is 0.015m and its length is 1.02m.

![Figure 1. Water tank diagram](image)

The beam measurements and pressure measuring point are showed in figure 2. The velocity measuring point is 0.005m under pressure measuring point. The transverse beam height is 8cm and width is 4cm. The longitudinal beam height is 5cm and width is 2cm. The simulation frequency is 2000Hz for getting the accurate peak values.

![Figure 2. Schematic diagram of beam measurement](image)

2.3. Tank grid setting
The grids created for calculation are structured quadrilateral grids. At the structure’s location and zone of wave height the grids should be higher concentrated.

The numerical simulation grid is shown in Fig. 3. In x-direction 60 cells are setting for one wavelength and 30 cells are setting at the structure’s location. In y-direction the grid changes with the rate of 1.03 and 10-20 cells are setting at the wave height zone.
2.4. Mathematical Models Validation

The comparisons of numerical and theoretical wave form are given in Fig.4. \( x \) is the distance from left boundary to monitoring point.

The comparisons of simulation and experiment results about peak impact pressure are given in Fig.5. \( p \) is the impact pressure. It repeats one time for each test. The average peak value is taken as the eigen value to compare which is counted by the successive 12 wave periods. Simulation results present larger because the sampling frequency of simulation is much higher than experiment’s so as to obtain the exact instant slamming pressures. Overall the created wave tank can work well to simulate the wave slamming.
Figure 5. Numerical calculation and test results comparison of the peak pressure under structures

For one case, Fig.6 displays that at the beginning the flow rushes at the structure, then it moves with larger velocity under the structure, finally the flow gradually weaker.

Figure 6. Flow field of wave action

d=50cm, H=0.15m, T=2.0s, Δh/H=0.3

3. Simulations of flow field below structures

3.1. Influence of Wave Steepness on Vertical Velocities
In Fig.7 V is the vertical velocities. From the pictures we can learn that the vertical velocities will decreases from a certain peak value with the wave steepness changing. The peak value often happens accompanying larger wave period and smaller steepness.

![Figure 7. Relationship between vertical velocities and wave steepness](image)

3.2. Influence of Over Height on Vertical Velocities
In Fig.8, for smaller wave driving force the vertical velocities are smaller and for larger wave driving force the vertical velocities will be larger.

![Figure 8. Relationship between relative clearance and vertical velocities](image)

3.3. Influence of Structure Width on Vertical Velocities
In Fig.9 we can see that relative clearances will affect vertical velocities a little. For larger relative clearances the vertical velocities are relatively larger.

![Figure 9. Relationship between relative structure width and vertical velocities](image)

3.4. Relationship between P and V
According to simulation results, we can count the relationship between the peak impact pressure P and the corresponding vertical velocity V^2. The value histograms of P/\rho V^2 appearance frequency are shown in Fig.10. The longitudinal coordinate presents the statistical appearance amount. It can be get that the maximum appearance frequency is about 1.0, the probability that P/\rho V^2 value is in the scope of 0.8-1.5 is more than 0.60. It means that in most cases P can be calculated with 0.8-1.5 \rho V^2.
4. Conclusion
The influence of regular waves on beam slab structure was mainly studied by numerical simulation and physical experiment data. The influences of each factor involving wave steepness, structure width and clearance on peak vertical velocities were analyzed. The conclusions about flow field were given.

The peak values happen with larger wave period and smaller steepness. The vertical velocities present small under small wave driving force and the vertical velocities will increase under larger wave driving force. The vertical velocities are often larger with larger relative clearances. The peak impact pressure $P$ is about $0.8-1.5 \rho V^2$.

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