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Research on the Hydrodynamic Characteristics of Heave Plate Structure with Different Form Edges of A Spar Platform*

SHEN Wen-jun (沈文君), TANG You-gang (唐友刚)[1] and LIU Li-qin (刘利琴)

State Key Laboratory of Hydraulic Engineering Simulation and Safety,

Tianjin University, Tianjin 300072, China

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ABSTRACT

The hydrodynamic characteristics of heave plates with different form edges of Truss Spar Platform are studied in this paper. Numerical simulations are carried out for the plate forced oscillation by the dynamic mesh method and user defined functions of FLUENT. The added mass coefficient C_m and the damping coefficient C_d of heave plate with tapering condition and the chamfer condition are calculated. The results show that, in a certain range, the hydrodynamic performance of heave plate after being tapered is better.

Key words: *spar platform*; *heave plate*; *hydrodynamic coefficients*; *taper*

1. Introduction

The heave plates are used to stabilize the SPAR type platform as shown in Fig. 1. In order to reduce vertical or heave motions, a series of square horizontal heave plates are suspended beneath the platform at varying depths. The heave plates are supported by a system of four vertical tubular members along with some additional truss structure. The heave plates greatly increase the heave added mass and viscous damping, which contribute to minimize the heave motion.

Most of the studies on heave plate are focused on the experimental method and numerical methods. Prislin *et al.* (1998) carried out hydrodynamic tests on arrays of square flat plates under high *Re* number and *KC* number, and compared the single plate result with the multi ones. The results showed that the interference effect between plates could be ignored with the increasing of plate spacing. Downie *et al.* (2000) studied the effect of configuration of heave plates on the heave responses, the results showed that the heave responses of spars with the smaller and perforated plates were larger than those with the larger and solid ones. Holmes *et al.* (2001) predicted the hydrodynamic loads on heave plates using the CFD methods, and obtained the Morison coefficient for the heave plates under different sea conditions using least mean squares method. Ji *et al.* (2003a, 2003b) carried out forced oscillation tests on single plate arrangement and double plate arrangement, and obtained the drag coefficients and inertia coefficients versus *Re* and *KC* number. Zhang and Yang (2006) studied the effects of heave plates for a Cell truss spar, the results showed that perforated plates present more

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1 Corresponding author. E-mail: tangyougang_td@163.com

effectively than solid plates, and the satisfactory heave motion could be obtained with a proper hole area ratio. Tao *et al.* (2007) studied the spacing effects on hydrodynamics of heave plates by experimental method and numerical method, the results showed that a significant influence of L/D_d (L is the distance between the disks, and D_d is the diameter of the disks) on the hydrodynamic is revealed when it is smaller than the critical value; if beyond that limit, added mass and damping coefficient are shown to be rather stable. Tao and Dray (2008) carried out tests on hydrodynamic characteristics for the solid and porous disks. The model tests revealed that, solid disk could produce the highest damping at large *KC* number, and the porous disk makes more damping at very low *KC* number.

Damping force is generated by the vortex shedding at the thin edges of the heave plate, and there is a close relationship between the heave plate thickness and the damping force. The research on the optimization of hydrodynamic performance for heave plates is scarce. Especially, the study on how to change the shape of heave plates to improve the hydrodynamic performance needs further research. In this work, heave plates with two types of constructions are studied by use of CFD method. More added mass and damping will be obtained for platform. Then the platform motion can be controlled, and the heave motion would be minimized effectively.

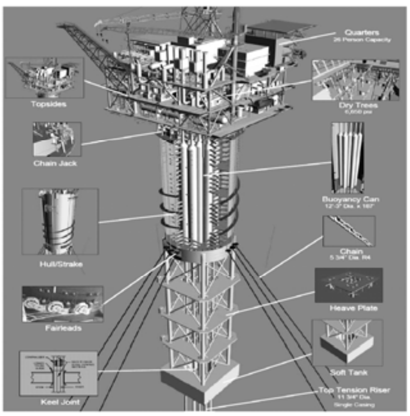

Fig. 1. Truss spar platform.

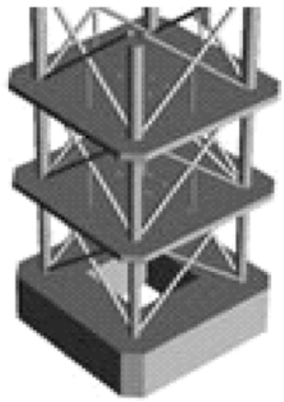

Fig. 2. Heave plate structure schematic.

2. Simulation Schema

The heave plate structure schematic is shown in Fig. 2. In general, there are three heave plates on a spar platform. The natural period of spar platform can be changed by the heave plate. As a result, we can choose appropriate number of heave plates under different sea areas. In this paper, tapered heave plate and the chamfered one are both investigated, and the schematics are shown in Figs. 3 and 4.

The method mentioned in this paper is to taper in the width and thickness direction with different dimensions (see Fig. 3), that is the ratio of '*a*' and '*b*', '*a* 'and '*b*' being the tapering width and depth respectively. Take the two factors into account, the actual situation and the structural strength of the heave plate, the ratio ranges of '*a*' and '*b*' are shown in Table 1.

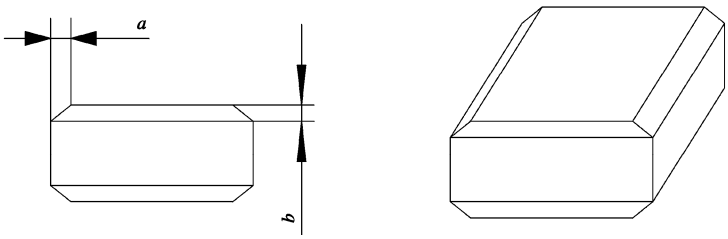

Fig. 3. Tapered schematic for heave plate.

Table 1 Calculation of tapered scheme

	Proportion of tapering (*a/b*)
The thickness is 0.4 m	1
	2
	3
The thickness is 0.5 m	2
	3
	4
The thickness is 0.75 m	4
	6
	8

Another structural style of the heave plate is the chamfer form. The four edges are chamfered by different angles 'θ', as shown in Fig. 4, and the angles θ are given in Table 2.

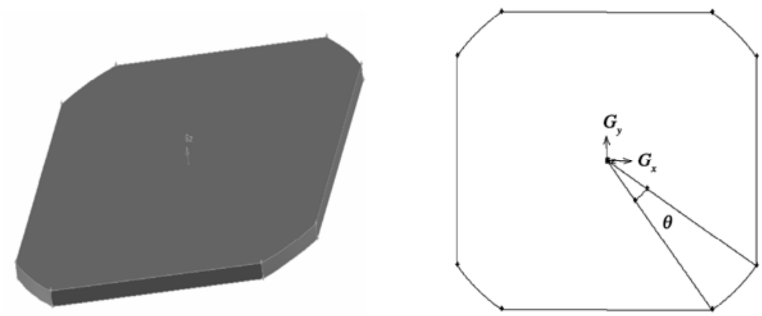

Fig. 4. Chamfered heave plate.

Table 2 Calculation of chamfered cases

Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
$\theta = 5°$	$\theta = 8°$	$\theta = 10°$	$\theta = 12°$	$\theta = 16°$	$\theta = 20°$

3. Simulation Method

3.1 Simulation Model

The results of hydrodynamic coefficients for heave plate are obtained by solving the RANS equation with CFD method. Viscous flow is solved by use of standard $k-\varepsilon$ two-equation model. Governing equations include the continuity equation, momentum equation, k equation and ε equation. The discrete equation is established by use of pressure-based coupled solver and the first-order upwind difference scheme. In order to control the motion of heave plate, UDF (user defined functions) is compiled to the model applying dynamic mesh method, thus the plate can perform a simple harmonic motion in the stationary field.

3.2 Computational Domain and Boundary Conditions

Determination of computational domain: the size of the computational domain in length and width are six times the size of the heave plate, and forty times the size in depth. It is because the heave plate performs a vertical motion, so the size of fluid domain is chosen largely in the vertical direction.

Boundary condition setting: pressure inlet, pressure value is set to zero; pressure outlet, pressure value is set to zero; the boundary of heave plate surfaces are set to wall.

3.3 Meshing Layout

The model is established and meshed by use of pre-processor modeling software Gambit. The grids around the heave plate are refined by use of size function. The total grids are 510000. The gird meshing is shown in Fig. 5.

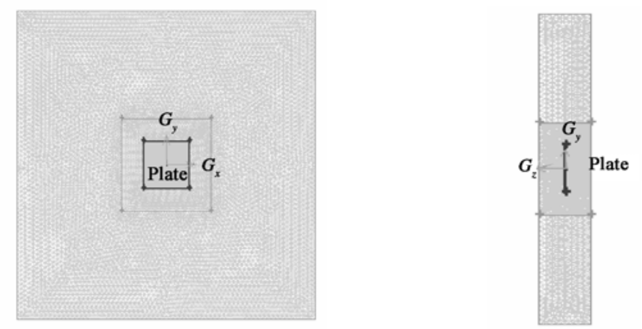

Fig. 5. Refined mesh around the plate.

3.4 Formulas Derivation for Hydrodynamic Coefficients

The displacement of heave plate is

$$z = A\sin(\omega t). \tag{1}$$

So the force of the heave plate subjected can be written as:

$$F_t = F_0 \sin(\omega t + \varphi). \tag{2}$$

Expanding the sine function, one can obtain the following form:

$$F_0 \sin(\omega t + \varphi) = -\frac{F_0 \cos\varphi}{A\omega^2}\ddot{z} + \frac{F_0 \sin\varphi}{A\omega}\dot{z} = -\frac{F_0 \cos\varphi}{A\omega^2}\ddot{z} + \frac{F_0 \sin\varphi}{A^2\omega^2}\dot{z}\left|\dot{z}\right|, \tag{3}$$

where A is the amplitude; ω is the motion frequency of heave plate; z indicates the displacement of heave plate; $\dot{z}$ indicates the velocity of heave plate, which equals $\dot{z} = A\omega\cos(\omega t)$; $\ddot{z}$ indicates the acceleration of heave plate, which equals $\ddot{z} = -A\omega^2 \sin(\omega t)$; φ indicates the phase difference between the velocity curve and the force curve of the heave plate.

If the object undergoes only heave motion in fluid, according to Morison equation, the vertical force F_z can be expressed as follows:

$$F_z = \frac{1}{2}\rho C_d L^2 u_z |u_z| + \rho C_m L^3 \dot{u}_z , \tag{4}$$

where ρ is the fluid density; u_z and $\dot{u}_z$ are the velocity and the acceleration of the body relative to the fluid; L is the characteristic dimension of the object. The first part of the above equation is the drag force, the other is the inertia force. The value of drag coefficient and added mass coefficient in Morison's equation are obtained by combining Eq. (3) and Eq. (4).

$$C_d = \frac{F_0 \sin\varphi}{\frac{1}{2}\rho L^2 A^2 \omega^2}, \quad C_m = \frac{F_0 \cos\varphi}{\rho L^3 A \omega^2}, \tag{5}$$

where ρ, L, A, and ω are all known, so we only need to know the force amplitude F_0 and the phase difference φ. Then the hydrodynamic coefficients C_d and C_m can be obtained.

4. Analysis of the Simulation Results

The hydrodynamic performance of the heave plate structure (as shown in Fig. 2) is studied in this paper, and furthermore, the heave plates of different tapered dimensions are also considered. Time history of velocity and force curves is shown in Fig. 6. According to the simulation results, several rules can be summarized. Firstly, the force period and the velocity period are the same, and the phase difference between two curves is obvious. Secondly, there is an obvious jump phenomenon of vibration amplitude at the peak of the force curve, especially at the first one. With time goes on, the force amplitude tends to be steady.

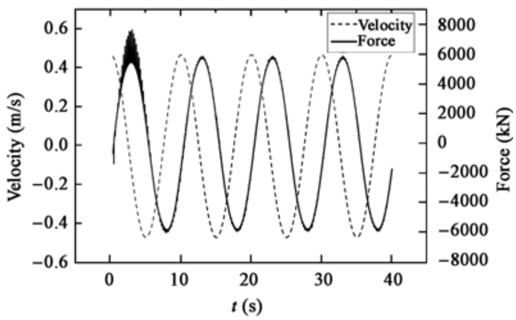

Fig. 6. Time history of velocity and force.

So the force curve can be approximately regarded as a sinusoid with initial phase. The initial phase φ can be acquired according to the value at peak F_0 and time t. Then the values of C_m and C_d can be obtained by Eq. (5). To reduce the calculation errors, the value of F_0 is the average of the latter peak values.

The values of C_m and C_d are obtained under the numerical simulation according to the calculation cases in Tables 1 and 2, and the results are shown in Figs. 7~9, in which '*a*' indicates the tapering width and '*b*' indicates the tapering depth.

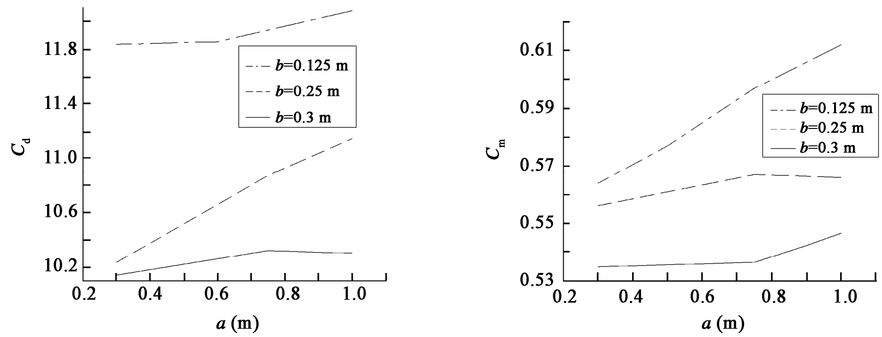

Fig. 7. Values of C_d and C_m with different '*a*' and '*b*'.

From Fig. 7, we can see that when '*b*' equals 0.3 m, the heave plate has the maximum C_d, while the minimum values are obtained when *b* is 0.125 m. On the other hand, the added mass coefficient with $b = 0.25$ is larger than the other cases. The reason for this may be the following points.

First, the interaction between the vortexes which appear at the upper and lower edges of the heave plate is enhanced, when edges of heave plate are of the inclined forms, which make the vortex shedding strengthen, and then the damping increases. At the same time, the area of the heave plate contacting with water increases, which can generate more vortexes, so the damping also increases. Second, the area of the heave plate contacting with water increases, which can make more water move, so the added mass also increases. Third, the phase difference φ increases with the increase of tapering size, so $\sin\varphi$ increases, and $\cos\varphi$ decreases. When φ reaches a certain value, the value of $F_0\cos\varphi$ will be small, so the value of $C_m = \dfrac{F_0\cos\varphi}{\rho L^3 A\omega^2}$ will decrease, as shown in Fig. 7 in the case of $b = 0.3$.

Therefore, the excellent hydrodynamic performance of the heave plate can be obtained in an appropriate range of *a* and *b*. In addition, we can draw a conclusion that *b* has a more significant effect on the hydrodynamic coefficients than *a*. Based on an overall consideration of the factors of C_d and C_m, when *b* is equal to 0.25 m, both the damping coefficient and the added mass coefficient are large. Thus, in comparison of these simulation conditions, when *b* is equal to 0.25 m and *a* is equal to 1.0 m, the hydrodynamic performance of heave plate is the best. It should be noted that the tapered dimensions could not be too large to meet the strength needed for the heave plate.

Fig. 8 is the simulation results of the damping coefficients and added mass coefficients of the heave plate when *b* is equal to 0.25 m, and *a* is 0.5 m. It can be seen that, in a certain range, C_m increases with the increasing *KC* number, C_d decreases with the increasing *KC* number, and the trend tends to be steady.

In Fig. 9, it is shown that the values of C_m and C_d decrease with the chamfer angle. Different vorticity for tapered heave plate and chamfered heave plate is shown in Fig. 10. We can see that, the value of vorticity for tapered heave plate is larger than that for the chamfered one. From the simulation results, a conclusion can be obtained that the hydrodynamic performance of heave plate after being tapered is better than the one after being chamfered. Compared with the chamfering method, the tapering one is an effective method to improve the hydrodynamic performance of heave plate.

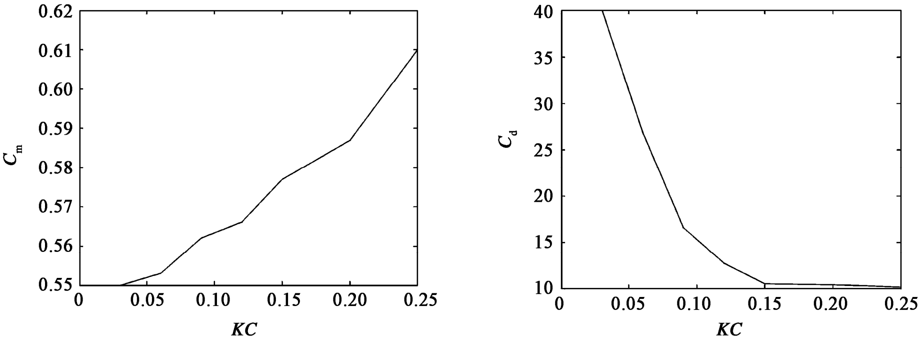

Fig. 8. Values of C_d and C_m with KC (b = 0.25 m, a/b = 2).

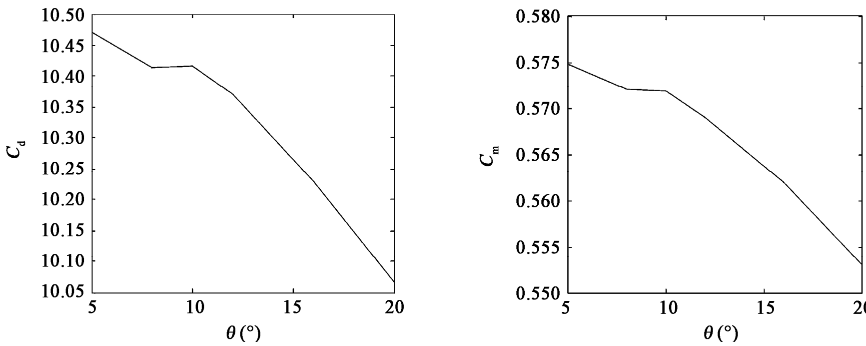

Fig. 9. Values of C_d and C_m with different chamfer angles.

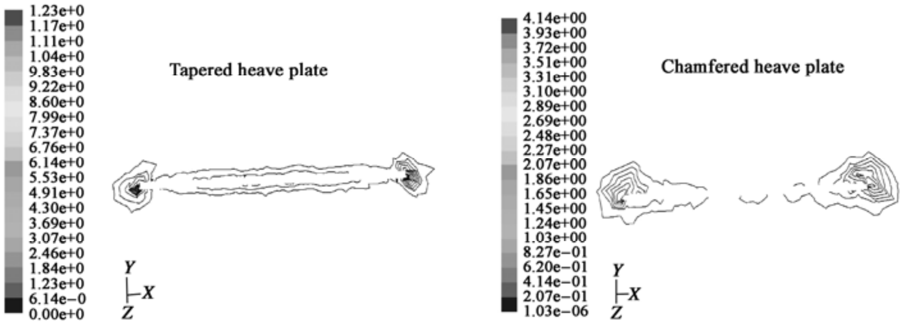

Fig. 10. Vorticity for tapered heave plate and chamfered heave plate.

5. Conclusions

The hydrodynamic performances of heave plate with different forms of the edges have been studied in this paper by applying CFD method. It is found that there are some relationships between hydrodynamic performances and the plate structure form. Following conclusions are obtained.

(1) The heave plate after being tapered performs better in hydrodynamic performance. The added mass and damping of spar platform can be largely increased. It is found that the optimization degree of the hydrodynamic performance for the heave plate is related to the tapered dimensions. The value of C_d increases with a and b, while the value of C_m increases firstly with them, but decreases later.

(2) It is found that, b (the thickness direction) has a more significant effect on the hydrodynamic coefficients than a (the width direction).

(3) In the chamfer simulation cases, the values of C_m and C_d decrease with the chamfer angle. Compared with the chamfering method, the tapering one is an effective method to improve the hydrodynamic performance of heave plate.

In conclusion, the heave plate after being tapered has a pretty good hydrodynamic performance. However, this new structure heave plate is only demonstrated in the numerical simulation. It needs further studies on the experimental verification and the construction process.

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