Study on impact force calculation formula of ship lock gravity dolphin

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Abstract: Ship impact force is one of the main loads of the ship lock hydraulic structures. In order to understand its main influence factors and reasonably determine the calculation method, the transient dynamic analysis method is used in this paper to study the dynamic response of the dolphin under the ship - dolphin collision. Taking the dolphin of a ship lock in Jiangsu province as an example,the 3D finite element model of the ship, the dolphin and the foundation soil was established by the explicit module of ABAQUS to simulate the transient process of the ship's impact under different conditions,and the change law of impact force under different working conditions was obtained. The results are as follows: A linear relation between the impact force and ship impact velocity was founded. Under the condition of a certain impact velocity, the greater the ship's displacement, the greater the impact force, and the impact force and displacement $M^{0.5}$ was approximately linear. A approximate sine curve relationship between impact force and impact angle was founded. Considering the three factors that the ship's displacement, impact velocity and impact angle, the calculation formula of the impact force $P = 244.7M^{0.5}V\sin q$ was obtained by using the nlinfit function of MATLAB. The research results of this paper can provide reference for the revision of the shiplock design codes and the design of the ship pier structure.

Introduction

Dolphin is an important hydraulic structure of ship lock for the temporary stop of waiting ship and directly bears the repeated ship's impact. Under the ship's impact, the ship pier may be damaged by different degrees, which will affects the normal navigation of the ship lock[1,2,3]. At present, the impact force in the design of Chinese lock structure is calculated according to the formula $P = 0.9K\sqrt[3]{M^2}$ of 《Code for Design of Hydraulic Structures of Shiplocks》,which was recommended in 《shiplock》written by Mikhailov of the Soviet Union in 1967[4]. According to the damage situation of domestic ship lock dolphins and the related research of domestic scholars[5,6,7,8], the influence of the ship's displacement is mainly considered in the calculation of the impact force , but the influence of other factors is ignored, such as the impact velocity of the ship. The calculation results are small and the calculation formula needs to be further improved. In order to determine the

impact force more reasonably, this paper took the whole system of ship pier, foundation soil and ship as the research object, simulated the transient process of the ship's impact on the dolphin by using ABAQUS/Explicit. After the establishment of three-dimensional transient dynamic model, the influence factors of the impact force are analyzed, and the reasonable calculation method of the impact force is determined to provide reference for the design of ship lock dolphin structures.

Transient dynamic analysis finite element model

In this paper, the transient dynamic analysis method was used to study the dynamic response of the dolphin structure under the ship's impact. A three dimensional finite element model was built on the dolphin of a ship lock in Jiangsu province to simulate the transient dynamic process of the ship dolphin impacted under different speeds, different impact angles and different ship's displacement. The calculation parameter of the dolphin and the foundation soil is shown in Table 1. A linear elastic constitutive model was used in the dolphin. D-P model was adopted for foundation soil. Dolphin and soil were all meshed by using three-dimensional hexahedral element .

Tab.1 Calculation parameters

Components	Length [m]	Width [m]	Height [m]	Material modulus [Pa]	Poisson's ratio	Density [kg/m³]	Cohesive force [kPa]	Internal friction angle [°]
Dolphin coping	2.7	2.8	0.5	2.8×10^{10}	0.167	2400	-	-
Dolphin body	5.5	5	8.7	7×10^{9}	0.2	2300	-	-
Dolphin floor	7	6	0.8	2.8×10^{10}	0.167	2400	-	-
First layer soil	21	18	4	2.5×10^{7}	0.35	1980	53.2	13.9
Second layer soil	21	18	6	2.1×10^{7}	0.4	1890	46.1	18

The basic scale of the ship refers to《Standard ship's main scale series of Beijing-Hangzhou Grand Canal transport ship》. In order to simplify the ship model, the ship is considered as a steel shell, the steel shell wall thickness is 30mm, and the shell element is used to simulate the model. The material is modeled by elasto-plastic model, and the density is 7800kg/m^3. The goods on board is taken as the solid element and is modeled by elastic model. In the model, the contact between the ship dolphin and the foundation soil as well as the contact between the ship and the dolphin are considered. The influence of water in the collision is considered by the method of adding mass, and the quality of the water is 0.05 times the mass of the ship.The normal constraint is used in surrounding foundation soil, and the bottom of the foundation soil is fixed. The ship bottom is set to the normal constraint and other directions are free. In order to improve the computation efficiency, this paper used the fixed time increment Δt which is 0.0001s to determine the explicit analysis step. The finite element analysis model is shown in Figure 1.

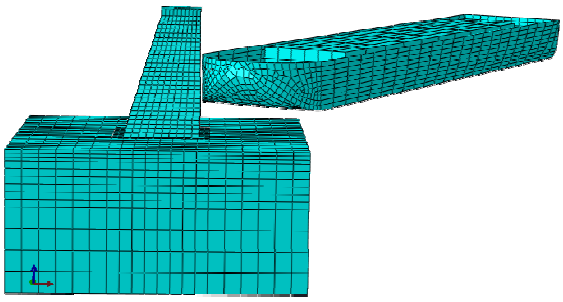

Figure.1 The finite element model

Analysis of impact factors

The influence of ship's displacement on impact force. Considering the influence of actual ship berthing and natural conditions and other factors , thirty-six conditions are studied in this paper. The study takes the ship's displacement respectively for 100t, 300t, 500t, 1000t, 2000t, 3000t, the impact velocity takes 0.2m/s, 0.4m/s, 0.6m/s, 0.8m/s, 1.0 m / s and 1.2m / s, and the impact angle selects 30^0. The mean value of the impact force can be obtained by the integral of the time-history curve of the impact force. The relationship between the impact force and the ship's displacement at different impact velocities is shown in Figure.2 (the impact angle takes 30 degree).It can be seen from the diagram that the impact force increases with the increase of the ship's displacement, but the two is nonlinear. When the impact velocity is small, the influence of the ship's displacement on impact force is little. Because the impact force is in nonlinear growth, a power function $y = \alpha x^{\beta}$ is used to fit the data. The correlation coefficient R is about 0.977,and β is close to 0.5 at different speed conditions.That is $P \sim M^{0.5}$. The coefficient α increases as the speed increases.The results show that the impact force P is linear with the 0.5 power of the ship's displacement M when other conditions are definite. When the impact velocity of ship is large, the influence of the ship's displacement on impact force is large.

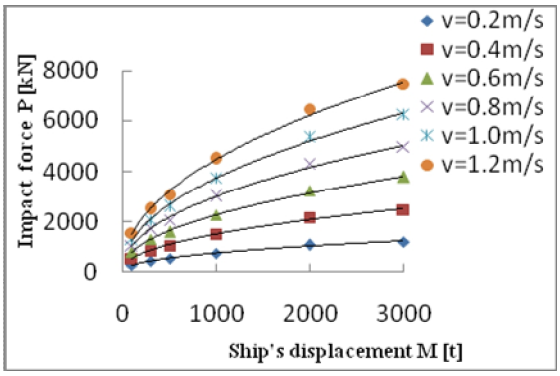

Fig.2 Relation between P and M

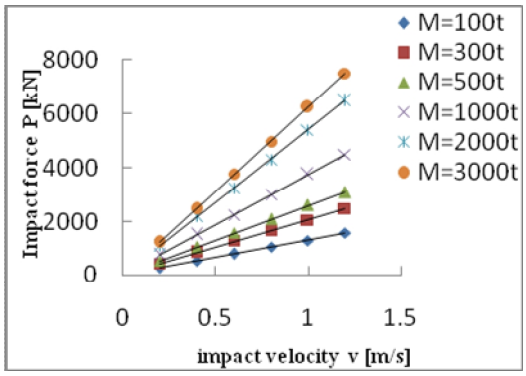

Fig.3 Relation between P and V

Influence of impact velocity on impact force. The relationship between the impact force and the impact velocity at different ship's displacement is shown in Figure.3. It can be seen that the impact force increases with the increase of the impact velocity under different ship's displacements. The power function $y = \alpha x^{\beta}$ is used to fit the data. The correlation coefficient R of the curve fitted by least square method is about 0.99989, more than 0.8, which indicates that the fitting curve is highly

related to the data. β is close to 1.0 at different ship's displacements.That is P~v. The coefficient α increases as the ship's displacement increases. The impact force is linear with the ship's impact velocity when other conditions are definite. When the ship's displacement is large, the influence of the ship velocity on impact force is large.

The influence of impact angle on impact force. In this section, the determined impact velocity 0.6m/s and different ship's displacements as well as the determined ship displacement 1000t and different impact speeds are set as two kinds of condition to research the influence of impact angle on impact force. Impact angle is set as 15°,30°,45°,60°,75°,90°. According to the time history curve of the impact, when the impact velocity is 0.6m/s, the average impact force at different ship's displacement and impact angles is calculated.The sinusoidal relationship between the impact angle and the m at different ship's displacements is shown in Figure.4. When the ship's displacement is 1000t,the sinusoidal relationship between the impact angle and m at different impact velocities is shown in Figure.5. The curve is a sine function in the form of [0, 90°].m is the ratio of the impact force with an impact angle θ to the impact force when is frontal impact. It can be seen from the figure that the simulated data points all fall below the sine curve.The ship impact force and the impact angle are about of a sinusoidal relationship.

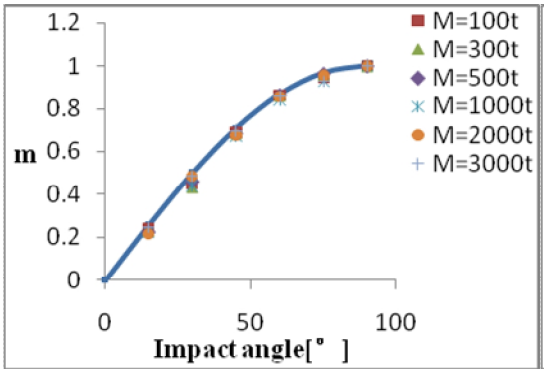

Figure.4 relationship between m and q (under v=0.6m/s and different M)

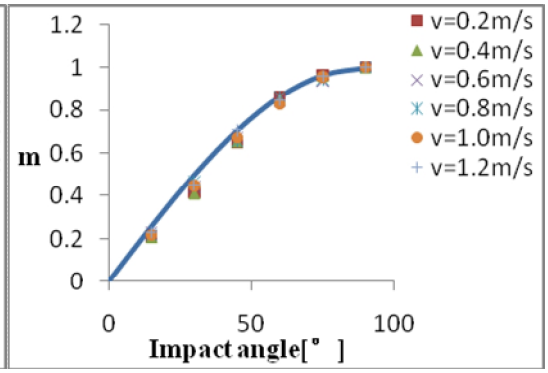

Figure.5 relationship between m and q (under M=1000t and different v)

Impact force formula fitting of ship lock dolphin structure

Formula fitting. According to the above results, we can know that the impact force has a approximate linear relationship with the 0.5 power of the ship's displacement, a linear relationship with impact velocity and a sine relationship with impact angle. Assuming the impact force as $P = \alpha M^{0.5} V \sin\theta$,the nlinfit function of MATLAB is used to determine the parameter α. According to the fitting result that α=244.7and the correlation coefficient r=0.9838,it can be concluded that the fitted curve has a good correlation with the data points simulated by finite element analysis. Thus the calculation formula can be expressed as $P = 244.7M^{0.5} V \sin\theta$。

Comparison of calculation results of impact force. In order to verify the rationality of the calculation formula of the impact force, the field measured data of the ship impact force is

compared with the calculated results by the formula in this paper [5]. The ship's actual load displacement is 777t. The comparison is shown in table 2.

Table.2 Comparison of calculation results of impact force

Method	Impact angle [°]	The average impact force corresponding to different velocities [kN]		
		1.0m/s	1.2m/s	1.5m/s
Literature 5	19.861	2225	2649	3286
The formula of this paper $P = 244.7M^{0.5}V\sin q$	19.861	2317	2780	3476
The code in China: $P_c = 0.9K\sqrt[3]{M^2}$		127	127	127

From the table 2, the results of the impact force calculated by the formulus in this paper are close to that measured by field test. The results calculated by the formula recommended by《Code for Design of Hydraulic Structures of Ship Locks》(JTJ 307-2001) have large difference with the finite element simulation and the field measure. The larger the impact velocity, the greater the difference.

Conclusions

In this paper,the ship lock gravity dolphin structure is taken for an example to study the main influence factors and the calculation method of the ship impact force during the ship lock design. The main conclusions are as follows:

1) The impact force has a linear relationship with the 0.5 power of the ship's displacement, a linear relationship with the impact velocity and a sine relationship with the impact angle.

2) The influence of ship's displacement, impact velocity and impact angle is considered. The average impact force is calculated by the finite element software. The calculation formula of impact force $P = 244.7M^{0.5}V\sin\theta$ is fitted by MATLAB.When compared with field measured data,the value calculated by formula in this paper is relatively close to experiment results and it can provide reference for the design of ship lock dolphin structure.

3) When the ship berthing velocity is small, the impact force calculated according to 《Code for Design of Hydraulic Structures of Ship Locks》(JTJ 307-2001) is close to actual value；When the ship berthing velocity is large, the calculated value according to code is relatively small. If the ship impact force is calculated according to existence code, there will be security risks in the ship dolphin structure.

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