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Resistance Analysis of Open Caisson Towing on Water in the Construction of the Large Scale Bridge

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Abstract: In order to solve the towing problem on water of the open caisson in the construction of the large scale bridge efficiently, combining with the towing operation project, the dragged open caisson and environmental data, etc. we design and produce the open caisson physical model and configure the test environment, use the force cell to collect real-time experimental data, analyze and demonstrate the towing resistance of the open caisson. Use the experimental data and the model of resistance similarity transformation to calculate the resistance, while the towing speed is 1m/s, 2m/s and 3m/s, the resistance is 323 KN, 724KN, 1398KN in the straight test mode and the resistance is 365 KN, 861KN, 2326KN in the transverse test mode. The results show that the resistance of the open caisson has certain growth trend with the towing speed rising, which both have large correlation, and the resistance of transverse situation is larger than straight mode.

Keywords: Open caisson, physical model, resistance analysis, towing operation on water.

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1. INTRODUCTION

With the development of economic construction, by 2020, there will be more than a hundred large scale bridges are built in China. In the construction process of the large span bridges, most of them are constructed and piece together directly in the bridge waterway, therefore, many operations are involved in the construction technology of bridge pier, such as the construction, towing and positioning of open caisson, etc. The most complex and challenging operation is the towing operation of the open caisson, which mainly influenced by its own scale, stress characteristics, external environments, towing force and other factors. As a general rule, the open caisson have no sailing power with their own, they need the external assistance to keep their sailing, so a certain number of tugs are required during the towing operation of the open caisson. In consideration of the complexity and risk in towing operation, we have to fully research the resistance of the open caisson in towing operation, and equipped with sufficient tug horsepower. In recent years, there are also some studies on the resistance of caissons have been carried out.

Chen *et al.* [1]. (2008) conduct model test research on mechanical characteristics in the process of open caisson foundation sinking into water with current influence, and to take in the norms of the corresponding flow drag coefficient were discussed.

Xu *et al.* [2] (2009) use the calculation fluid software FLUENT to calculate the value of viscous resistance of square steel caisson under the different current speed, and by comparing the calculating results obtained from FLUEN with that from empirical formula, it's shown that the formula, regarding only the outer wall of the caisson as the water-breaking area, is not justified.

Hu *et al*. [3]. (2013) research the resistance and drag coefficient of immersed tunnel element under the combined effect of different flow rates, different directions and different draft by the physical model test. Obtain the resistance characteristics of immersed tunnel element for different water environment.

Zhang *et al.* [4]. (2013) research the resistance of caissons based on the extended development of the general CFD software FLUENT, regular head wave series is numerically simulated and the resistance in the wave is computed with close attention paid to the effects of the inner fluid sloshing against the caisson resistance in the wave, the results show that the inner fluid sloshing can not be neglected, otherwise it can overcast the wave effects.

Thus it can be seen that those scholars conduct the resistance problem based on mathematic model or physical model separately, in this paper combined the physical model and the resistance similarity transformation model to calculate the real resistance of the open caisson at a higher accurate calculating result.

2. DESCRIPTION OF THE PROBLEM

In order to fully understand the resistance of the open caisson in towing operation, and make sure the comprehensiveness and integrity of the test, we design the test method for towing resistance of the open caisson in the ship model experimental tank, that is the tank trailer fixed towing method, The design principle of the physical model is let it well fixed on the trailer, and then install the force cell, making the towing velocity under the corresponding conditions, detecting and recording the model force data in real time. There are two kinds of test model, one is towing straight by constant speed, as shown in Fig. (**1**), and the other

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one is towing transversely by constant speed, as shown in Fig. (**2**), both test model have the same test environment except the towing direction and the incident flow area.

Fig. (1). Straight towing test by constant speed.

Fig. (2). Transverse towing test by constant speed.

3. THE PHYSICAL MODEL OF THE OPEN

In the physical model test, we should select the type of model firstly according to the mission and purpose of the experiment. After the theoretical analysis to the research object, based on the analysis of similarity for equation method and dimension analysis method, to determine the similarity constant geometry and a geometry model, eventually extended the model test results to the prototype object [5]. Then calibrate the parameters of physical model through the analysis of historical data, [6]. The goal of calibration is to seek the most satisfactory model and the optimal parameter in objective system, which needs to take the effect of various factors of model designing process in the physical model test into comprehensive consideration.

Ship model test of domestic and international shows that, the ship model tank test designed usually requires the ship length more than 2m [7]. The open caisson used in this paper is different form the ship model ordinary of streamlined shape features. Which is actually closer to upper and lower opening box, and need to get a relatively stable and balanced flow effect in the tank, but the towing speed requirements are relatively weakening. According to the main scale of the real open caisson (Table **1**), it is difficult to find the calibration feature of open caisson physical model test from the available data and literature. Therefore, in consideration of the model type, material, product condition, draught, sensor placement, experimental site, equipment conditions and other factors, the final determination of main scale ratio of the open caisson model is 116:1 by manual trial and error method [8]. The specific scale and parameters of open caisson model are shown in Table **1**, the open caisson design diagram and the physical model are shown in Fig. (**3**), Fig. (**4**). The open caisson is composed of 24 holes, 12 of them are sealed on top and inject compressed air to provide enough buoyancy.

Table 1. The size of the open caisson and the parameters.

Parameters	The Open Caisson Prototype	The Open Caisson Physical Model
Length	86.9m	0.73m
Width	58.7m	0.49m
height	56.0m	0.48m

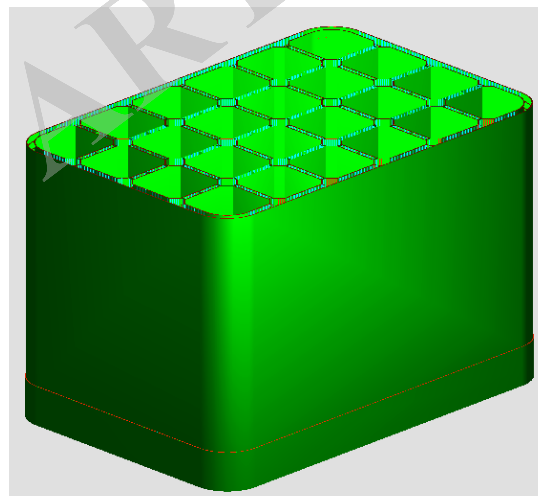

Fig. (3). The open caisson design diagram.

Fig. (4). The open caisson physical model.

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4. THE PHYSICAL MODEL TEST OF OPEN CAISSON

4.1. Test Equipment Layout and Installation

The related basic testing tools and auxiliary tools include force cell fixed on trailer, Wireless data acquisition and data acquisition software, etc.

The force cell is installed in the tank Trailer, as shown in Fig. (**5**), the test object is fixed in the back of tank trailer, and then the force cell is working. The working pattern is dragging the object in different speed, collect 3 kinds of force data. The data acquisition software has wireless data acquisition unit, as shown in Fig. (**6**), It can carry out real time data acquisition upon the nodes of all sensors on the access network, the frequency of data collection can be set according to the requirements of the experiment.

Fig. (5). Force cell fixed on trailer.

Fig. (6). Data gathering software.

4.2. Constant Speed Straight Test in the Hydrostatic Water

This experiment led the open caisson model navigating in the tank under the speed of 0.1m/s, 0.2m/s, 0.3m/s, and resistance of open caisson model during the test be recorded under different speed, the experimental data is available in Fig. (**7-9**).

4.3. Constant Speed Transverse Test in the Hydrostatic Water

This experiment led the open caisson model transverse in the tank under the speed of 0.1m/s, 0.2m/s, 0.3m/s, and resistance of open caisson model during the test be recorded under different speed, the experimental data is available in Fig. (**10-12**).

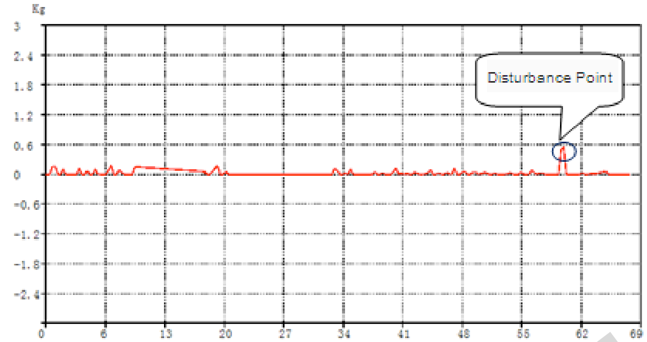

Fig. (7). Resistance at the speed of 0.1m/s in straight test mode.

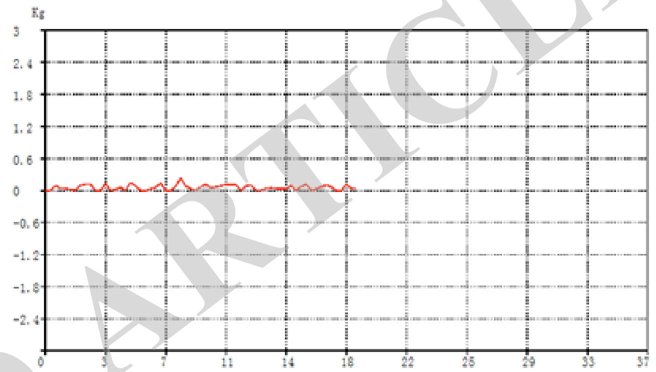

Fig. (8). Resistance at the speed of 0.2m/s in straight test mode.

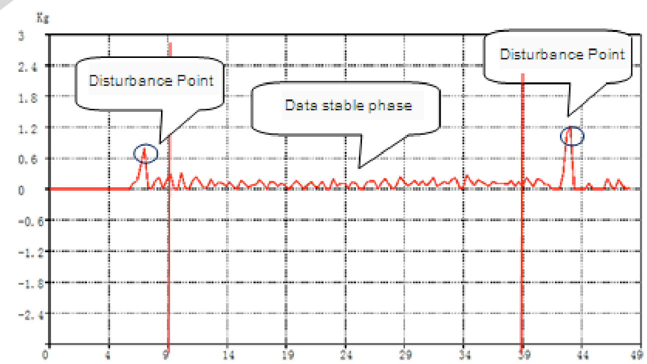

Fig. (9). Resistance at the speed of 0.3m/s in straight test mode.

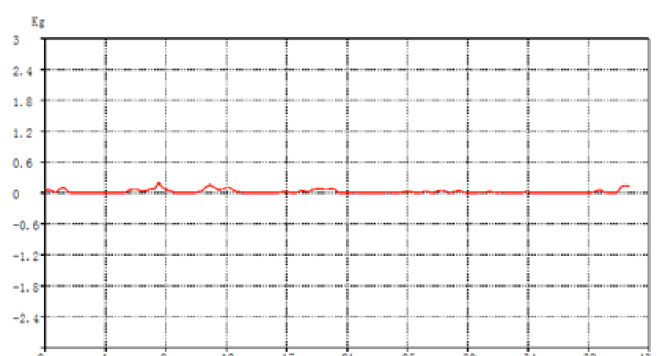

Fig. (10). Resistance at the speed of 0.1m/s in transverse test mode.

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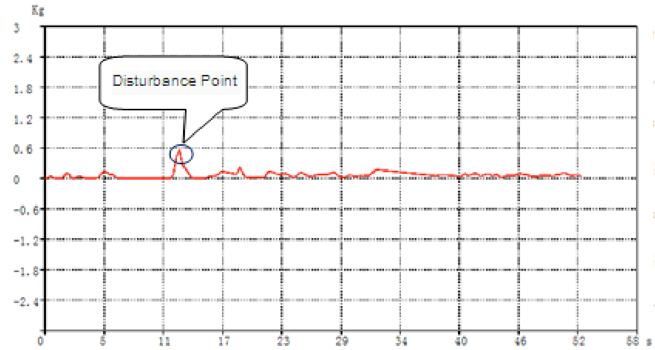

Fig. (11). Resistance at the speed of 0.2m/s in transverse test mode.

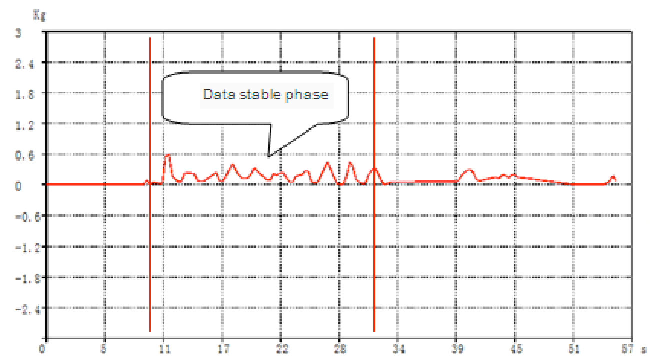

Fig. (12). Resistance at the speed of 0.3m/s in transverse test mode.

5. THE MODEL OF RESISTANCE SIMILARITY TRANSFORMATION

All components except the friction resistance, which can be used to considerable friction resistance formula, the other resistance such as viscous resistance, eddy current resistance and so on, usually to be determined by physical model test. According to the test data, on the basis of the similarity theory to calculate the other resistance of the open caisson, plus the frictional resistance on basis of the theory of plate friction, obtain the actual total resistance values in open caisson, the similarity calculating principles are used as follows:

1. Geometric similarity relation [9]:

$$\frac{L_s}{L_m} = \frac{B_s}{B_m} = \frac{T_s}{T_m} = \lambda \tag{1}$$

2. Velocity similarity relation [9]:

$$V_m = \frac{V_s}{\sqrt{\lambda}} \tag{2}$$

3. Total resistance similarity relation [10]:

$$R_{ts} = R_{fs} + \frac{\rho_s}{\rho_m}\lambda^3\left(R_{tm} - R_{fm}\right) \tag{3}$$

4. Among them: friction resistance [10]:

$$R_f = \frac{1}{2}\left(C_f + \Delta C_f\right)\rho S V_s^2 \tag{4}$$

5. Basic resistance [11]:

$$R_t = R_f + R_r \tag{5}$$

6. Friction resistance coefficient of smooth plate [12]:

$$C_f = \frac{0.075}{\left(\lg R_e - 2\right)^2} \tag{6}$$

7. Subsidized coefficient of roughness [13]:

$$\Delta C_f = \left[105\left(\frac{K_s}{L_s}\right)^{1/3} \text{-} 0.64\right] \times 10^{-3} \tag{7}$$

8. Reynolds number [14]:

$$R_e = \frac{VL}{v} \tag{8}$$

The above all kinds of formulae:

L_s, B_s, T_s	=	The scale of the prototype of open caisson (m);
L_m, B_m, T_m	=	The scale of the open caisson physical model (m);
V_s	=	Actual speed (m/s);
V_m	=	Model speed (m/s);
λ	=	Scaling factor;
R_{ts}, R_{fs}	=	The total resistance and friction resistance of open caisson prototype (KN);
R_{tm}, R_{fm}	=	The total resistance and friction resistance of open caisson physical model (KN);
R_r	=	Other resistance (KN);
V	=	Velocity (m/s);
L	=	Length (m);
ΔC_f	=	Additional correction coefficient of roughness;
K_s	=	Surface roughness of real ship (according to ITTC is 150×10^{-6});
v	=	The kinematic viscosity coefficient of water (m^2/s), value according to Table **2**.

According to the similarity conversion formula shows above and the similarity transformation formula, to calculate the actual resistance situation of open caisson. Among them, the calculation process parameters, see Table **3**, the test results in Table **4**, by data conversion, we get the actual open caisson resistance in Table **5**.

According to Table **5**, the open caisson with speed of 3m/s while in constant speed straight test in the hydrostatic water, the average resistance is 1398KN, in constant speed transverse test in the hydrostatic water conditions, the average resistance is 2326KN, and the resistance of transverse mode is larger.

CONCLUSION

1. By physical model test and resistance similarity data conversion, it shows that the open caisson resistance increasing as the towing speed increasing, it means that they have great relevance.
2. In different open caisson towing operations, the open caisson transverse resistance is larger than straight mode,

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Table 2. The kinematic viscosity coefficient of water.

Water temperature (C°)	**0**	**5**	**10**	**15**	**20**	**25**	**30**
ν (10^{-6} m^2/s)	1.79	1.52	1.31	1.14	1.00	0.89	0.80

Table 3. The parameters of model transformation calculation.

The physical model	**Velocity V_m (m/s)**	**0.1**	**0.2**	**0.3**
	Reynolds number R_e	61432	122864	184295
	Friction resistance coefficient of smooth plate C_f	0.0096	0.0079	0.0070
	Plate wet surface area S (m^2)	0.6993	0.6993	0.6993
	friction resistance R_{fm} (N)	0.0337	0.1099	0.2213
The actual caisson	**Velocity V_s (m/s)**	**1**	**2**	**3**
	Reynolds number R_e	76230000	152500000	228700000
	Friction resistance coefficient of smooth plate C_f	0.0022	0.0020	0.0019
	Plate wet surface area S (m^2)	7281	7281	7281
	friction resistance R_{fs} (KN)	7.89	28.57	60.76

Table 4. The physical model test results.

Test Model	**Test Resistance**	**Test Speed (m/s)**		
		0.1	**0.2**	**0.3**
straight towing test	The average resistance (N)	0.225	0.539	1.05
transverse towing test	The average resistance (N)	0.25	0.62	1.60

Table 5. Similarity transformation of actual caisson resistance.

Test Model	**Actual Resistance**	**Actual Speed (m/s)**		
		1	**2**	**3**
straight towing test	The average resistance (KN)	323	724	1398
transverse towing test	The average resistance (KN)	365	861	2326

the difference is mainly depends on the towing speed and the lateral area of the open caisson.

3. The situation of the actual towing is more complex, there is the condition coupling with wind, current and wave, the open caisson resistance may suddenly increasing, in consideration of the safety and margin, it is recommended to equipped with tugs by larger calculating results.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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Declared none.

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