CHAPTER 183

DYNAMIC STUDIES ON CAISSON-TYPE BREAKWATERS

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Abstract

In this paper, studies on dynamic characteristics and responses under waves of caisson-type breakwaters by field and model testings as well as dynamic analyses are described. It is found that the gravity-type structure-foundation system can be simplified as a rigid body on a linear or non-linear elastic foundation for evaluating its dynamic characteristics and responses. The dynamic displacements of the caisson are found related to the wave heights, the water depth as well as the foundation soil properties.

Introduction

Along with the increase of the ship tonnage, the construction of breakwaters, either for the development of a new port or for the extension of the existing port requires that the structures are to be built in deeper coastal areas, and these breakwaters are being subjected to severer wave actions. A problem is raised as to the dynamic behaviours of the breakwaters under the tough environmental conditions. Based on such needs, we performed a series of studies on the dynamic characteristics and responses under waves through field testing, model testing and numerical analyses for the caisson-type breakwater, either rectangular or cylindrical. This paper presents these investigations, mainly the test results and the comparison between the test results and the analytical results with different methods of analysis. (Gao et al 1988, Dai et al 1985,1987)

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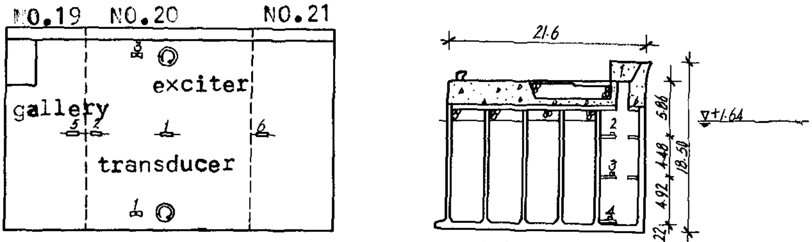
Field Test of the Reotangular-Caisson

The field testing site was chosen at a newly built port located in the southern part of Shandong province of China. The breakwater is one for composite use, i.e. with its inner side for ship berthing. Figure 1 shows the plane view and the profile of the breakwater. The rectangular caisson has a weight of 13,000t with a deck and a 2.1m high exterior parapet wall.



(a) plane (b) profile

Fig. 1 Test Caisson

Two mechanical-type exciters of 6t capacity, with frequency range of 0-30Hz and frequency resolution of 0.01Hz, were adopted to excite the caisson. The exciters were placed on the top of the No.20 caisson, and the displacement transducers were fixed on the top surface of the three caissons and on the vertical gallery of the No. 19 caisson. The test results are listed in Table 1, and the mode shapes and amplitude-frequency curve are shown in Figure 2.

Table 1 Test results

Meas. pt. No.	Caisson No.	First order freq.(Hz)	phase	damp.	2nd order freq.(Hz)	phase
1	20	3.8	Ref.	.0579	8.01	Ref.pt.
2	20	3.8	same	.0592	8.48	same
3	19	3.8	same	.0329	8.48	same
4	21	3.8	same	.0619	8.48	same

From the tests, it shows that:

1. Under the excitingfocre of 10-12KN, the three oaissons have the same 1st and 2nd order natural frequencies and nearly the same values of damping ratio. It illustrates that due to the surface deck connection, the breakwater caissons vibrate simultaneously with good integrity.
2. From the vibration modes measured, it illustrates that the vibration is coupled, with lateral vibration as the primary and rocking as secondary for the fundamental mode

and rocking as primary and lateral vibration secondary for the 2nd order mode.

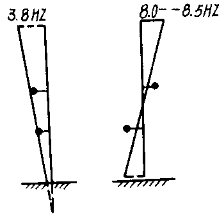


Fig. 2(b)

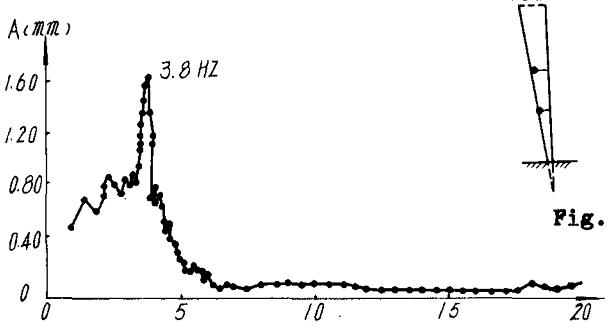


Fig.2(a) Resonance curve of pier caisson

It means that the vibration of caisson-type structure can be regarded as the vibration of a rigid body on elastic foundation, linear or nonlinear, for evaluating its dynamic characteristics and dynamic responses.

Using corresponding equations of vibration, it is feasible and easy to determine the compression and lateral coefficients of the subgrade by measuring the fundamental frequencies of the structure undergoing vertical or horizontal-rocking vibration and then to determine the bearing capacity of the subgrade.

Model Tests of the Rectangular-Caisson

The model tests were performed on a similar regular caisson-type composite breakwater at a model scale of 1 to 87. The model was not simulated exactly to the above existing structure but was for a new caisson-type breakwater in design stage. Plexiglass and weighted rubber were used as modelling materials for caisson structure and subgrade foundation. A portion of foundation, with a depth nearly equal to the height of the caisson and a width equal nearly to 3 times the width of the caisson was included in the model.

The models were tested for various restraint conditions. Table 2 shows the influence of the different foundation conditions of restraint and sizes on the natural frequency of caisson. The results given are in prototype scale.

Table 2

Foundation size M^3	Restraint condition of the foundation	Nat. freq. (Hz)	
		1st	2nd
71.3*62.3*26.1	Restricted on four side	1.18	1.85
71.3*62.3*26.1	Non-restraint	1.06	1.93
71.3*44.0*26.1	Non-restraint	0.93	2.02

Shown in Fig. 3 is the resonance curve and mode shapes of the rectangular caisson from model tests.

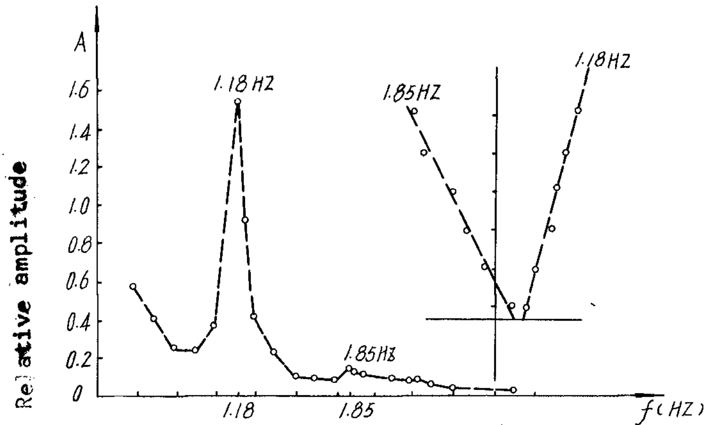


Fig. 3 Resonance curve and mode shapes

Tests for Different Water Levels

The model was tested for different water levels to investigate the added mass coefficient. Fig.4 shows the response-frequency curves with various water levels. The natural frequency of the system lowers with the rise of water level. At the checking high water level the fundamental natural frequency lowered down about 9%. From this it can be estimated that the added mass coefficient of the water for the tested

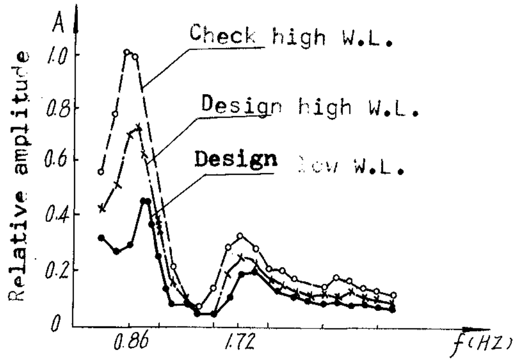


Fig. 4 Resonance curve for various water levels

caisson is around 0.6, about the same as that recommended by Dr. Hallam (Hallam 1977).

Table 3

Water level	Nat. Freq. (Hz)		Damping ratio	
	1st	2nd	1st	2nd
Without water	1.06	1.93	0.024-0.038	0.024-0.065
Design low w.l.	1.01	1.82	0.08	0.084
Design high w.l.	0.94	1.72	0.134	0.091
Check high w.l.	0.86	1.72	0.163	0.094

Dynamic Responses under Waves

The model with foundation was placed in a wave basin to test the dynamic responses under regular waves of various wave heights and wave periods with three different water levels. From these test results, it can be seen that the dynamic displacements increase with the increase of wave height as well as to water depth, the dynamic displacement is also increasing with the increase of wave period in general. The uplift forces measured show an evident linear relationship with wave heights.

Field Dynamic Experimental Studies on Cylindrical Caisson-type Breakwater

Field dynamic measurements were also carried out on cylindrical caisson of an island breakwater in the same port mentioned above. The caissons were 14m in diameter, 13.5m in height and connected together with a block at the top. Each caisson weighs 5000t. The same exciters as aforementioned were used, and the method of ambient vibration was also adopted for excitation. Fig. 5 shows the frequency-amplitude curve and the power spectra curve. The main results are listed in Table 4.

Table 4

Caisson No.	Ambient test freq. (Hz) with cap	no cap	Reson. test freq. (Hz) with cap	damping ratio
15	1.95		1.90	0.047-0.071
16	1.95			
40		2.18	2.20	0.032-0.075
41		2.18		

In order to determine the vertical dynamic characteristics, the caisson was also tested by the method of applying shock load vertically and the fundamental natural frequency for vertical vibration measured is 4.3-5 Hz..

Model Tests for Cylindrical Caisson-Type Breakwater

A model made of plexiglass for a cylindrical caisson of 14m in diameter and 26.5m in height was tested for a practical pier design at a scale of 1 to 30, also with a portion of foundation included. The foundation is simulated to different compression stiffness. The model is tested

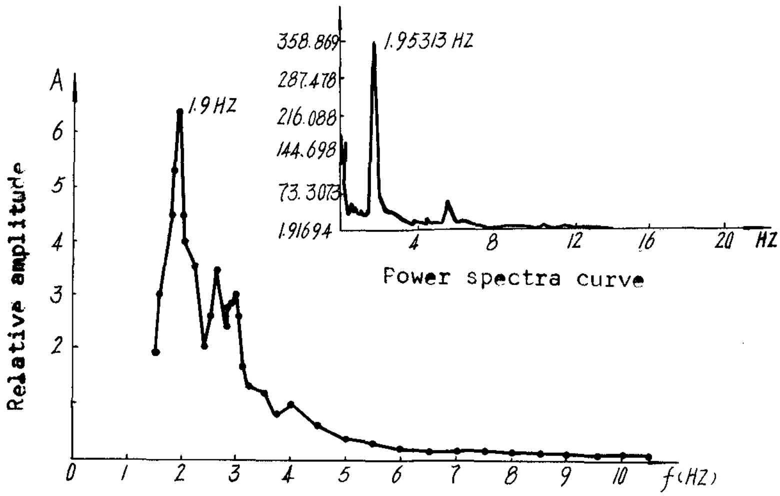


Fig. 5 Frequency-amplitude curve

in air by an actuator as well as by the method of hammering. The tested frequency-amplitude curve and the response spectrum, transfer function and coherence coefficient are shown in Figs. 6 and 7.

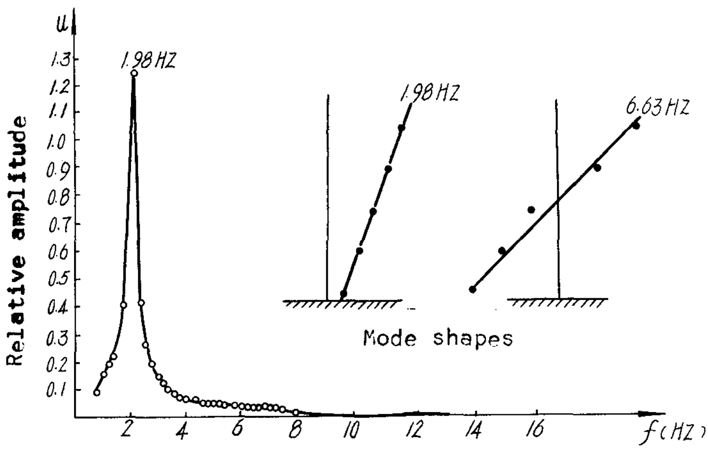


Fig.6 Frequency-amplitude curve

It agrees well with the results obtained from the field tests.

The model was then placed in a wave basin to test its respones under regular and irregular waves in different water depths. The irregular wave spectra used are the Pierson-Moskowitz spectrum and the local spectrum evaluated by Nanjing Hydraulic Research Institute. The input wave height spectrum as well as response spectrum are shown in Figs. 8(a), (b). Fig. 8(c) is the displacement response spectrum. The displacement of the caisson top versus wave height are plotted in Fig. 9 by solid line for various water depths and wave periods. The Tested results show that the displacement of the caisson is in nearly linear relation to the wave height and are much small than th those for rectangular-caisson under the same wave condition. In Fig. 9 it also shows in dotted lines the calculated values of the responses without taking into account the dynamic effect. It can therefore illustrate that the dynamic effect can be neg-

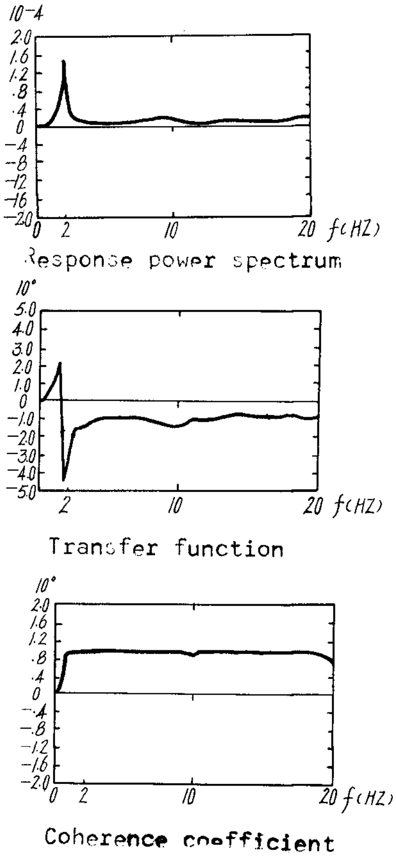


Fig. 7

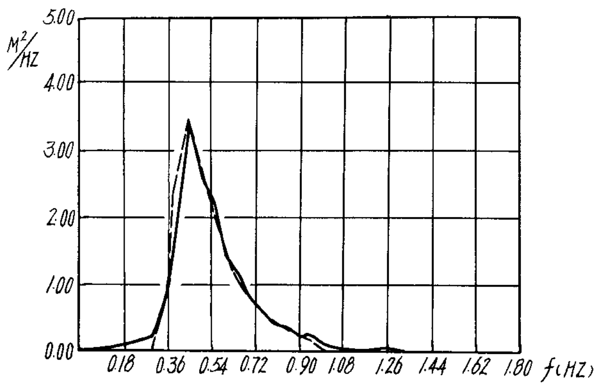


Fig. 8(a) Local wave spectrum

lected under ordinary wave condition.

Dynamic Analysis

The dynamic analysis for the caisson-type breakwater has been carried out. Two methods are adopted in the analysis: (1) The method of concentrated parameters: The system can be simplified as a 3 degree-of freedom rigid body

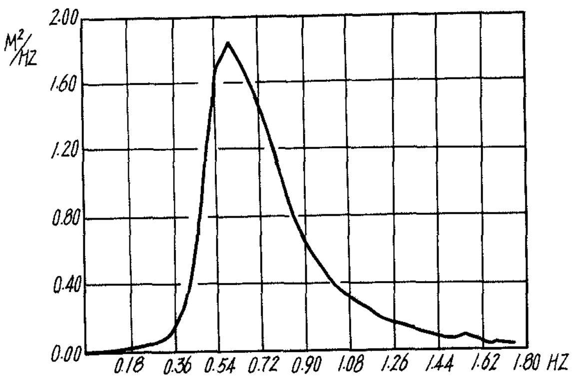


Fig.8(b) P-M wave spectrum

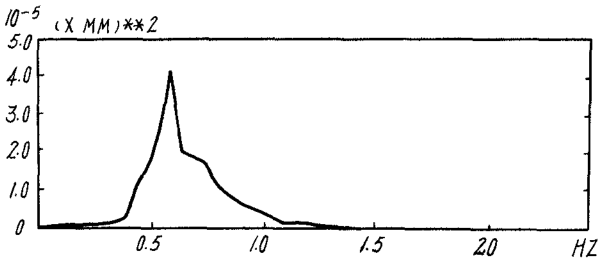


Fig.8(c) Displacement response spectrum

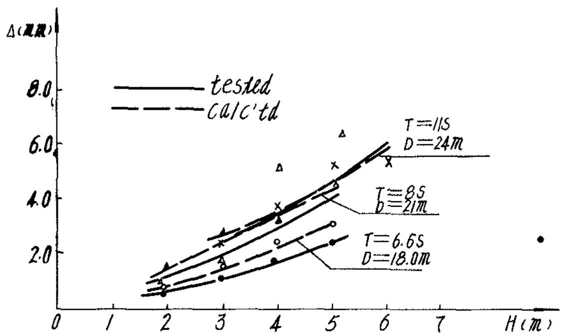


Fig. 9 Displacement versus wave height

on elastic foundation, treated as a series of vertical and lateral springs, with lateral, vertical and rocking spring constants denoted by C_x, C_z and C_ϕ respectively, as shown in Figure 10; (2) The finite element method: For the rectangular caisson, together with the foundation included, the system can be treated as a 2-dimensional problem. The calculated results for natural frequency are given in Table 5, and the test results are also listed for comparison. It can be seen from Table 5, that good agreements are reached by applying these methods.

In the finite element the dynamic responses of the rectangular caisson under different wave heights are evaluated, using the wave pressure formula recommended by Miche-Biesel and the results are shown in Table 6. It shows that, while the wave height ranges between 7 to 8m, the test results are also listed for comparison, and it can be found that the a agreement is satisfactory.

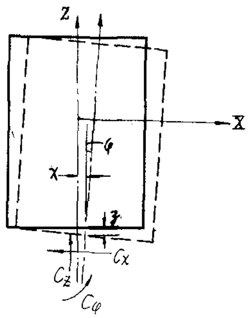


Fig. 10

Table 5

Caisson Type	Cz value of foundation (KN/M3)	1st Nat. Freq.(Hz)			2nd Nat. Freq.(Hz)		
		Test	CPM	FEM	Test	CPM	FEM
Rect.	5,150 68,000 102,000	0.98- 1.06	0.95	1.07	1.83- 1.93	2.81	2.31
Cylind.	76,820	1.92	1.91		6.66	6.85	
	71,280	1.83	1.81			6.50	
	46,530	1.44	1.46			5.25	

C_z - the vertical compressive coefficient of the subgrade.

Table 6 D/H 0.766

Wave height (m) \ Wave period (s)	8.0		10.0		12.0		14.0	
	test	cal.	test	cal.	test	cal.	test	cal.
6.86	3.05	2.96	3.48	3.65	5.22	4.18	6.00	4.70
7.76	3.57	3.39	3.74	4.34	5.48	4.96	6.79	5.66

D - water depth, Hc - height of caisson.

Concluding Remarks

Through the field testing, the model testing and the dynamic analysis using different methods, a quite thorough investigation of the problem of caisson-type breakwater has been made on its dynamic characteristics and dynamic responses to waves, and the following can be concluded:

1. The caisson-type breakwater, either rectangular or cylindrical, can be regarded as a system of rigid body on linear or nonlinear elastic foundation for evaluating its dynamic characteristics and dynamic responses.

2. The foundation stiffness has a great effect on the dynamic characteristics and responses, and any weak soft layer underlain should better be dredged out.

3. Under strong waves, the top displacement responses of the rectangular caisson will be much larger then those of the cylindrical caisson.

4. In general, the dynamic magnification factor under waves is very close to 1, and therefore, in the calculation of the stability of the caisson, it can be treated as a static problem.

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