On the characteristics of the motion and the mooring force of a mid-layer type floating structure in waves

Rie MIYAHARA
Kuniaki SHOJI
Sigeo MITA
Risa NAGASE

Faculty of Marine Technology
Tokyo University of Marine Science and Technology
2-1-6 Etchujima, Koto-ku, Tokyo 135-8533 JAPAN
rmiyaha@e.kaiyodai.ac.jp

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Abstract

In this study experiments are conducted with a mid-layer type structure. This structure can operate not only at water surface but also in water. Six degrees of freedom oscillations of the structure and mooring force were measured by model experiments.
From these experiments, it was shown that the lattice model has two peaks in the surge response curve and the oscillation amplitude and mooring forces increase according to the distance of separation between water level and upper deck.

1. Introduction

In recent years many experiments have been conducted for utilizing ocean space for various purposes in Japan. The model studied in the present report is a floating mid-layer type structure which is moored by chain. This structure is constructed to develop artificial breeding of marine species at Ryouri Bay in Iwate, Japan. (1),(2) The hull is submerged at depth of 4m under the sea surface during breeding time and an engine space is always positioned over the sea surface. The structure is moored by four points catenary mooring. It was assumed that the oscillation shows different characteristics according to the position of the structure.

Many researches have been published on the characteristics of floating structures. For example, the Megafloat is one of the most concerning issues in Japan. (3),(4),(5) These structures operate at the water surface. But the structure in this paper can also operate in the water.

In the present study, authors carried out experiments to investigate the oscillations of submerged marine structures. The tension of mooring lines and the motion in six degrees of freedom were measured. The parameters of experiments were the vertical level of the upper deck of the structure, wave direction and wave frequency. Two types of models (rectangular type and lattice type) were used for carrying our experiment.

2. Outline of the experiment

2-1 Ship Maneuvering Research Basin

Experiments are conducted in the ship maneuvering research basin of the Tokyo University of Marine Science and Technology. Dimensions of the basin are 50m long, 10m wide and 2.0m deep. Towing carriages, wave maker and wave absorber are installed in this basin. The flap type wave maker is operated by the external electric signal.

2-2 Experimented models

Authors used two kinds of models which are a rectangular model (Fig.1) and a lattice model (Fig.2). These models are made of acrylic board.

The dimensions of Rectangular model are as follows.

Length	: 1000 mm
Breadth	: 1000 mm
Depth	: 100 mm
Weight	: 27.76 kg

The dimensions of Lattice model are as follows.

Length	: 1000mm
Breadth	: 1000mm
Depth	: 100mm
Weight	: 15.06kg

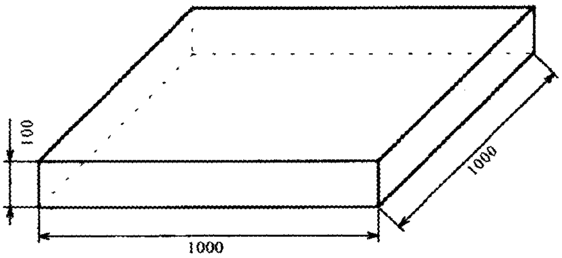

Fig.1. Rectangular model

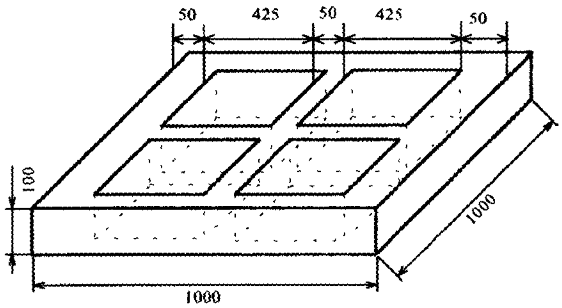

Fig.2. Lattice model

2-3 Mooring facilities

These models are moored at four points by the catenary method and an anchorage of the models consists of a square type fabricated steel structure. This anchorage structure consists of four steel channel sections of 5m length and its ends are riveted to form the square arrangement. Four corners of the floating structure were moored to the anchorage by mooring chains.

2-4 Experimental conditions

Wave direction and distance from the upper deck of the model to the water level were varied as shown in Fig.3. Distance from top of the model to water level was adjusted by putting weights inside the model.

Experiments are conducted in 13 conditions as shown in Table 1. Arrangement of experiment is shown in Fig.4.

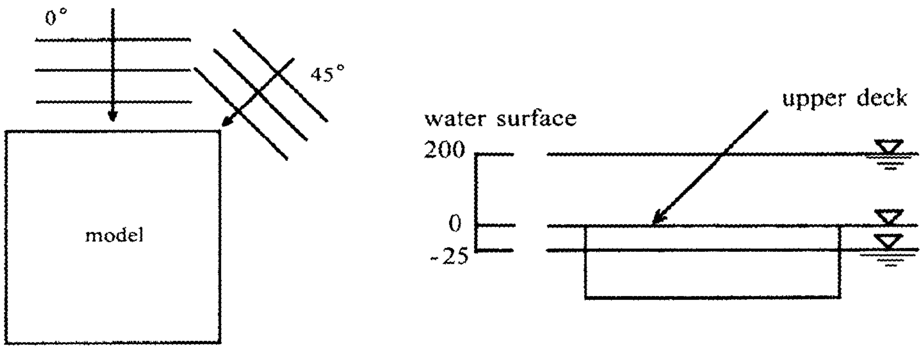

Fig.3. Wave direction and distance between upper deck of the model and the water surface

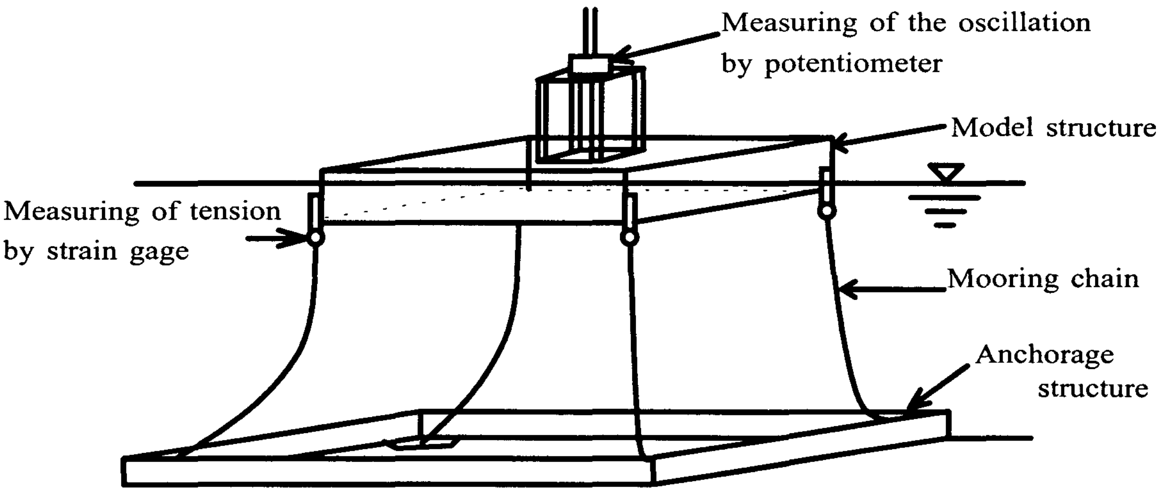

Fig.4. Arrangement of experiment

Table 1. Experimental conditions

Exp.No.	Model	Wave direction (degree)	Distance between upper deck of the model and the water surface (positive values indicated submergence)	Remarks
1	Rectangular	0	-25mm	-
2	Rectangular	45	-25mm	-
3	Rectangular	0	0mm	-
4	Rectangular	45	0mm	-
5	Rectangular	0	200mm	-
6	Rectangular	45	200mm	-
7	Lattice	0	-25mm	-
8	Lattice	45	-25mm	-
9	Lattice	0	0mm	-
10	Lattice	45	0mm	-
11	Lattice	0	200mm	-
12	Lattice	45	200mm	-
13	Lattice	0	200mm	Balance weight attached under the model.

3. Oscillations in waves

Oscillations were measured in regular wave and transient wave. The frequency is varied from 0.45Hz to 1.8Hz. The wave height of regular wave is 20mm at each frequency. Two kinds of transient wave were used, which are constant wave slope type (wave amplitude / length = 1/40 sec) and constant wave amplitude type (wave amplitude = 20 mm·sec).

In this paper we show only results in regular wave. The results in transient waves are almost same as the result in regular wave.

3-1 Measuring devices

Oscillations were measured by potentiometers of six degrees of freedom oscillations which were installed on the main towing carriage. The gimbals were attached at the center of the model structure and at the height of 280mm from the upper deck. Pitch, roll and yaw motions are measured by angular potentiometers at the gimbals. Heave, surge and sway motions are also measured by angular potentiometers at the end of measuring rail. Digital oscillograph and digital data recorder were used in recording.

3-2 Analytical method

Pitch, roll, yaw, surge, sway and heave amplitudes in regular waves were recorded from the digital oscillograph and non-dimensonalised as follows.

Pitching coefficient	: $\theta a / k \cdot \zeta a$
Rolling coefficient	: $\phi a / k \cdot \zeta a$
Yawing coefficient	: $\psi a / k \cdot \zeta a$
Surging coefficient	: $X a / \zeta a$
Swaying coefficient	: $Y a / \zeta a$
Heaving coefficient	: $Z a / \zeta a$

where

θa (deg)	: Pitching amplitude
ϕa (deg)	: Rolling amplitude
ψa (deg)	: Yawing amplitude
$X a$ (mm)	: Surging amplitude
$Y a$ (mm)	: Swaying amplitude
$Z a$ (mm)	: Heaving amplitude
k	: wave number
ζa (mm)	: wave amplitude

3-3 Experimental results

The frequency response curve of surge motion is shown in Fig.5 and 6. These figures show the comparison between rectangular model and lattice model at each water level. In these figures, it was shown that the maximum value of the surge motion occurs at 1.0 Hz (1.56 λ/L) in case of rectangular model. However in case of lattice model the maximum value occurs not only at 1.0Hz but also at 1.4Hz (0.80 λ/L). Thus in case of lattice model the surge motion has two peaks.

From Fig.7 to 12 show the influence of draught on oscillation amplitude. From these figures it is known that the amplitude decreases when water level increase in all motions.

Fig.13 and 14 show the influence of balance weight. There is no difference in amplitude of oscillation when the position of balance weight is changed.

In this report the results during the case of yaw, roll and sway motions were not compared as oscillations were very small and without any trend to be seen.

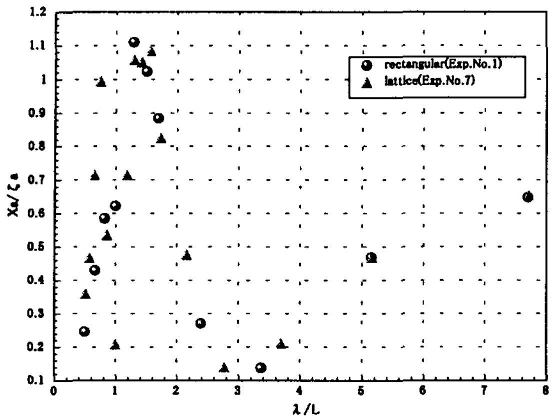

Fig.5. Surge (wave direction 0°, water level -25mm)

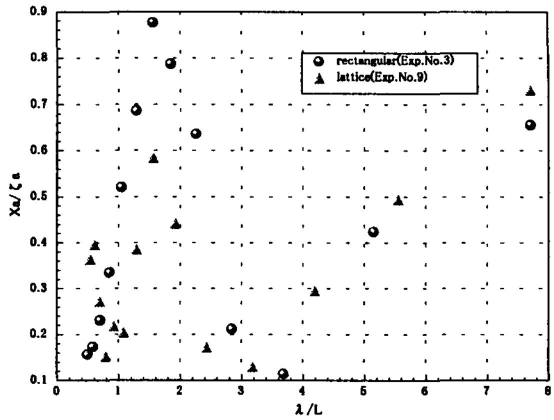

Fig.6. Surge (wave direction 0°, water level 0mm)

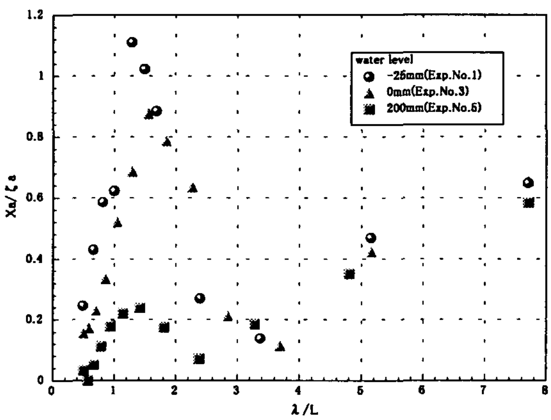

Fig.7. Surge (rectangular model, wave direction 0°)

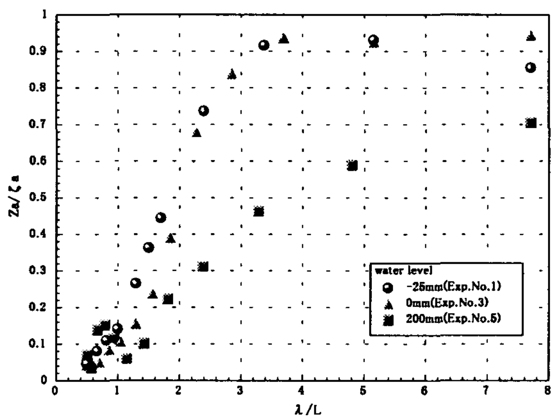

Fig.8. Heave (rectangular model, wave direction 0°)

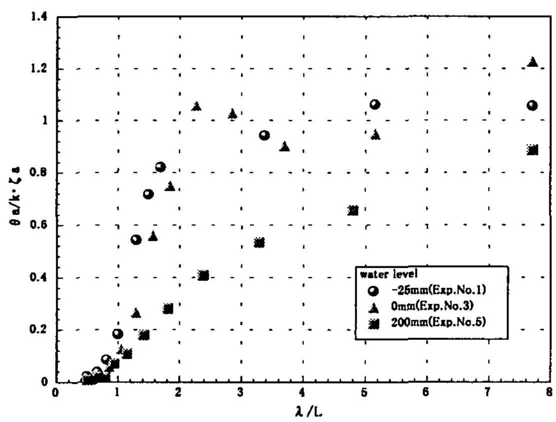

Fig.9. Pitch (rectangular model, wave direction 0°)

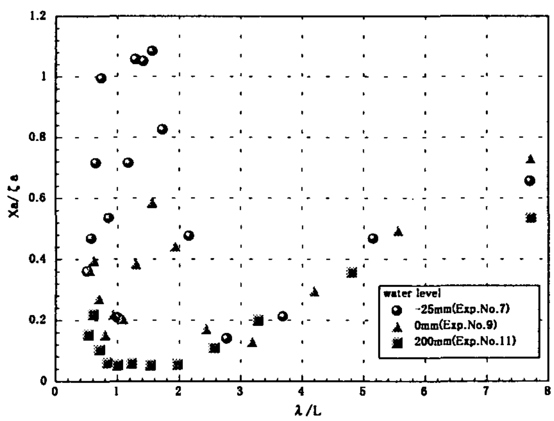

Fig.10. Surge (lattice model, wave direction 0°)

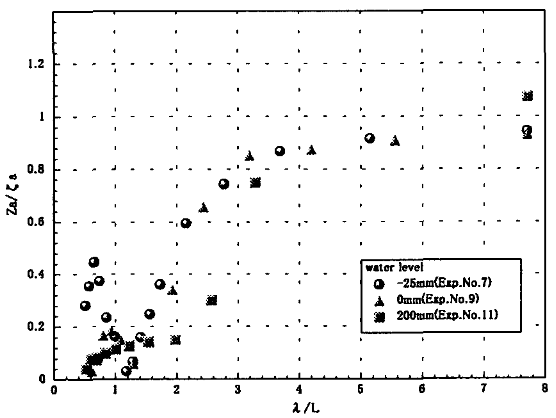

Fig.11. Heave (lattice model, wave direction 0°)

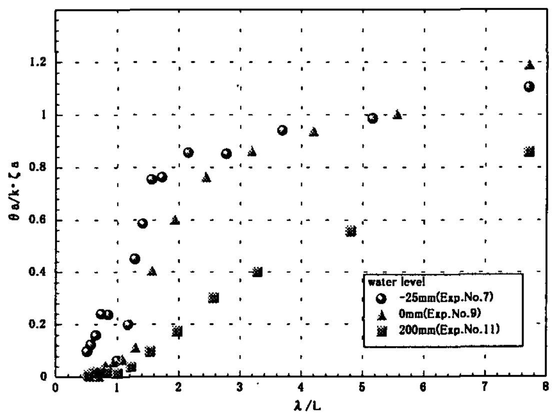

Fig.12. Pitch (lattice model, wave direction 0°)

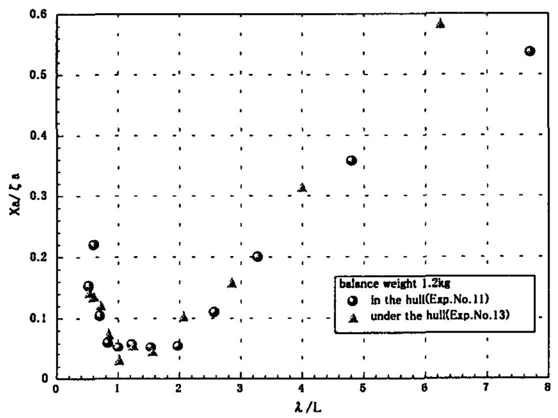

Fig.13. Surge (lattice model, wave direction 0°, water level 200mm)

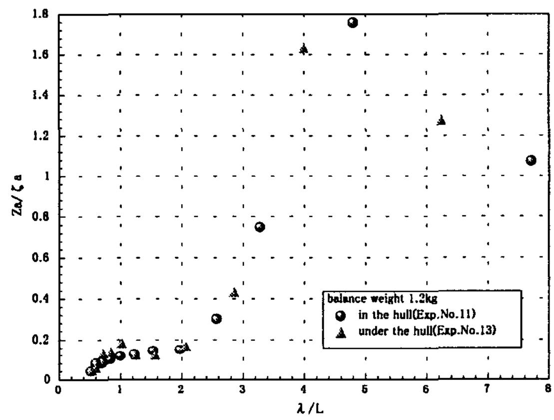

Fig.14. Heave (lattice model, wave direction 0°, water level 200mm)

4. Mooring force in waves

4-1 Measuring devices

The ring type measuring devices were attached to waterproof strain gage.

One end of measuring devices was connected to the pillars of four corners of the model and another end connected to the mooring chain. Digital oscillograph and digital data recorder were used for recording.

The position of the measuring point (A, B, C, D) is shown in Fig.15 in each wave directions.

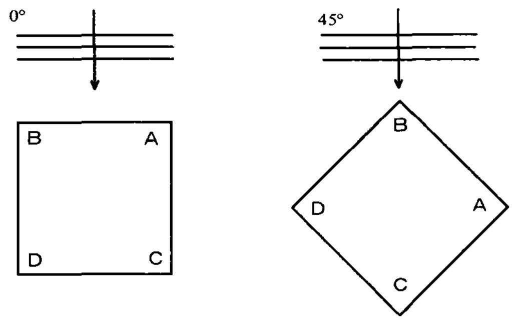

Fig.15. The position of the measuring point

4-2 Analytical method

From voltage of the digital oscillograph mooring tension was converted. Mooring tension was non-dimensionalied by the following equation.

$$C_T = \frac{T}{\left(\frac{1}{2}\right)\cdot \rho \cdot g \cdot H_w \cdot \nabla^{2/3}}$$

where

T	(kg)	: Tension of mooring line
ρ	(kg/m^3)	: Density of water
g	(m/sec^2)	: Acceleration gravity
H_w	(m)	: Wave height
∇	(m^3)	: Displaced volume of model

4-3 Result of mooring tension

Fig.16 and 17 shows the mooring tension of rectangular and lattice model at four mooring points. From these figures it was observed that the effect of mooring point was not so much in the rectangular model and lattice model.

Tension in chains which are parallel to wave direction is relatively high when compared with other chains in case of model position is relatively 45° to the wave direction. (Fig.18 and 19)

The influence of water level was shown from Fig.20 to 23. It is observed the mooring tension increases with draught.

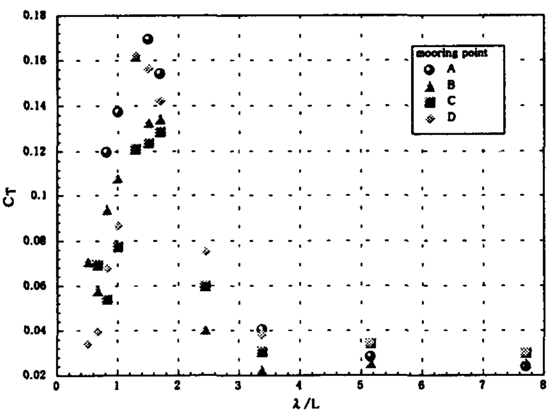

Fig.16. Mooring tension (rectangular model, wave direction 0°, water level -25mm, Exp.No.1)

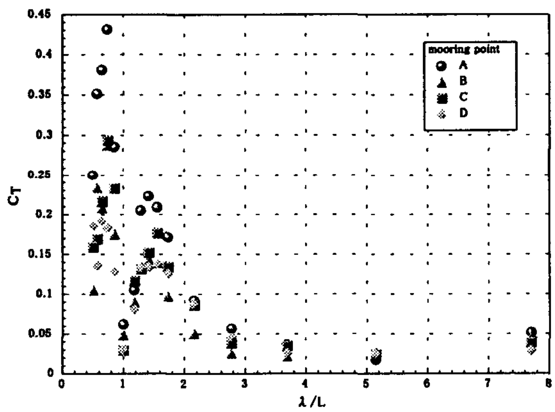

Fig.17. Mooring tension (lattice model, wave direction 0°, water level -25mm, Exp.No.7)

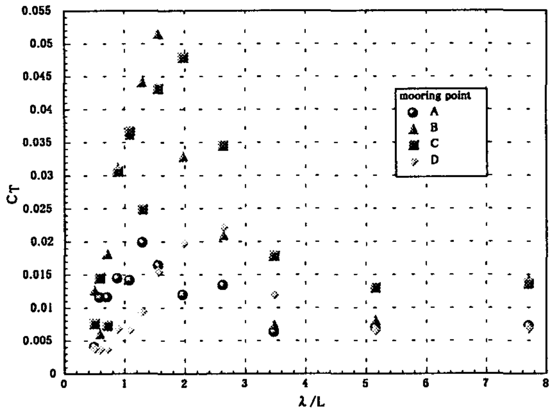

Fig.18. Mooring tension (rectangular model, wave direction 45°, water level 0mm, Exp.No.4)

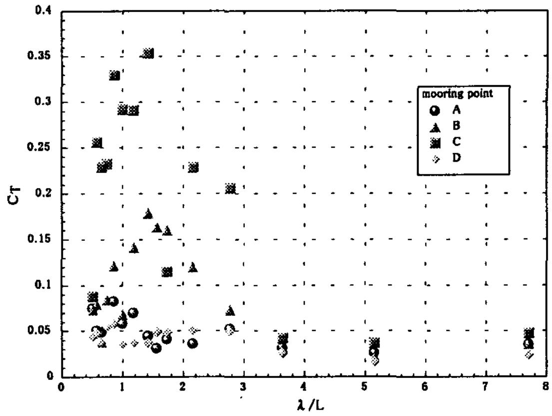

Fig.19. Mooring tension (lattice model, wave direction 45°, water level –25mm, Exp.No.3)

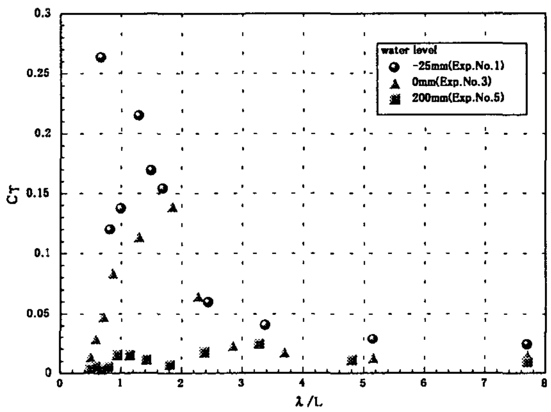

Fig.20. Mooring tension (rectangular model, wave direction 0°, mooring point A)

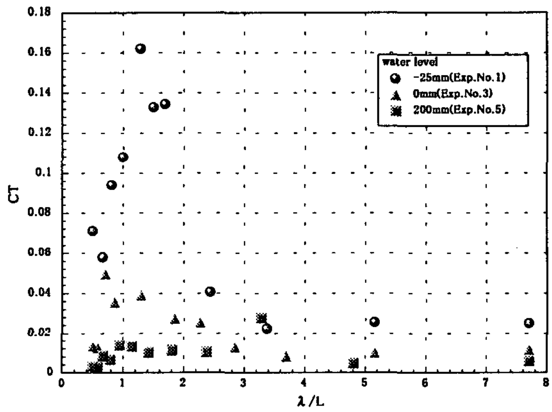

Fig.21. Mooring tension (rectangular model, wave direction 0°, mooring point B)

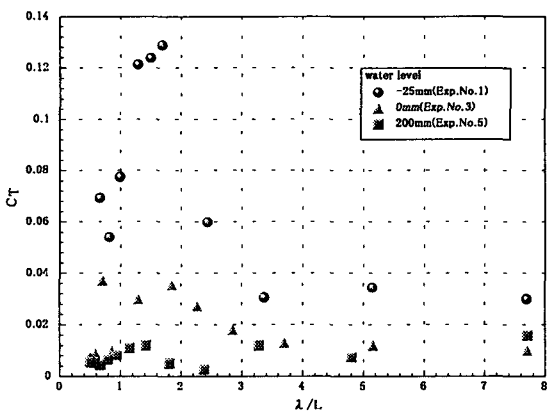

Fig.22. Mooring tension (rectangular model, wave direction 0°, mooring point C)

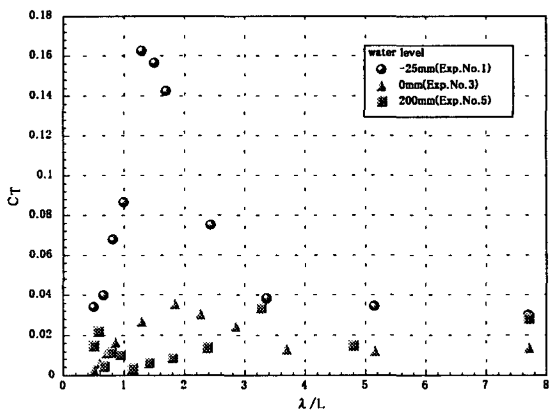

Fig.23. Mooring tension (rectangular model, wave direction 0°, mooring point D)

5. Conclusions

Experiments carried out to investigate the application of the ocean space for various purposes. Two kind models of a rectangular type and a lattice type were experimented. The vertical position of the model also changed with respect to the water level. Oscillations of the model and tensions of four mooring lines were measured. Experiments were conducted both in regular waves and in transient waves.

The maximum peak of surge response was observed at wave frequency of 1.0 Hz in case of rectangular model. However it was observed that surge response has two peaks at frequencies of 1.0Hz and 1.4Hz in case of lattice model. The influences of draught on oscillations were investigated by varying the waterline level of the model. It was observed that the amplitude of surge, heave and pitch oscillation came down as the positive distance from top of the model to water level increases. However the yaw, roll and sway oscillations are very small to compare.

The mooring tension of chains attached to the model was studied by changing wave direction and draught. It was observed that the relatively high tension occurred in the chains that were parallel to the wave direction when compared with other chains. It was observed that the tension decrease when the positive distance from top of model to water level increases.

From these results, it may be observed that it is possible to reduce the oscillations of ocean structure by increasing the draught and consequently the stability the structure can be expected.

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