Proceedings of OMAE2005
24th International Conference on Offshore Mechanics and Arctic Engineering (OMAE 2005)
June 12-17, 2005, Halkidiki, Greece

OMAE2005-67365

DEVELOPMENT OF MULTI-CONNECTED FLOATING BODY SYSTEM

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ABSTRACT

A multi-connected floating body system composed of many connected small-scale floating body units has a number of advantages with regard to construction and performance. To realize the multi-connected floating body system, a new type of mechanical connecting device was developed. It is composed of multi-degrees of freedom connecting mechanism and restricting mechanism to control a restricting condition between floating body units, and its effectiveness was confirmed by model basin test in waves. Next, friction and wear tests in the seawater environment led to the discovery of suitable materials for oscillatory sliding parts in multi-degrees of freedom connecting mechanism. Finally, a field test performed for two floating body units connected by use of the mechanical connecting device proved that the developed mechanical connecting device was of practical use.

1. INTRODUCTION

Utilization of ocean space by floating structures is considered to be one of the most important subjects from the viewpoint of preservation of the ocean environment and proof against earthquakes, and several plans to construct various kinds of floating structures have been proposed. One example is shown in Fig.1. This figure shows the image of floating structure for preservation of the ocean environment and utilization of natural energy.[1] Judging from the construction and performance of these kinds of floating structure, the floating structure with multi-connected floating body system composed of many connected small-scale floating body units is more rational than the usual united floating body, because the multi-connected floating body system has a number of advantages such as the easiness of coping with changes of scale, structure and function, the possibility of construction in small-scale shipyards, and the short term of work compared with the usual united floating body.

The key to realizing the multi-connected floating body system is the technology to connect each floating body unit. In order to make use of the advantages of the multi-connected floating body system, a mechanical connecting device is

Fig. 1 Example of multi-connected floating body system

necessary to connect and disconnect each floating body unit and to endure heavy loads due to waves. The usual mechanical connecting device uses a bolt or pin, but this is applicable only to small-scale floating structures in moderate sea area considering the wave loads acting on connecting parts.

Moreover, a technique to lubricate sliding parts without oil and by means of seawater is required to prevent pollution of the sea. Since seawater is inferior to oil in lubricating ability, it is necessary to design the sliding parts in consideration of wear seizure. Almost all usual sliding bearings lubricated by seawater are small-sized, so the technique to apply these materials to large scale sliding bearing is very important and difficult.[2,3]

In this study, we developed a new type of mechanical connecting device to satisfy the above conditions. Based on the characteristics of response of multi-connected floating body system to waves investigated by theoretical analysis, an original new concept for the mechanical connecting device was obtained, and its effectiveness was confirmed by model basin test. Materials to lubricate sliding parts without oil and by means of seawater were selected by means of friction and wear tests in the seawater environment. Finally a field test was performed, and the developed mechanical connecting device was proven to be of practical use. This paper describes the outline of development of the new type of mechanical connecting device.

2. MECHANICAL CONNECTING DEVICE

2.1 New Concept of Mechanical Connecting Device

The basic idea of our mechanical connecting device is shown in Fig.2. The new concept of mechanical connecting device features multi-degrees of freedom coupling mechanism and restricting mechanism.[4] The term "multi-degrees of freedom coupling mechanism" will hereinafter be abbreviated to "coupling mechanism". The coupling mechanism is positioned at the center of the floating body unit and permits relative rotations in all directions between floating body units so that the connecting forces acting on the mechanical connecting device can be reduced.

The restricting mechanism is positioned at both sides of the floating body unit and adjusts the restricting condition between floating body units. An explanatory diagram of the effect of adjusting the restricting condition between floating body units is shown in Fig.3. As the restriction between floating body units becomes hard, the relative motion becomes small while the connecting force becomes large. The restriction is controlled to suit the purpose of use and operating condition of the floating structure.

According to the basic idea of the mechanical connecting device, the coupling mechanism was designed as shown in Fig.4. The mechanism is based on the method of universal joint with freedom of rotation around the axial direction added to the mechanism. Thus a mechanical joint to permit rotations in all directions such as a ball joint was realized easily at a low cost.

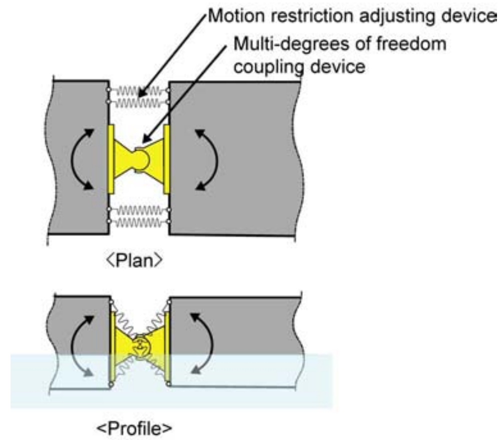

Fig. 2 Basic idea of mechanical connecting device

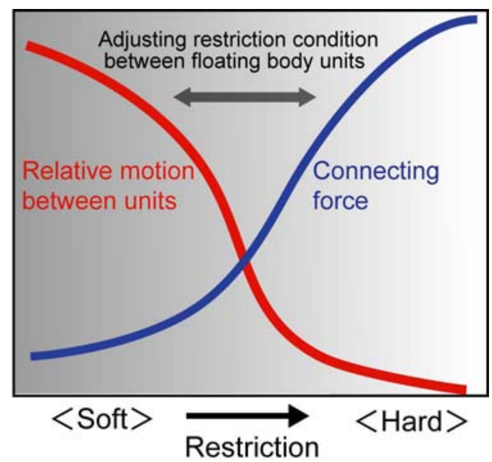

Fig. 3 Explanatory diagram of effect of adjusting restriction between floating body unit

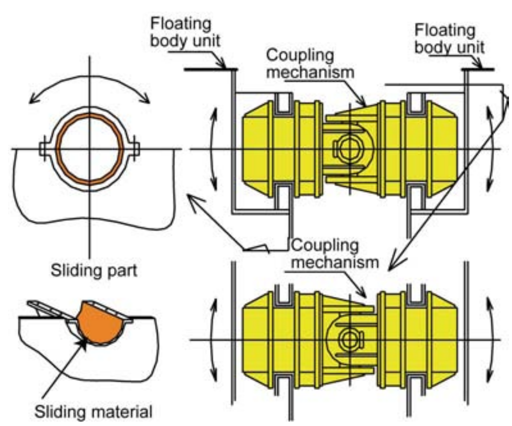

Fig. 4 Multi-degrees of freedom coupling mechanism

2.2 Fundamental Characteristics of the Multi-connected Floating Body System

In order to examine the characteristics of the multi-connected floating body system, theoretical calculations were conducted for motions of the floating body unit and connecting forces acting on the mechanical connecting device in waves.

2.2.1 Calculation method

The theoretical calculations were carried out by use of the computer program for motion analysis of multiple floating bodies connected and moored in waves. This computer program can be used widely for multifarious problems by modeling mooring or connecting conditions to linear dynamic system of mass-spring-damper.[5,6]

The analytical procedure selected for prediction of motions of a body freely floating in waves is the basis of the present study, and for that procedure we adopted the three dimensional singularity distribution method. The equation of motions for a single body freely floating in waves is given as follows in matrix notations,

$$(\boldsymbol{M}+\boldsymbol{A})\ddot{\boldsymbol{\eta}}+\boldsymbol{B}\dot{\boldsymbol{\eta}}+\boldsymbol{C}\boldsymbol{\eta}=\boldsymbol{F} \qquad (1)$$

where

$\boldsymbol{M}$: generalized mass for body; 6 x 6 matrix

$\boldsymbol{A}$: added mass ; 6 x 6 matrix

$\boldsymbol{B}$: damping coefficients ; 6 x 6 matrix

$\boldsymbol{C}$: hydrostatic restoring coefficients ; 6 x 6 matrix

$\boldsymbol{\eta}$: motions $(\eta_j=\eta_{Aj}e^{i\omega t},\ j=1,2,\cdots,6)$; 6 x 1 vector

$\boldsymbol{F}$: wave exciting force and moment $(F_j=F_{Aj}e^{i\omega t},\ j=1,2,\cdots,6)$; 6 x 1 vector

ω : circular frequency of regular waves

A : subscript indicating complex amplitude

Defining the linear operator $\boldsymbol{D}$ as follows:

$$\boldsymbol{D}=-\omega^2\,(\boldsymbol{M}+\boldsymbol{A})+i\omega\,\boldsymbol{B}+\boldsymbol{C} \qquad (2)$$

Equation (1) may be simplified in the form:

$$\boldsymbol{D}\cdot\boldsymbol{\eta}_A=\boldsymbol{F}_A \qquad (3)$$

The equation of motions for multiple floating bodies moored and connected each other is given in a general form as follows:

$$\begin{bmatrix} & \vdots & & \vdots & \\ \cdots & \boldsymbol{D}_l+\boldsymbol{E}_{ll}+\boldsymbol{G}_l & \cdots & \boldsymbol{E}_{lm} & \cdots \\ & \vdots & & \vdots & \\ \cdots & \boldsymbol{E}_{ml} & \cdots & \boldsymbol{D}_m+\boldsymbol{E}_{mm}+\boldsymbol{G}_m & \cdots \\ & \vdots & & \vdots & \end{bmatrix}\begin{bmatrix}\vdots\\ \boldsymbol{\eta}_{lA}\\ \vdots\\ \boldsymbol{\eta}_{mA}\\ \vdots\end{bmatrix}=\begin{bmatrix}\vdots\\ \boldsymbol{F}_{lA}\\ \vdots\\ \boldsymbol{F}_{mA}\\ \vdots\end{bmatrix} \qquad (4)$$

where

$\boldsymbol{D}_l$: coefficients for a single body freely floating ; 6 x 6 matrix

$\boldsymbol{G}_l$: added coefficients due to mooring members ; 6 x 6 matrix

$\boldsymbol{E}_{lm}$: added coefficients due to connecting members ; 6 x 6 matrix

$\boldsymbol{F}_{lA}$: wave exciting forces for a single body freely floating ; 6 x 6 matrix

The subscripts *l*, m indicate quantities related to number of bodies, and added coefficients matrices $\boldsymbol{E}_{lm}$ can be obtained from the forces acting on the *l*-th body when the *m*-th body is forced to oscillate and the other bodies are obtained. The hydrodynamic interaction is ignored.

The matrix $\boldsymbol{K}$ representing the characteristics of the mooring or connecting member is defined in reference to the local coordinate system as follows,

$$\boldsymbol{K}=\left[K_{ij}\right] \quad ;\ i,j=1,2,\cdots,6 \qquad (5)$$

Defining the transformation matrix $\boldsymbol{T}$ from the fixed coordinate system located on the body to the local coordinate system of the mooring member, the added coefficient matrix $\boldsymbol{G}$ due to mooring member is given as follows:

$$\boldsymbol{G}=\boldsymbol{T}^t\boldsymbol{K}\boldsymbol{T} \qquad (6)$$

Where the superscript *t* is referred to the transpose of the matrix.

It is assumed that the transformation matrices $\boldsymbol{T}_l$ and $\boldsymbol{T}_m$ are defined for the transformation from the fixed coordinate systems located bodies to the local coordinate system of connecting member, respectively, where in the local coordinate systems of connecting members, the one is a parallel translation of the other. The added coefficients $\boldsymbol{E}$ are expressed as follows,

$$\boldsymbol{E}_{ll}=\boldsymbol{T}_l^t\boldsymbol{K}\boldsymbol{T}_l$$

$$\boldsymbol{E}_{lm}=\boldsymbol{T}_l^t\boldsymbol{K}\boldsymbol{T}_m \quad (l\neq m) \qquad (7)$$

Where the matrix $\boldsymbol{K}$ describes the characteristics of a connecting member. By taking into account the damping and the inertia forces as well as the restoring forces, the matrix $\boldsymbol{K}$ can be written in the same form as the matrix $\boldsymbol{D}$ shown in equation (2). Its form can be written as follows,

$$\boldsymbol{K}=-\omega^2\boldsymbol{A}^k+i\omega\boldsymbol{B}^k+\boldsymbol{C}^k \qquad (8)$$

where

$\boldsymbol{A}^k$: mass coefficients due to mooring or connecting member; 6 x 6 matrix

$\boldsymbol{B}^k$: damping coefficients due to mooring or connecting member; 6 x 6 matrix

$\boldsymbol{C}^k$: restoring coefficients due to mooring or connecting member; 6 x 6 matrix

Since it treats the mooring or connecting member as a linear dynamic system in a unified manner, the present method can be applied to a wide variety of motion problems related to floating bodies under composite external loads.

2.2.2 Calculated results

The calculations were conducted for a model case in which four floating body units are connected to each other in a longitudinal direction by use of the mechanical connecting device as shown in Fig.5. The principal dimension of the floating body unit is shown in Table 1, and the distance between the floating body units was set at 2.0 m. The restricting mechanism is made by use of connecting line to restrict the relative roll, pitch and yaw motions between adjacent floating body units. The restriction can be adjusted by controlling the spring characteristics of the connecting line.

Comparative calculations were conducted for two typical coupling conditions of the coupling mechanism; rigid connection which transmits moments and connection to free relative rotations which does not transmit moments between adjacent floating body units. The calculated results are shown in Fig.6. These figures show the maximum values; the maximum expected value for 1000 samples, of forces and moments acting on the coupling mechanism between adjacent floating body units as a function of significant wave period. In the case of rigid coupling condition, the connecting forces in lateral and vertical directions are larger than those for the condition to free relative rotations. As a result, it can be understood that the coupling mechanism to free relative rotations has the ability to minimize the connecting forces between adjacent floating body units. By use of the coupling mechanism, the multi-connected floating body system can be realized.

In order to examine the effect of the restricting mechanism upon the connecting forces acting on the coupling mechanism, the calculations were conducted while varying the spring constant of the connecting line of the restricting mechanism. The calculated results are shown in Fig.7. In these figures, the significant values of connecting forces acting on the coupling mechanism and relative motions between adjacent floating body units in irregular waves with unit significant wave height and 5 seconds of significant wave period are shown as a function of the spring constant of the connecting line. The connecting forces in all directions tend to be larger as the spring constant becomes stronger. When the range of the spring constant is smaller than 1,000 kN/m, the increase in connecting force is not so large. But the connecting force becomes very large suddenly at 1,000 kN/m of spring constant.

With regard to the relative motions, the relative roll motion tends to be smaller because the restricting moment for roll motion becomes larger as the spring constant becomes larger. The relative pitch motion shows almost no change, and it can be understood that it is very difficult to restrict the pitch motion. This is due to the fact that the restoring pitch moment is too large to restrict the relative pitch motion by use of restricting mechanism. On the other hand, the relative yaw motion tends to be larger as the spring constant becomes larger. In the case of relative yaw motion, yaw motion with natural period is caused by the restricting mechanism. Therefore, it seems that the effect of resonance of relative yaw motion to waves appears in the usual wave period range because the natural period of relative yaw motion becomes shorter as the restriction by spring becomes harder.

According to the results, the most suitable spring constant of connecting line can be set. In the case shown here, it can be said that the spring constant should be smaller than 1,000 kN/m.

2.3 Model Basin Test

In order to investigate the characteristics of response of multi-connected floating body system in waves and to confirm the effectiveness of the new concept of mechanical connecting device and the applicability of the theoretical calculation method, the model basin test was conducted for the multi-connected floating body system.[1] Four floating body units of 1/30 scale models are connected by the new concept of mechanical connecting device as shown in Fig.5. The spring constants of connecting line of restricting mechanism were varied between 200 kN/m and 1000 kN/m. The position of the model is kept by mooring the end of the floating body units with soft springs. A photograph of the model basin test is shown in Fig.8.

Some examples of test results in regular waves are shown in Fig. 9 in comparison with the calculated values. In these figures, the amplitude of motions of the floating body units for unit wave amplitude in the wave direction of 45 degrees is shown as a function of wave period. There are slight differences in motions among floating body units. The influence of spring constant is found on roll motion in the shorter wave period range and yaw motion in the longer wave period range. Comparing the measured results and calculated ones, even though some discrepancies are found, it can be said that fairly good agreement is obtained on the whole.

Table 1 Main dimensions of floating body unit

Length	30.0 m
Breadth	15.0 m
Depth	6.0 m
Draft	3.0 m
Displacement	1384 ton

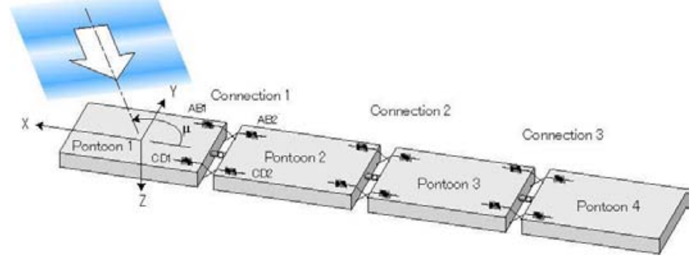

Fig. 5 Multi-connected floating body units

The measured and calculated results of connecting forces acting on the coupling mechanism between No.1 and No.2 units are shown in Fig.10. The influence of spring constant is especially remarkable in the vertical component of connecting force in the longer wave period range. Comparing the measured and calculated results, even though some discrepancies are found, it seems that fairly good agreement is obtained on the whole. And it can be said that the applicability of the theoretical calculation method was experimentally confirmed.

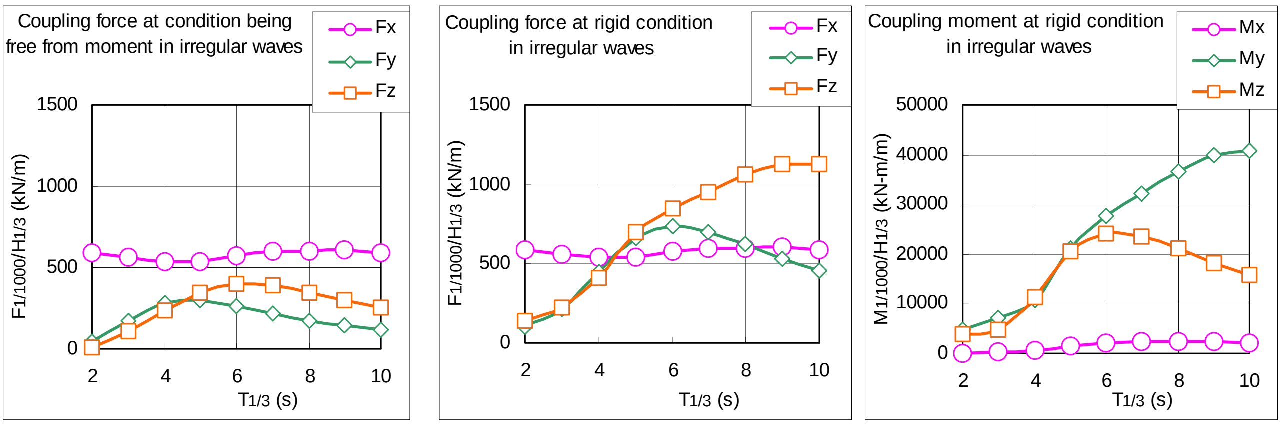

Fig. 6 Maximum values of forces and moments acting on coupling device between adjacent floating body units in two typical coupling conditions

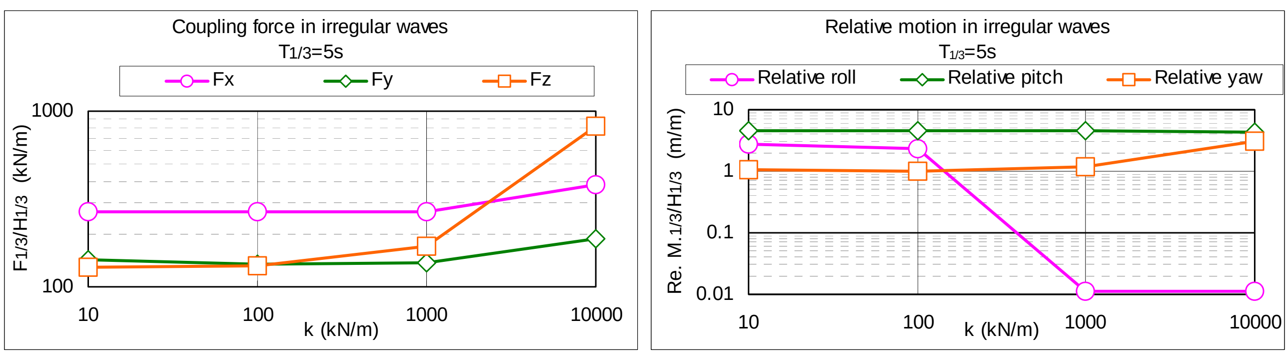

Fig. 7 Effect of stiffness of restriction device on forces acting on multi-degrees of freedom coupling device and relative motion

Fig. 8 Model basin test using four floating body units of 1/30 scale models

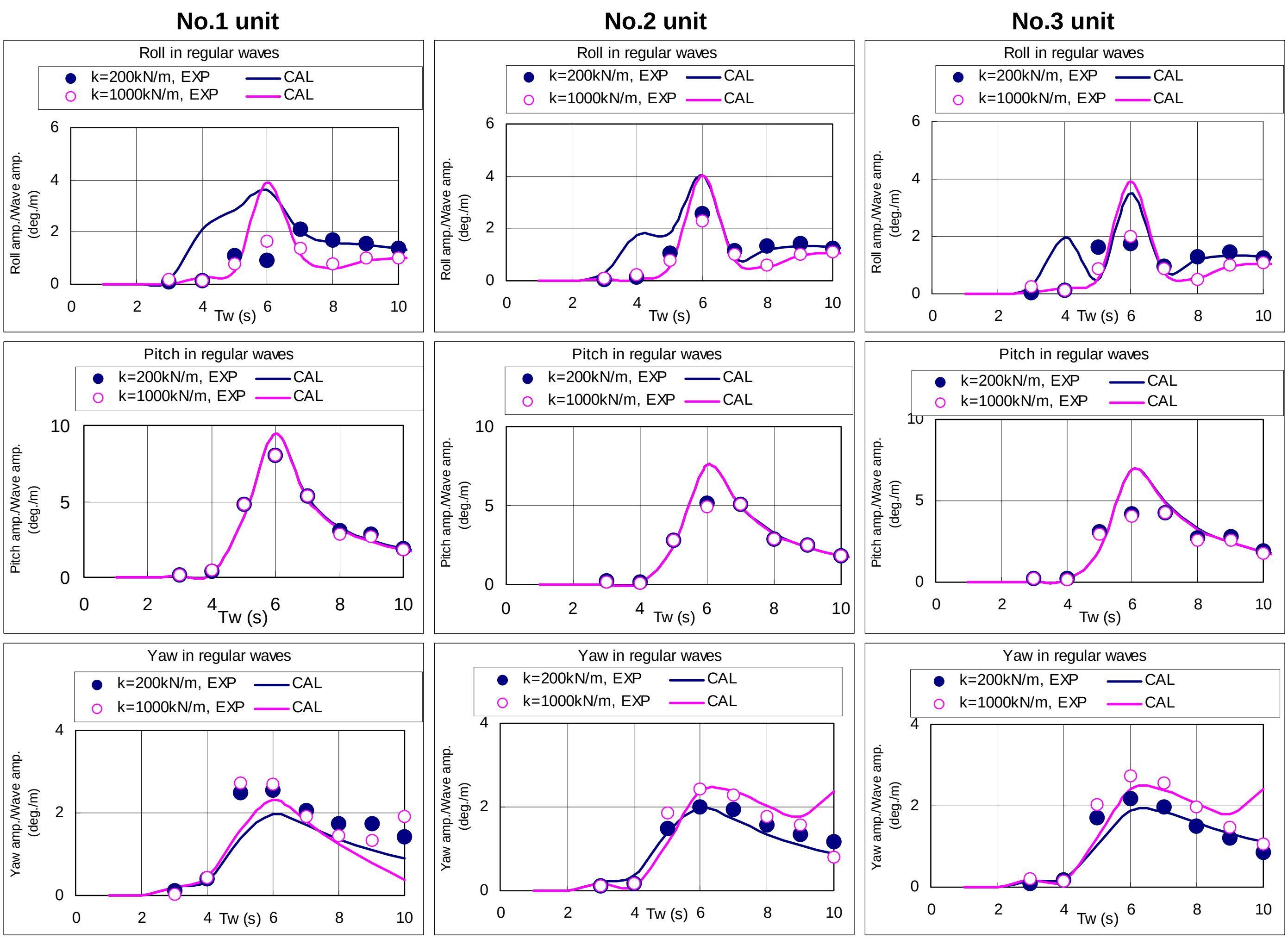

Fig. 9 Measured and calculated results of motions of floating body units in regular waves

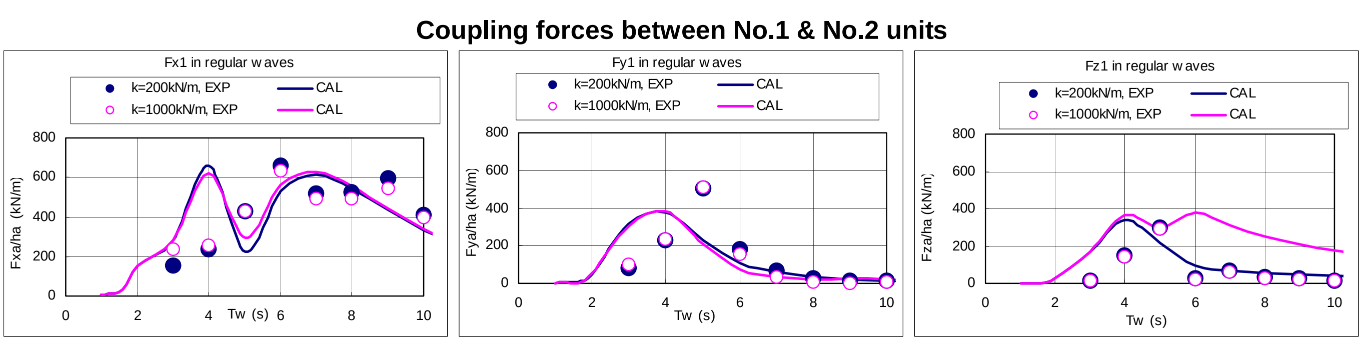

Fig. 10 Measured and calculated results of forces acting on coupling mechanism in regular waves

3. MATERIAL FOR THE OSCILLATORY SLIDING PART

Friction and wear tests in seawater were carried out, and materials suitable for oscillatory sliding parts employed in the coupling mechanism were selected.[7]

3.1 Test Procedure

A friction and wear test apparatus simulating the oscillatory sliding condition which the coupling mechanism suffers in practical use, was manufactured for this study. In the friction and wear tests, oscillating angle between sliding parts, i.e. a journal bearing and a shaft, is 90 degrees, and friction and wear were evaluated under the sliding condition expected in the coupling mechanism. The bearing materials prepared for the tests are shown in Table 2. Five kinds of polymers such as PTFE, phenolic and PA (polyamide) resins, and two kinds of high corrosion resistant Cu alloys were prepared as bearing material, and stainless steel (JIS SUS304) shafts were used as the mating surface with the bearings. As a test environment, seawater, atmosphere and seawater-atmosphere repeated conditions were used, and when the test environment was changed, contact pressure was changed under a determined sliding condition.

3.2 Test Results

Fig.11 shows specific wear rates of bearing materials in seawater obtained under various contact pressures at sliding speed of 0.05 m/s and sliding time of 6 hours. The specific wear rate is defined as follows.

$$Ws = V/(P/L) \quad (mm^2/N) \qquad (9)$$

Where,

V : Volume of wear (mm^3)

P : Contact pressure (N)

L : Sliding distance (mm)

From this result, it can be found that the specific wear rates of bearing materials become larger in the following order: Cu alloys, PA, PTFE, phenolic resins. The influence of contact pressure on specific wear rates is different in each bearing material. And in the tests in the seawater environment, seizure was not observed for any bearing material under the maximum contact pressure in this study, which is the maximum value expected in the actual coupling mechanism. Fig.12 shows the mean value and fluctuation of friction coefficient in seawater when contact pressure was 10 MPa. The average friction coefficient shows a similar tendency to specific wear rates except PTFE. The friction coefficient of PTFE is very small because PTFE acts as a solid lubricant.[8]

Fig.13 shows specific wear rates of bearing materials in various environments. These data have been obtained when contact pressure was 2.5 MPa. The specific wear rates of bearing materials in various environments indicate almost the same tendency as those in seawater.

As for test results, the characteristics of friction and wear of the various bearing materials were obtained and Cu alloys and PA resin show excellent wear resistance. For the field test, PA resin, which shows excellent wear resistance, and phenolic resin, which is not the most suitable material for the sliding parts but can be easily made to bearing, were chosen as the materials for the sliding parts in the coupling mechanism.

Table 2 Bearing materials prepared for the tests

	Main contents	Structure of bearing material	Diametric clearance
A	Phenolic resin	Multilayer of phenolic resin + solid lubricants (thickness: 4mm)	0.50mm
B	Phenolic resin	Multilayer of phenolic resin + solid lubricants for high PV* use (thickness: 4mm)	0.50mm
C	PTFE	Bimetal plated layer: PTFE + Pb (thickness: 0.3mm) back metal: sintered Cu alloy (thickness: 1.2mm)	0.33mm
D	PTFE	Bimetal plated layer: PTFE + Pb + Sn (thickness: 0.3mm) back metal: sintered Cu alloy (thickness: 1.2mm)	0.35mm
E	Polyamide	Cast polyamide + solid lubricants for high PV* use (thickness: 4mm)	0.73mm
F	Cu alloy	Bimetal plated layer: Pb bronze +solid lubricants (thickness: 0.5mm) back metal: sintered alloy (thickness: 1mm)	0.31mm
G	Cu alloy	Al bronze + solid lubricants buried therein (thickness: 4mm)	0.53mm

*PV: contact pressure and sliding velocity

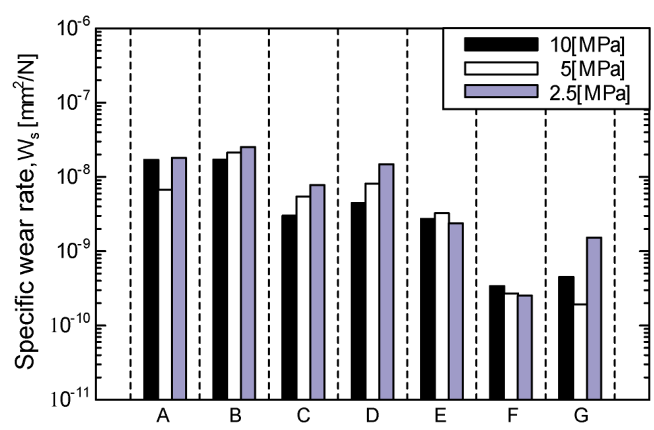

Fig. 11 Specific wear rate of bearing material under various contact pressure in seawater environment

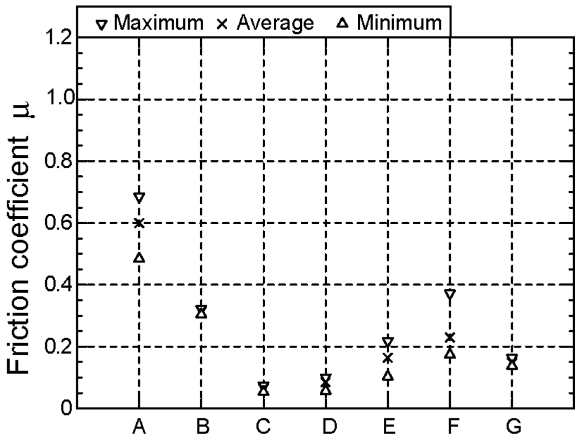

Fig.12 Friction coefficient of bearing materials in seawater environment

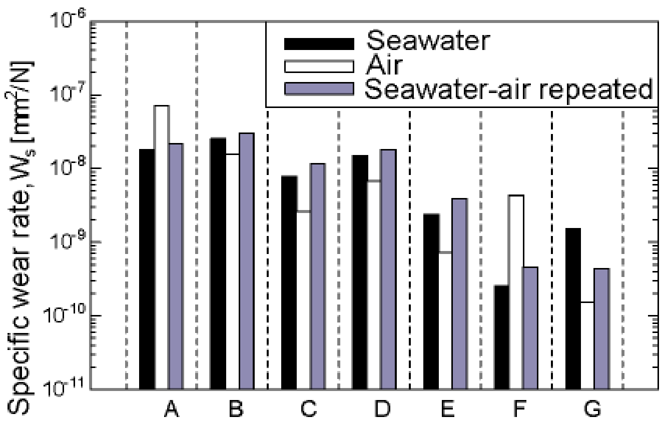

Fig.13 Specific wear rate of bearing materials under various environmental condition

Fig. 14 Field test

4. FIELD TEST

The field test was performed by use of large-sized floating body units and the developed mechanical connecting device, and the practicality of the developed mechanical connecting device was verified.[4]

4.1 Procedure of the Field Test

A photograph of the field test is shown in Fig.14. The floating body unit was 12 m in length and 4.5 m in breadth, and made of steel. Two floating body units were connected to each other by use of our mechanical connecting device and moored by use of the mooring chain and yoke mooring system.[9] The mechanical connecting device was composed of the coupling mechanism and four sets of restricting mechanism. The coupling mechanism was used to connect the end of yoke to land too. Phenolic resin and PA resin were used as the material of sliding parts of the coupling mechanism. The restriction mechanism was made by use of hydraulic cylinder and accumulator.

In view of the purpose of the field test, it was important to measure the environmental conditions, behaviors of the floating body units and mechanical connecting device and connecting forces acting on mechanical connecting device. An automatic data acquisition system was prepared using a personal computer, and continuous measurement was performed for four months. Moreover, the conditions of wear and corrosion of sliding parts were observed.

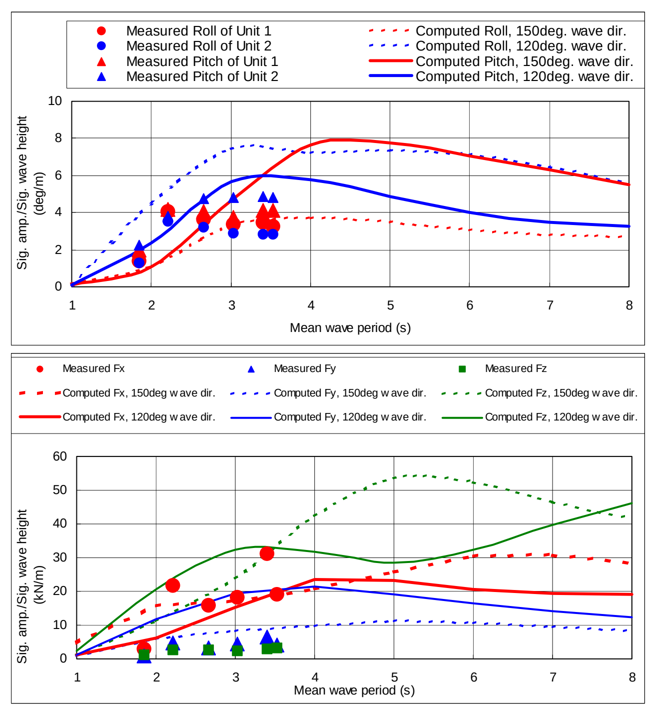

Fig.15 Measured results of motion and connecting force in field test

4.2 Test Results

In data analysis, the so-called “Statistical Time-history Analysis” was performed, and the significant and maximum values of responses were obtained. As results of the field test, measured results of motions of floating body unit and connecting forces acting on the coupling mechanism are shown in Fig.15 in comparison with the calculated results. In these figures, significant amplitudes of responses for unit significant wave height are shown as a function of significant wave period. The calculations were carried out for wave directions of 120 degrees and 150 degrees because wave direction was not measured. Comparing the measured results and those of calculated motions, it can be said that fairly good agreement was obtained on the whole. On the other hand, some discrepancies were found for connecting forces. This seems to be due to the fact that the accuracy of the measurement of connecting forces was not satisfactory except axial component of force. During the field test, no unique phenomenon was observed, and it was confirmed that the mechanical connecting device displayed the required function.

In order to inspect wear and corrosion of the sliding parts of the coupling mechanism, dismantling inspection was performed. Fig.16 shows photographs of the sliding surface of thrust bearings made from of phenolic resin and PA resin and profiles of sliding surface before and after field test. Luster can be seen over the sliding surface of the thrust bearing made from of phenolic resin. From the profiles of sliding surfaces, even though increase of roughness can be found at part of the sliding surface due to extraneous matters, it can be found that almost all of the sliding surface was smoothed by running-in. Thus, wear and tear of bearing materials were not found to have

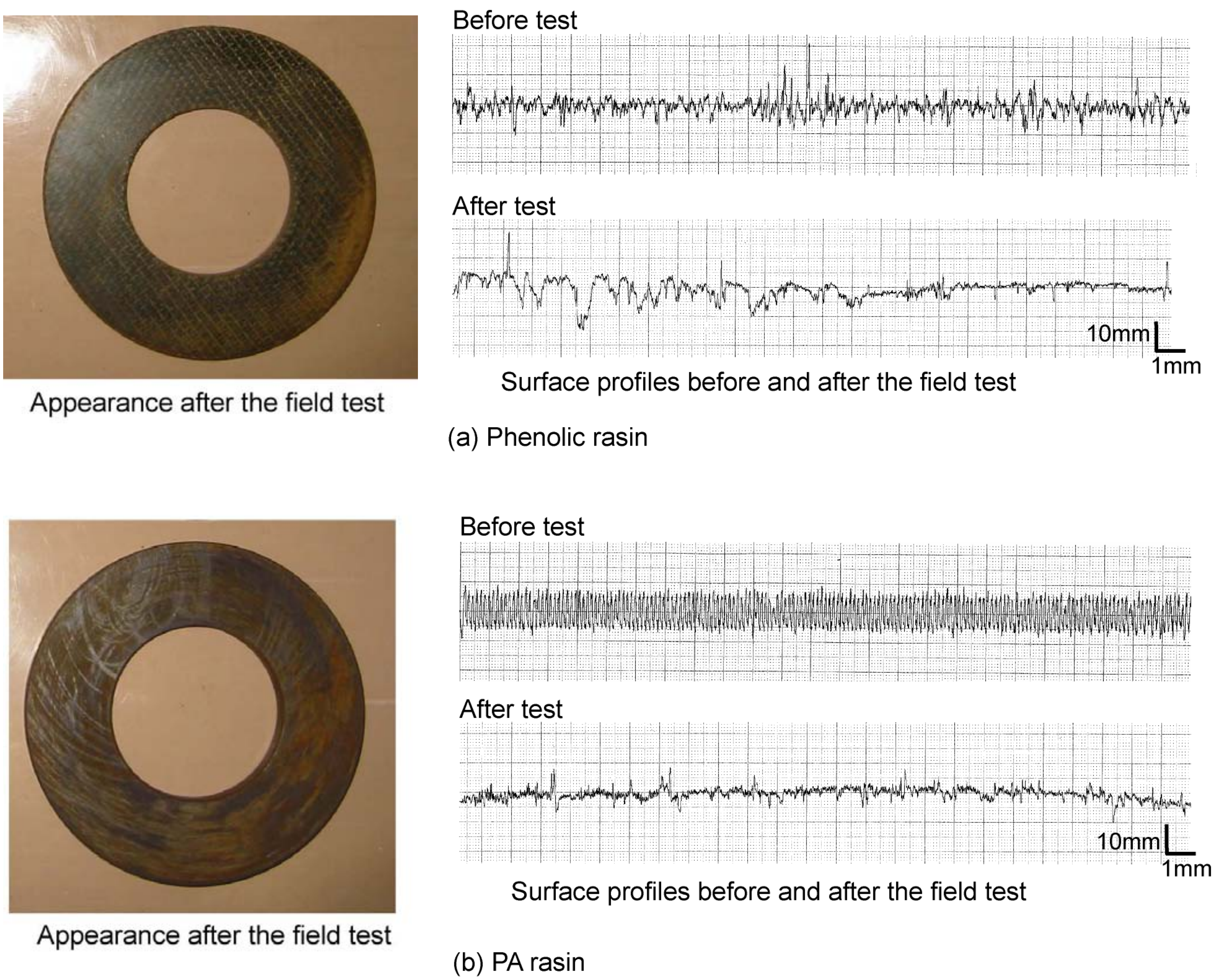

Fig.16 Photos and profiles of sliding surfaces of thrust bearings for the field test

progressed during the field test. On the other hand, carbon steel was severely corroded by seawater, so it is not suitable as a material of the sliding parts.

As a result of the field test, it was confirmed that the behavior of multi-connected floating body system was almost the same as that estimated and that the sliding surfaces of the coupling mechanism did not show severe wear. Thus, the results proved the practicality of our mechanical connecting device.

5. CONCLUDING REMARKS

To realize the multi-connected floating body system, a new type of mechanical connecting device was developed. It features a coupling mechanism to reduce connecting forces and restricting mechanism to control restricting conditions between adjacent floating body units. Model basin and field tests for the multi-connected floating body system, friction and wear tests for sliding bearing materials, and other tests were conducted, and our mechanical connecting device was shown to be of practical use.

The application of our mechanical connecting device is very wide. It can be applied to floating structures in port and harbor and coastal zones. Namely, it can be applied to mooring or connecting of usual floating pier and floating breakwater, as well as to create various kinds of multi-connected floating body system for ocean space utilization.

ACKNOWLEDGMENTS

The present study was performed as the contract research of the Kyushu Bureau of Economy, Trade and Industry of the Ministry of Economy, Trade and Industry. The authors wish to express their sincere gratitude to all the members of the committee for their guidance in the present study.

REFERENCES

[1] Matsuura, M. and Ikegami, K., et al., 2005, “Multi-connected Floating Body System with Multi-degrees of Freedom Coupling Device,” Proceedings of 18th Ocean Engineering Symposium of the Society of Naval Architects of Japan

[2] Jemmely, P., et al., 1999, "Tribocorrosion behavior of Fe-17Cr stainless steel", Tribology International, 32

[3] Kawazoe, T. and Ura, A., 2001, "Corrosive Wear Testing of Metals in Seawater", American Standard of Testing and Materials, STP, 1404

[4] Ikegami, K. and Matsuura, M., et al., 2004, "Development of Multi-connected Body System - Mechanical Connecting device -", Conference Proceedings of the Society of Naval Architects of Japan, Vol.3

[5] Ikegami, K. and Matsuura, M., 1978, "Study on Motions of a Floating Body under Composite External Loads", Journal of the Society of Naval Architects of Japan, Vol.144

[6] Ikegami, K. and Matsuura, M., 1981, "Study on Motions of a Floating Body under Composite External Loads", International Symposium on Hydrodynamics in Ocean Engineering, Trondheim

[7] Kawazoe, T. and Ikegami, K., et al., 2005, "Wear Characteristics of Oscillatory Sliding Bearing Materials in Seawater", Journal of the Japan Institution of Marine Engineering, Vol.40, No. 3

[8] Stachowaik, G. W., 2001, "Engineering Tribology", Book issued by Butterworth and Heinemann

[9] Yamaya, H. and Okumura, Y., et al., 2002, "Development of Yoke-Spring Mooring System for Floating Structures in Coastal Areas", Proceedings of the 12th International Offshore and Polar Engineering Conference

