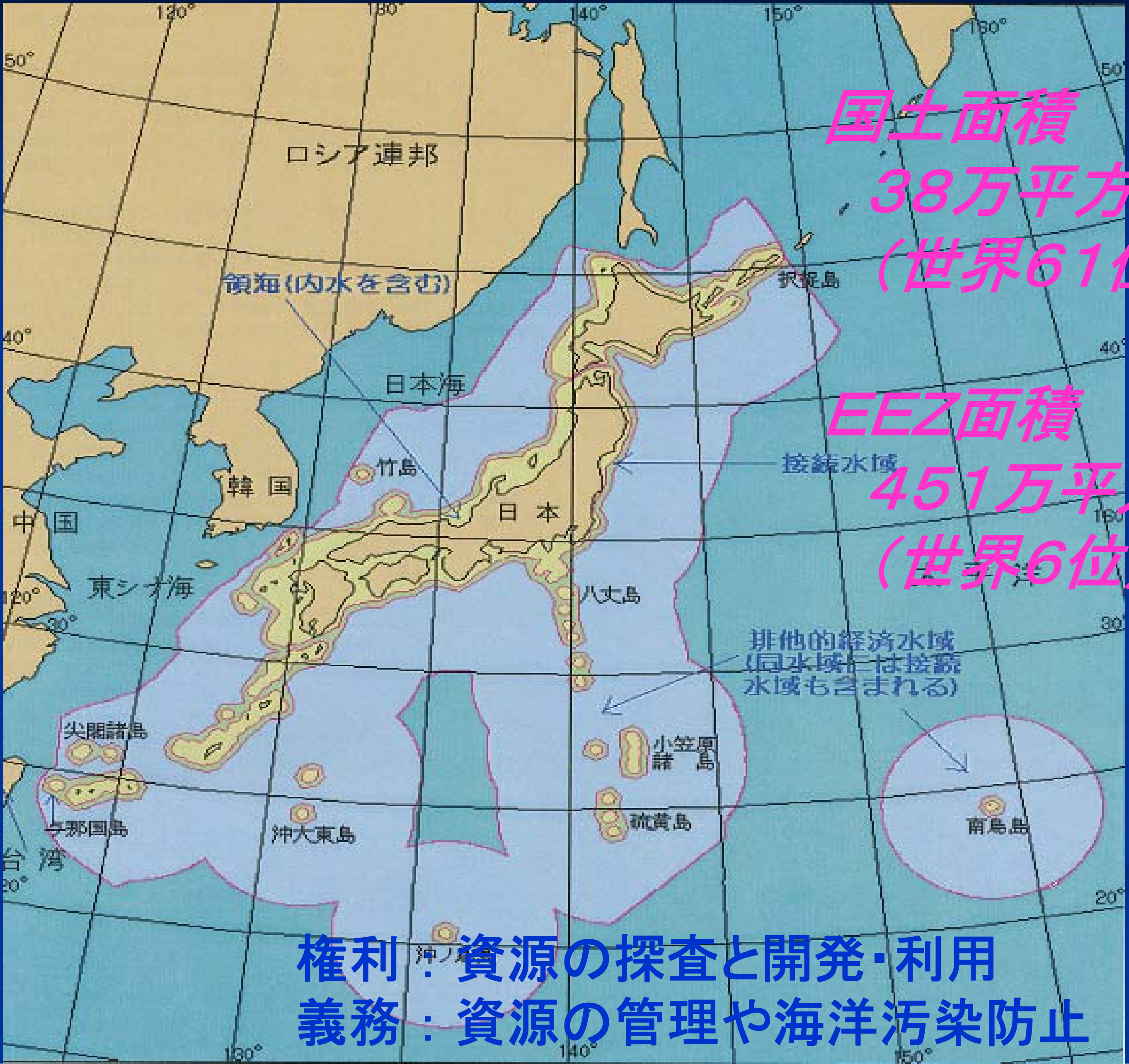
多連結浮体システムの研究開発

工学部　船舶工学科

池上　国広

排他的経済水域（EEZ）



国土面積
38万平方キロ
（世界61位）

EEZ面積
451万平方キロ
（世界6位）

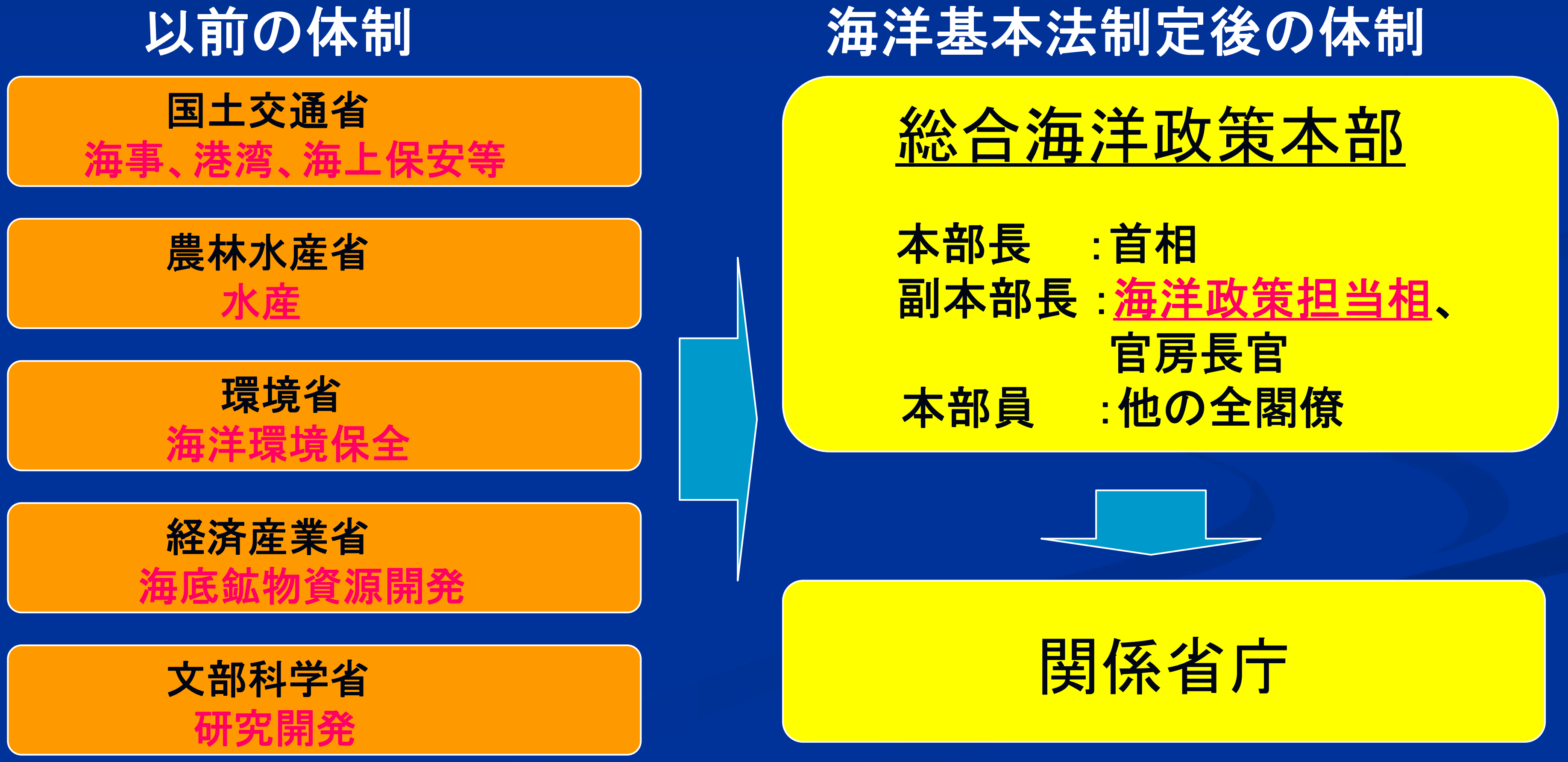
権利：資源の探査と開発・利用
義務：資源の管理や海洋汚染防止

海洋基本法の制定

海洋における諸問題の発生と海洋への関心の高まり

海洋政策の総合的、計画的策定と推進の一元化

海洋関連行政の推進体制



以前の体制

国土交通省
海事、港湾、海上保安等

農林水産省
水産

環境省
海洋環境保全

経済産業省
海底鉱物資源開発

文部科学省
研究開発

海洋基本法制定後の体制

総合海洋政策本部

本部長　：首相
副本部長：海洋政策担当相、
　　　　　官房長官
本部員　：他の全閣僚

関係省庁

海洋基本法の基本理念

究極的理念「海洋と人類の共生」

基本理念

（１）海洋の開発利用と海洋環境の保全との調和

（２）海洋の安全の確保

（３）海洋に関する科学的知見の充実

（４）海洋産業の健全な発展

（５）海洋の総合的管理

（６）海洋に関する国際的協調

→ 海洋基本計画で具体化

研究開発の背景・目的

最近の技術（メガフロート）：溶接接合

多連結浮体システム：機械的連結

トレンド

- ***海洋環境保全・耐震対策等***
- ***海洋構造物による海洋空間利用***

⇔

多連結浮体システムの利点

- ***規模・構造・機能変化へ対応***
- ***損傷時の対応***
- ***小規模施設で建造可能***

キーテクノロジー：浮体ユニット間の連結技術

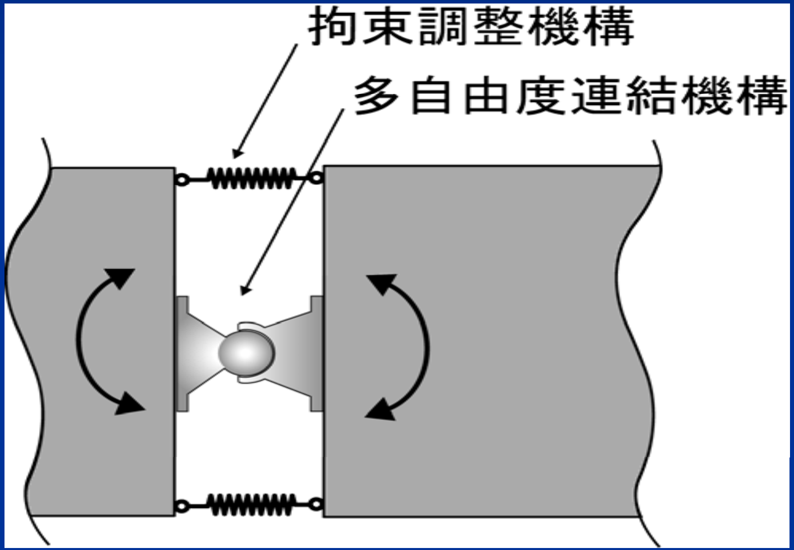
＜課題＞

- *大変位・高荷重の多自由度連結機構*
- *海洋汚染を起こさない環境調和型*
- *洋上での連結・切り離し容易*

目的：多自由度カップリング装置の開発

新形式浮体ジョイントの基本概念

連結装置の基本概念



多自由度連結機構

- *回転自由*
- *連結荷重の低減*

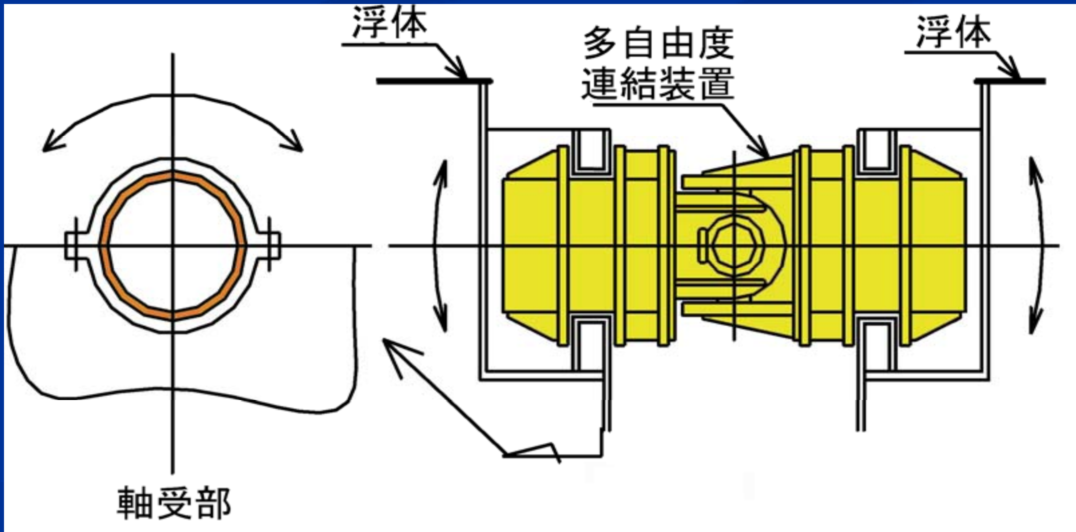
拘束調整機構

- *相対運動の拘束*
- *拘束度合いの調整*

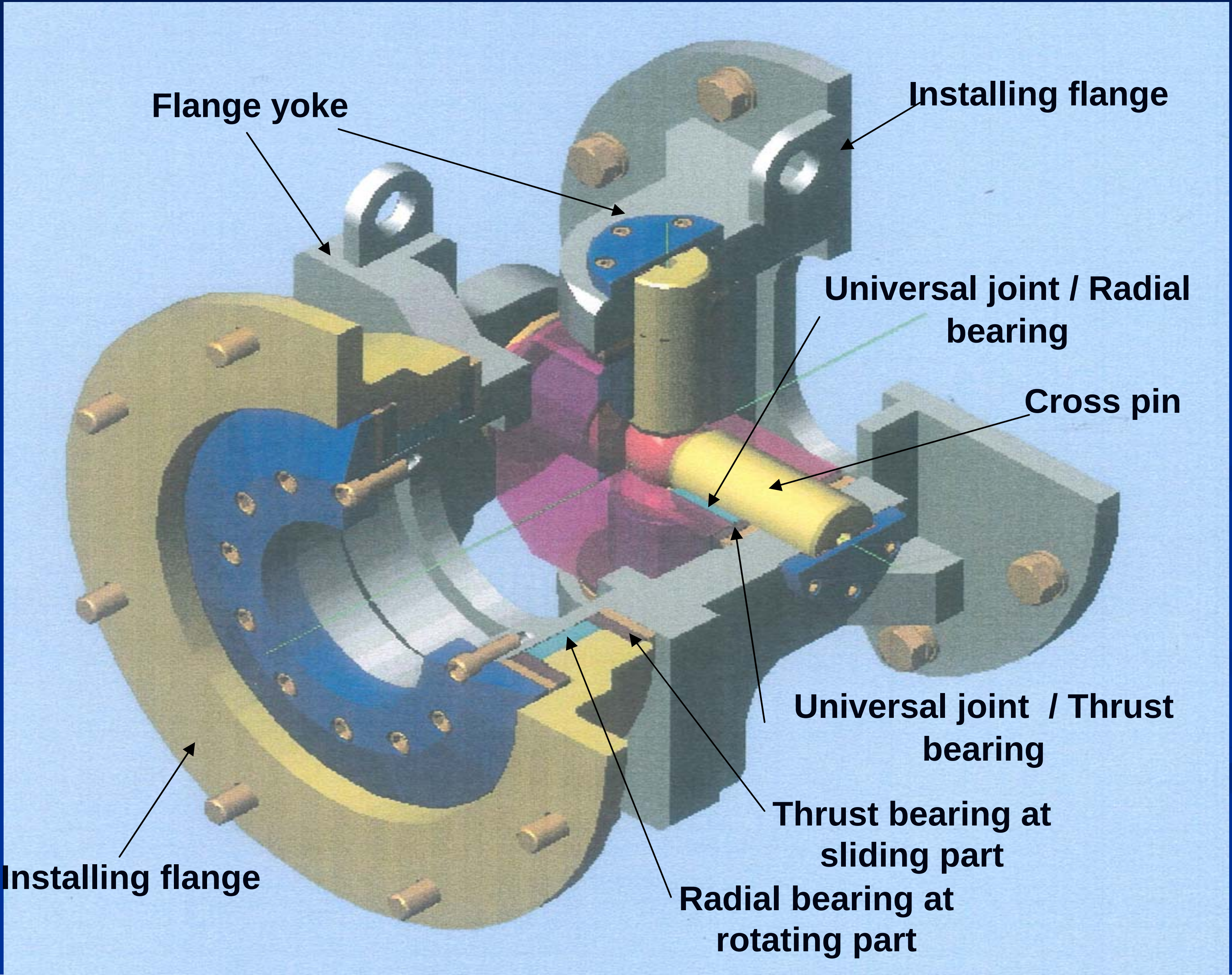
多自由度連結装置

ユニバーサルジョイント方式を基本
軸回転方向の自由度を付加

低コストでボールジョイント方式の
全回転方向自由を実現



MULTI-DEGREES OF FREEDOM COUPLING MECHANISM



CALCULATION METHOD

Equation of motions for multiple floating bodies

$$\begin{bmatrix} & \mathrm{M} & & \mathrm{M} & \\ \Lambda & \boldsymbol{D}_l + \boldsymbol{E}_{ll} + \boldsymbol{G}_l & \Lambda & \boldsymbol{E}_{lm} & \Lambda \\ & \mathrm{M} & & \mathrm{M} & \\ \Lambda & \boldsymbol{E}_{ml} & \Lambda & \boldsymbol{D}_m + \boldsymbol{E}_{mm} + \boldsymbol{G}_m & \Lambda \\ & \mathrm{M} & & \mathrm{M} & \end{bmatrix} \begin{bmatrix} \mathrm{M} \\ \boldsymbol{\eta}_{lA} \\ \mathrm{M} \\ \boldsymbol{\eta}_{mA} \\ \mathrm{M} \end{bmatrix} = \begin{bmatrix} \mathrm{M} \\ \boldsymbol{F}_{lA} \\ \mathrm{M} \\ \boldsymbol{F}_{mA} \\ \mathrm{M} \end{bmatrix}$$

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

$\boldsymbol{M}$: 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

$\boldsymbol{D}_l$: 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

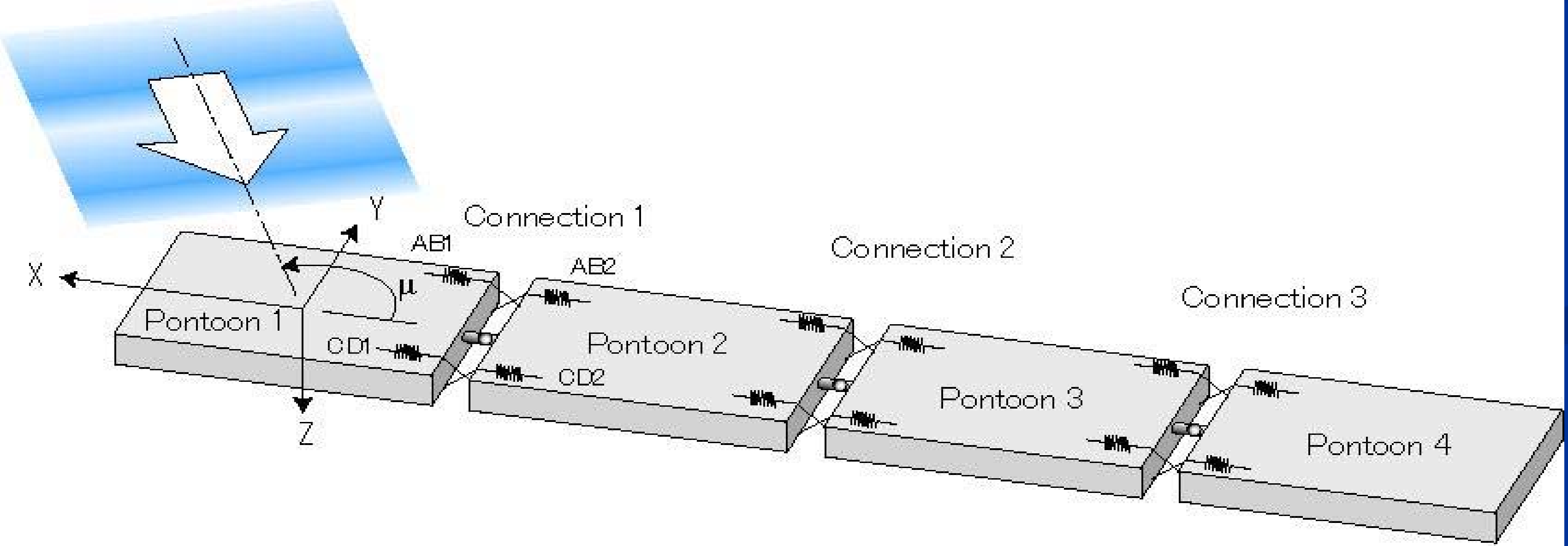
$\boldsymbol{\eta}$: motions $(\eta_j = \eta_{Aj}\, e^{j\omega t}, j=1,2,..,6)$; 6 x 1 vector

CALCULATION CONDITIONS

Principal dimensions of floating body unit

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

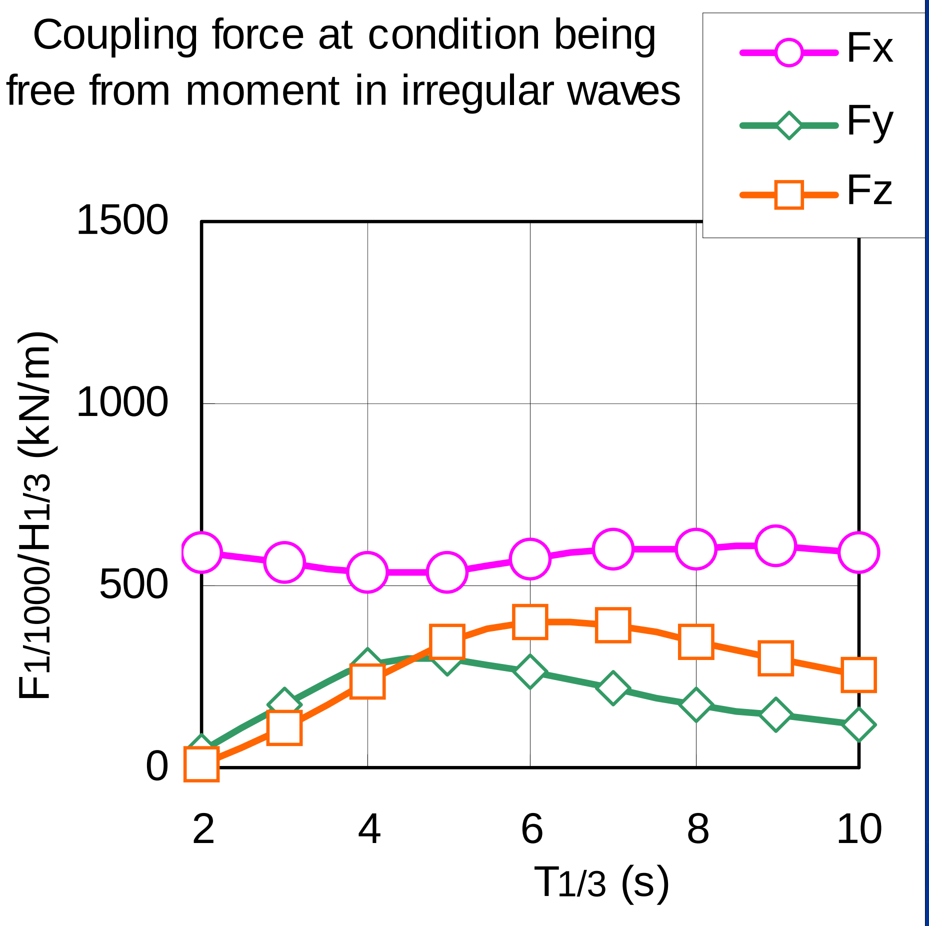
Multi-connected floating body units



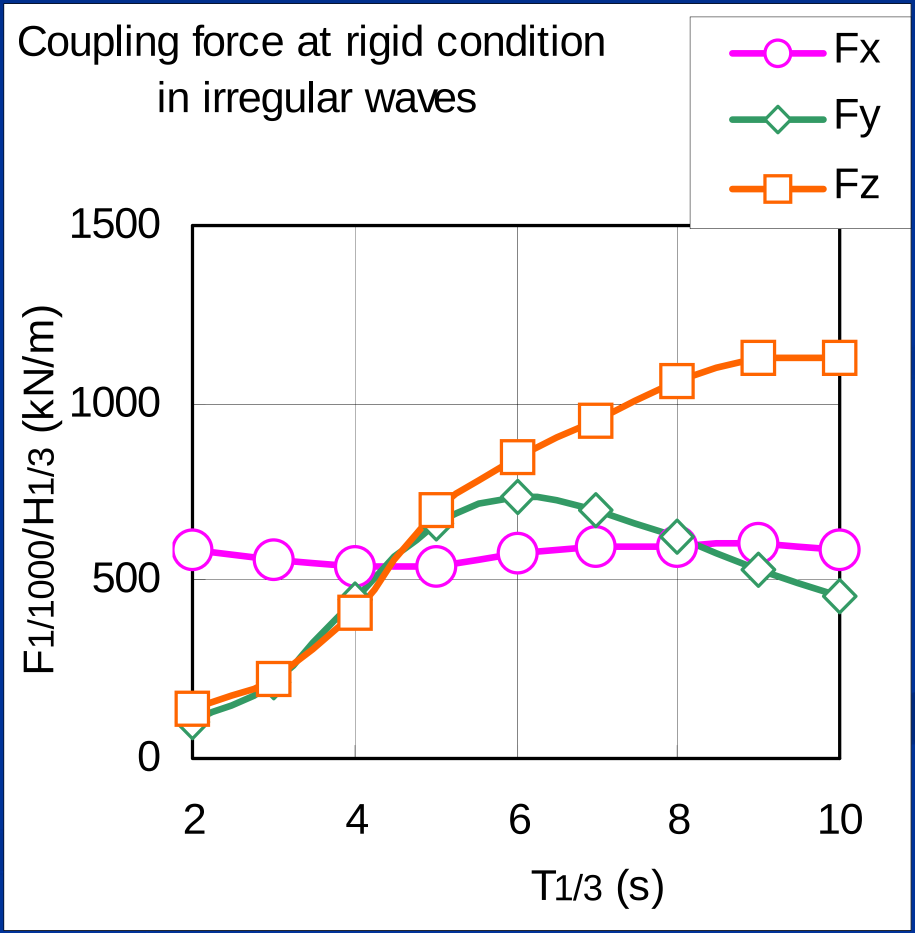
COMPARATIVE CALCULATION

For typical coupling conditions

Connection to free rotations



Rigid connection

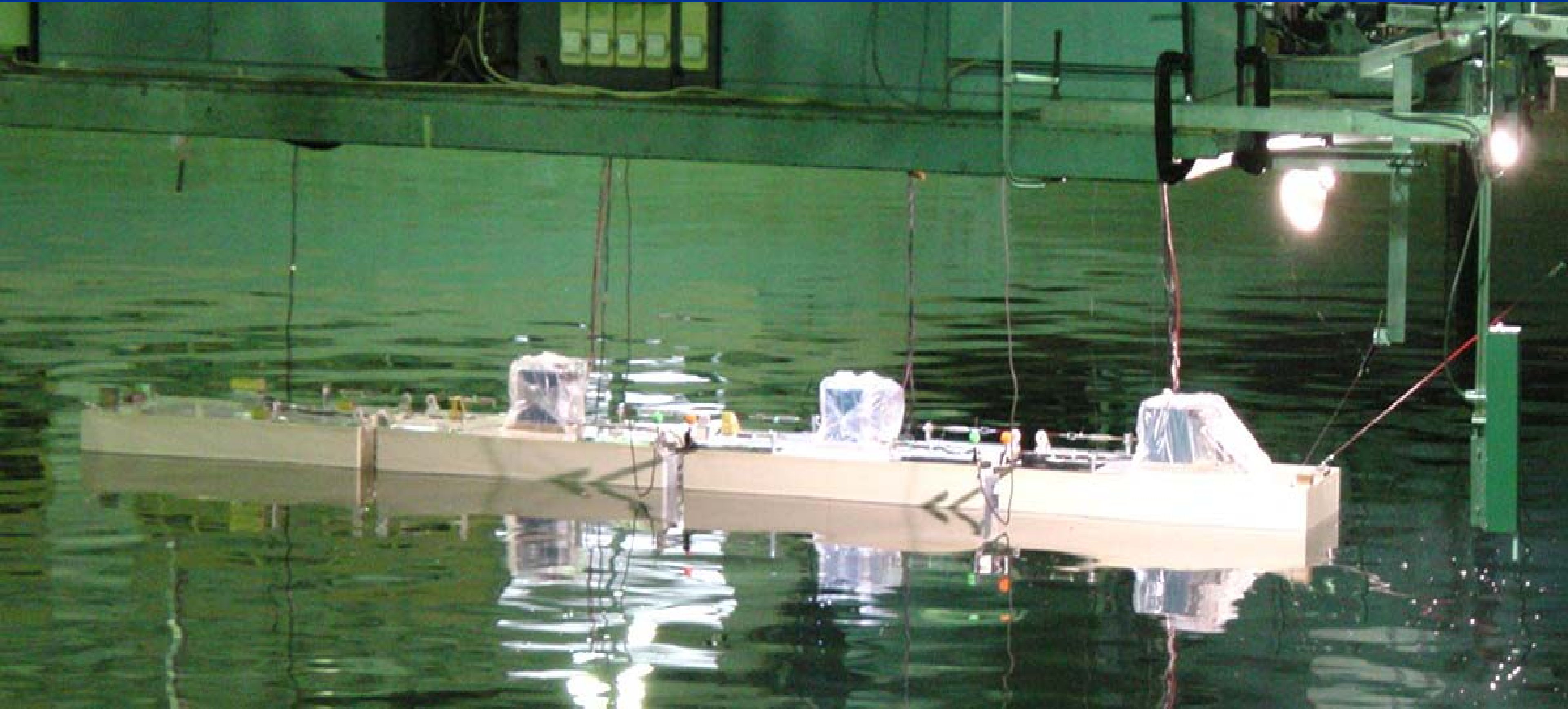


MODEL BASIN TEST

to investigate the characteristics of response

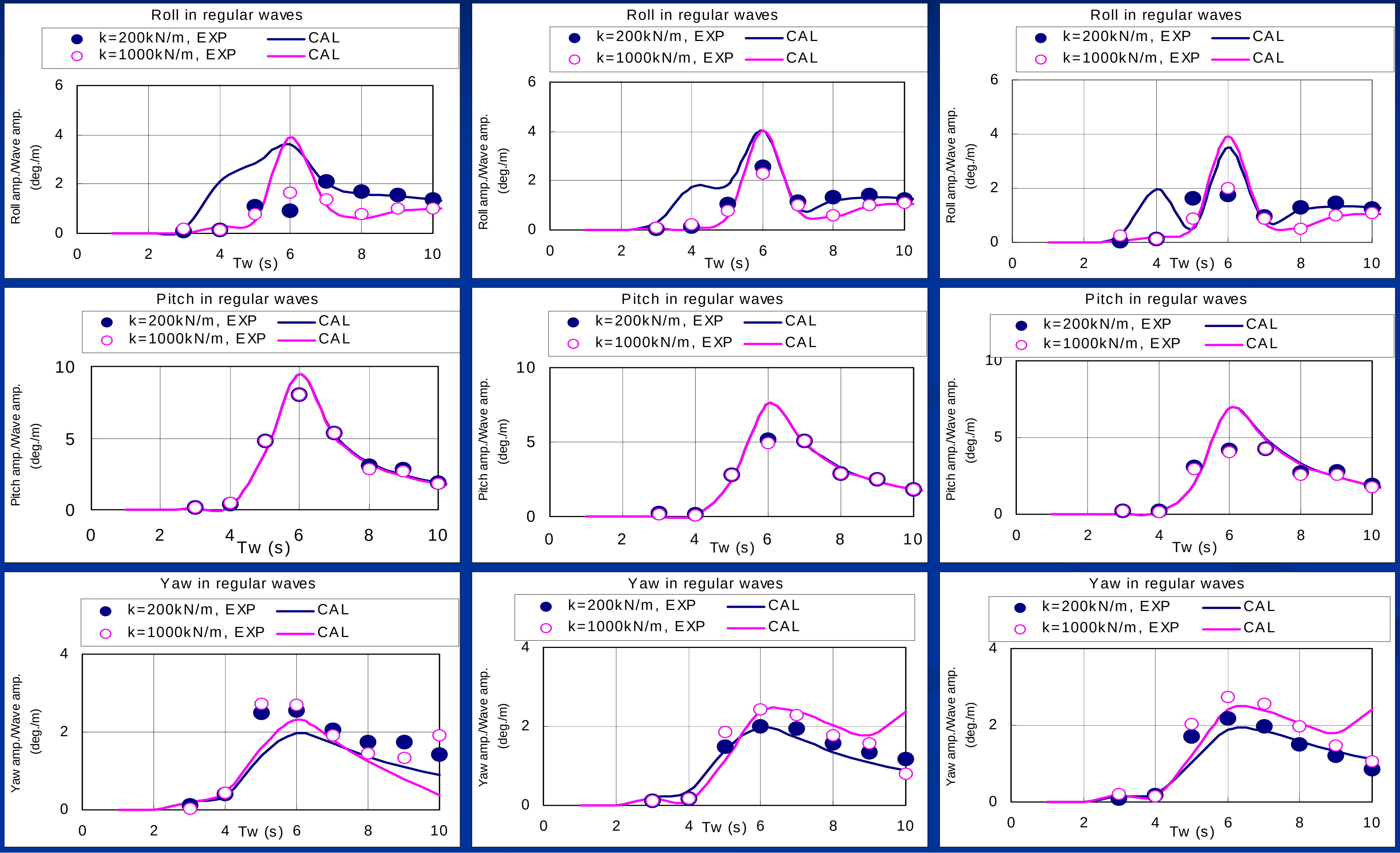
to confirm the effectiveness of the new concept

to confirm the applicability of calculation method



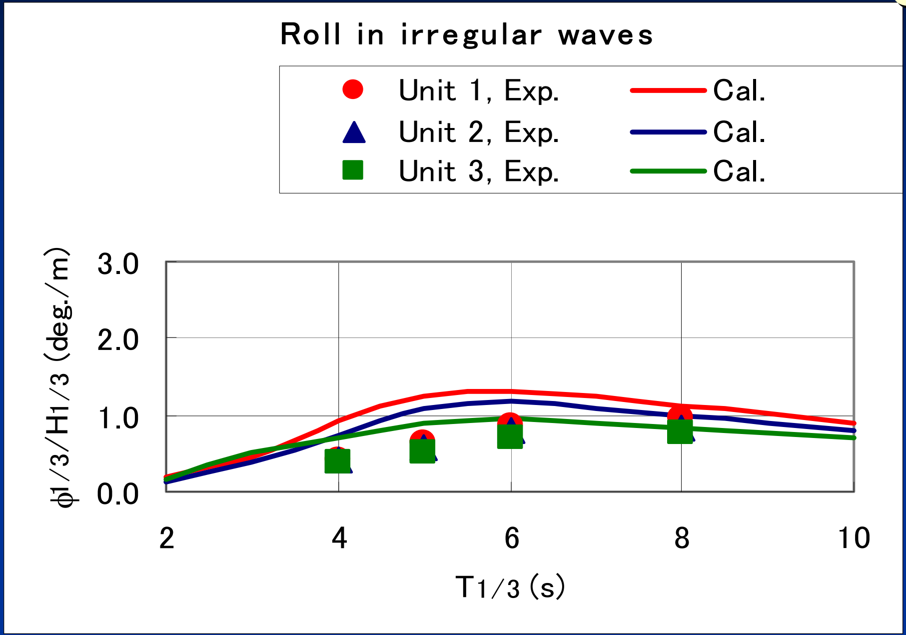
MOTIONS OF FLOATING BODY UNITS

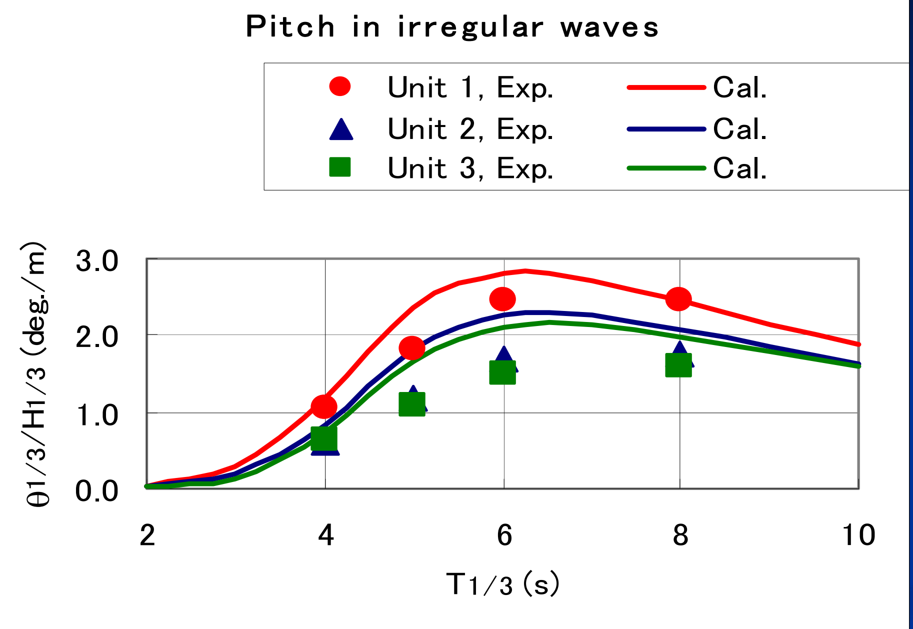
in regular waves

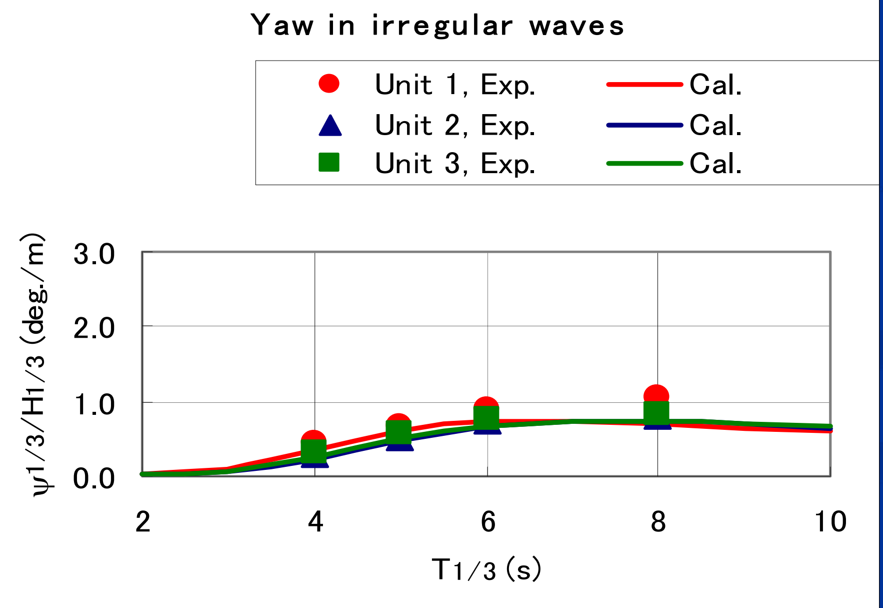


MOTIONS OF FLOATING BODY UNITS

in irregular waves

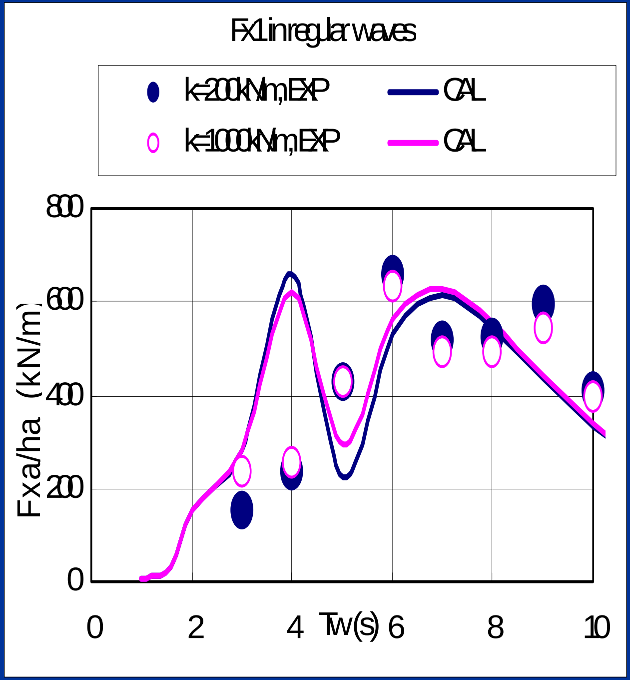


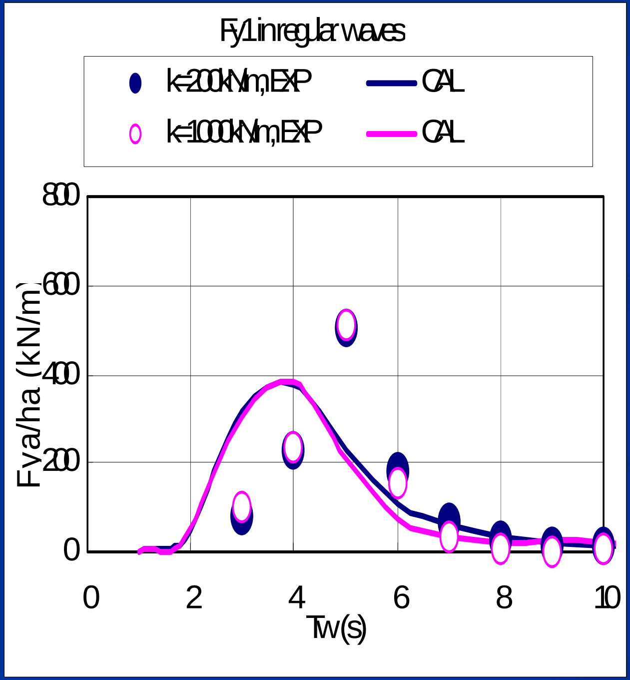


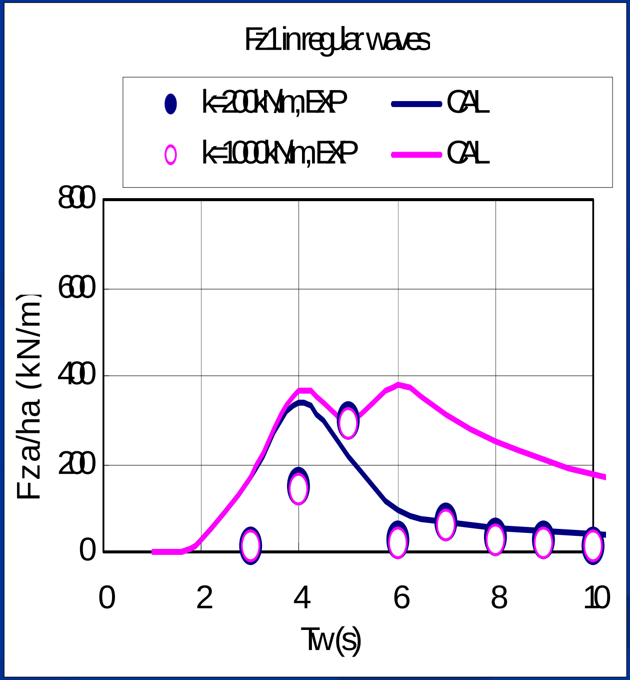


COUPLING FORCES

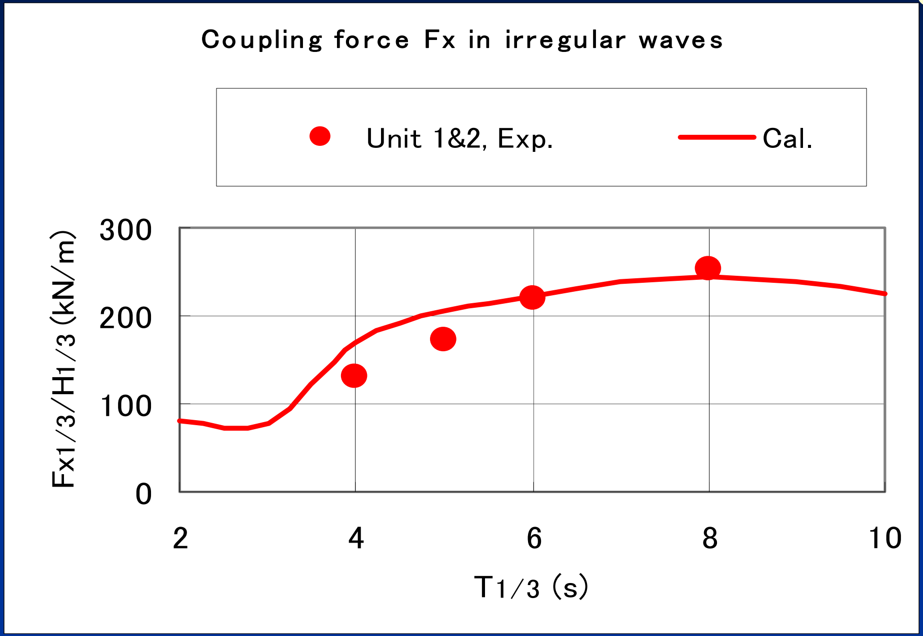
in regular waves

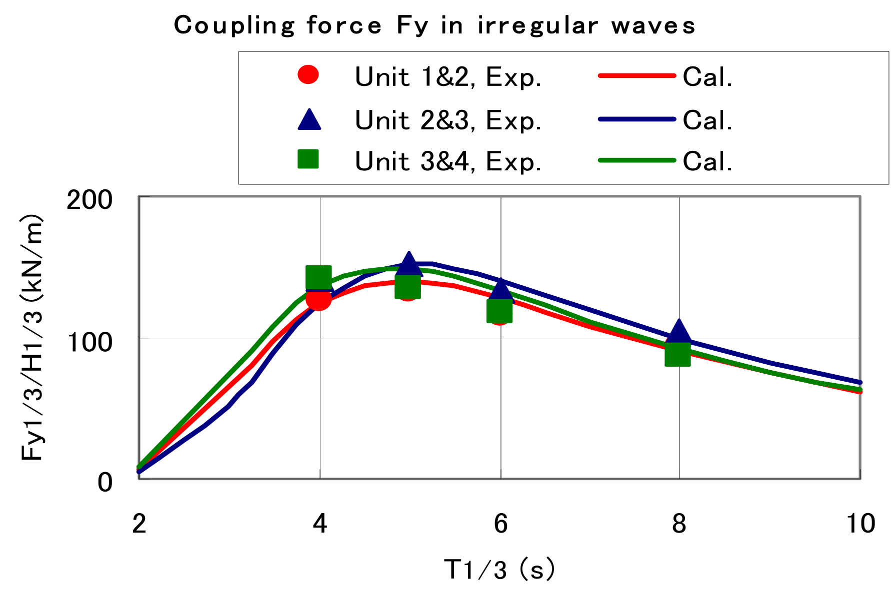


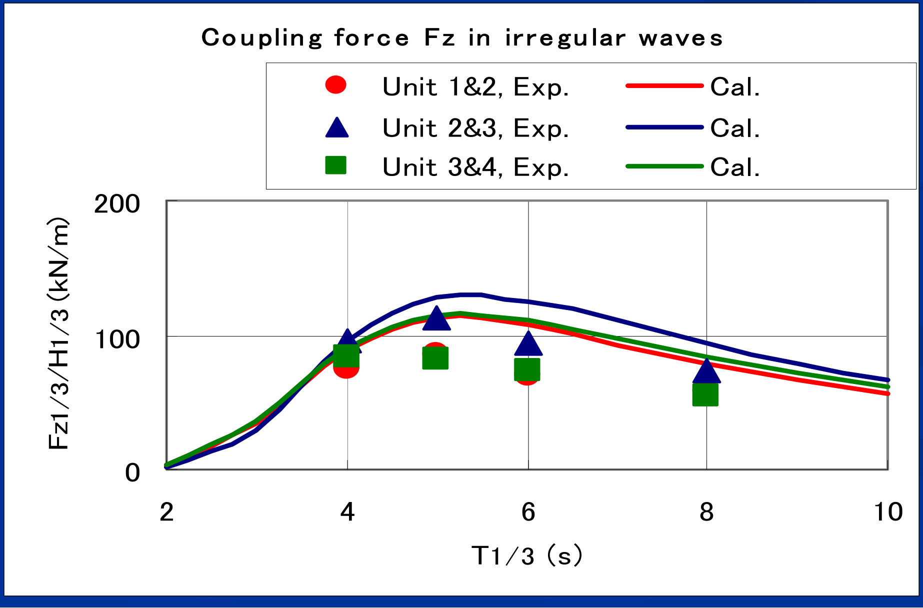




COUPLING FORCES
in irregular waves

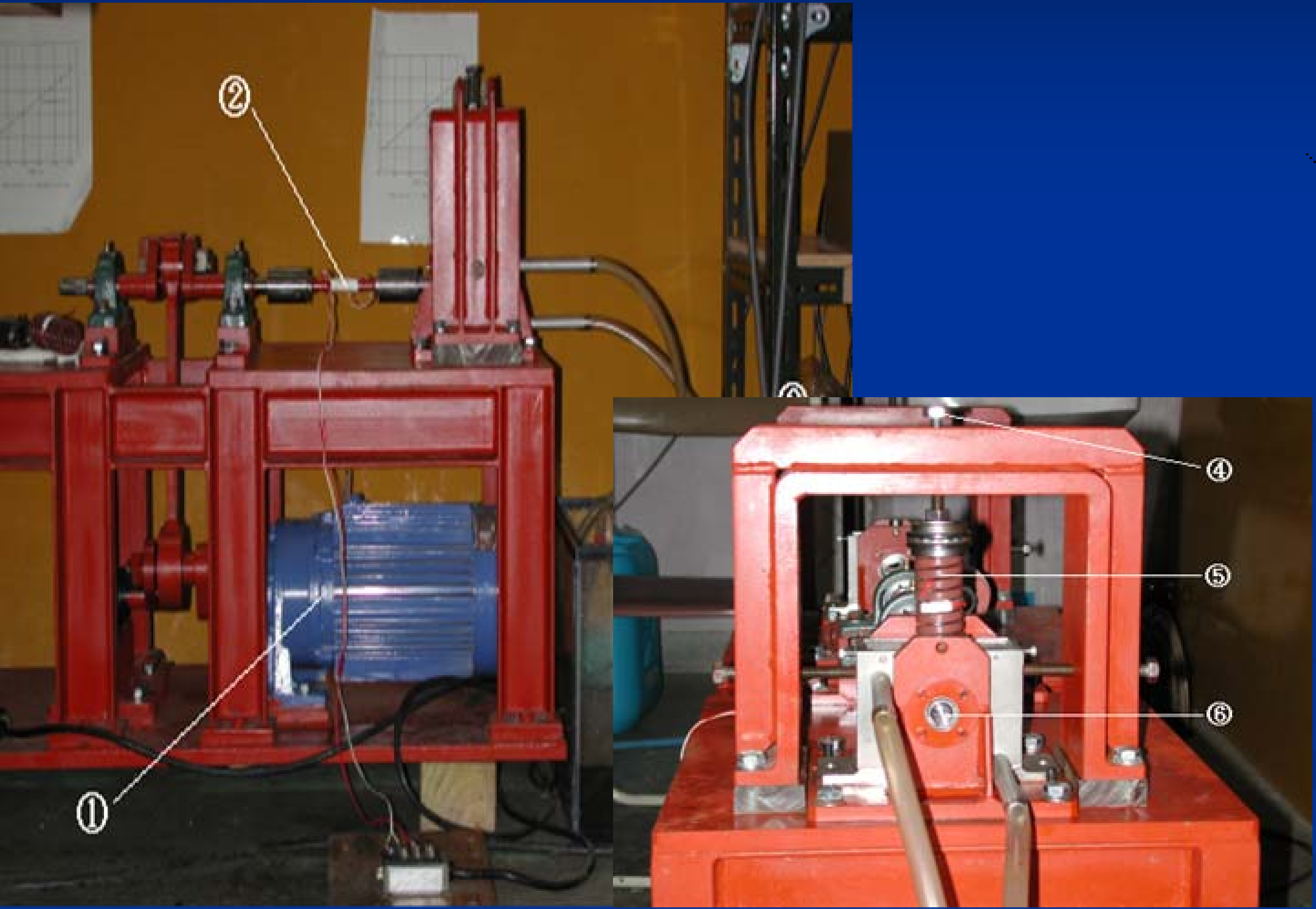






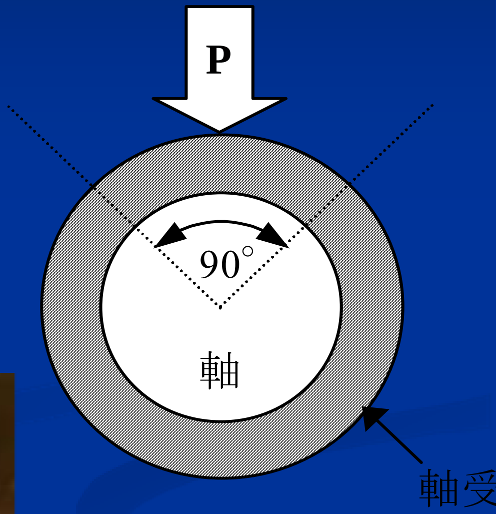
FRICTION AND WEAR TEST

to select materials suitable for sliding parts



（Test apparatus simulating sliding condition)

Contact pressure



Sliding time
6 hours
Sliding speed
0.05 m/s

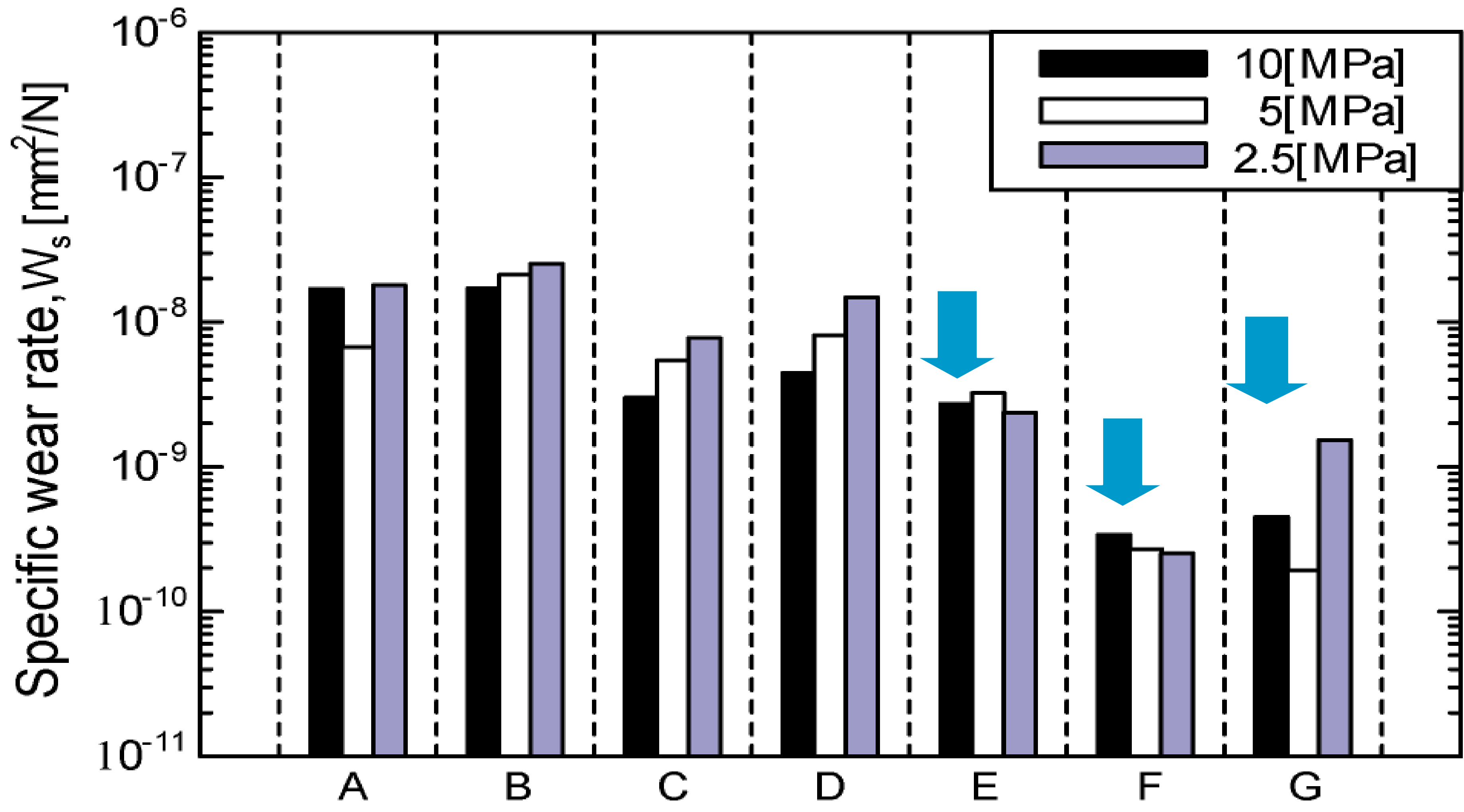
（Test procedure）

SPECIFIC WEAR RATE

under various contact pressure

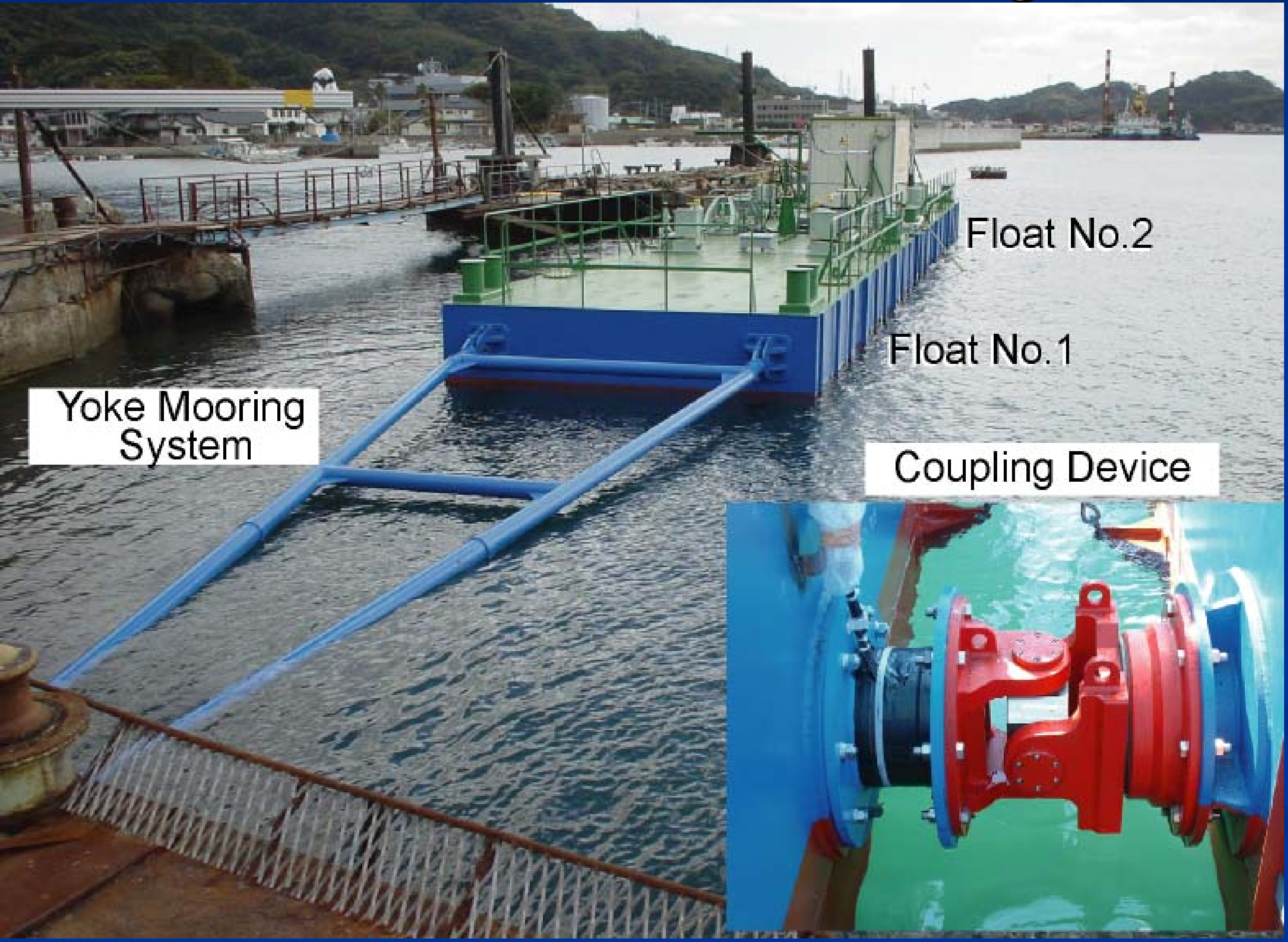
Ws＝V/（P･L）　（mm²／N）

V：Volume of wear（mm³），　P：Contact pressure（N）
L : Sliding distance（mm）



FIELD TEST

to verify practicality of the new concept of mechanical connecting device

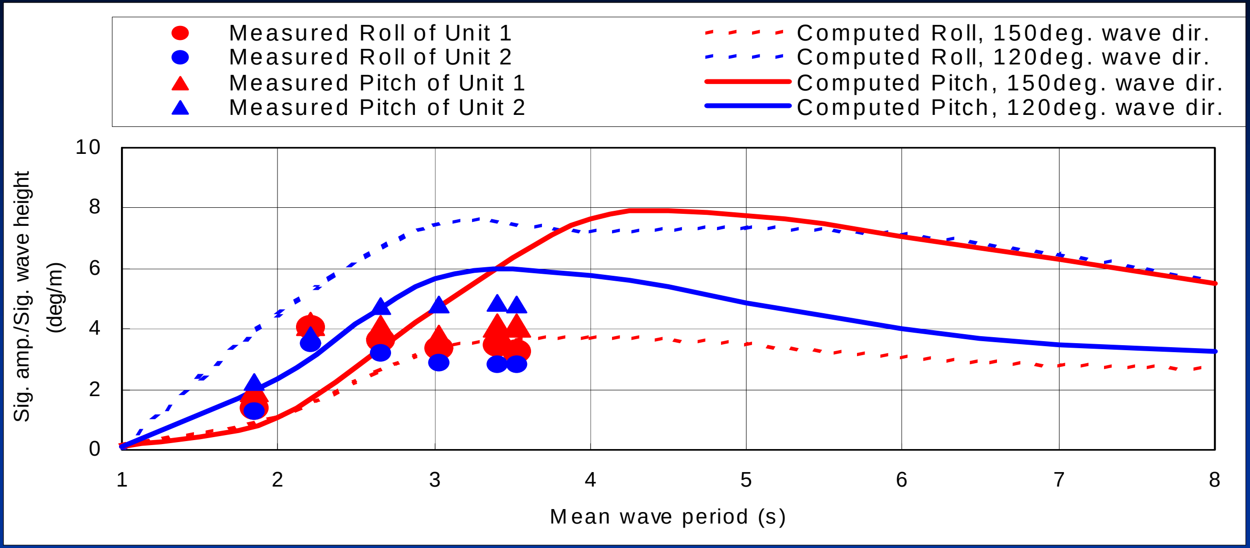


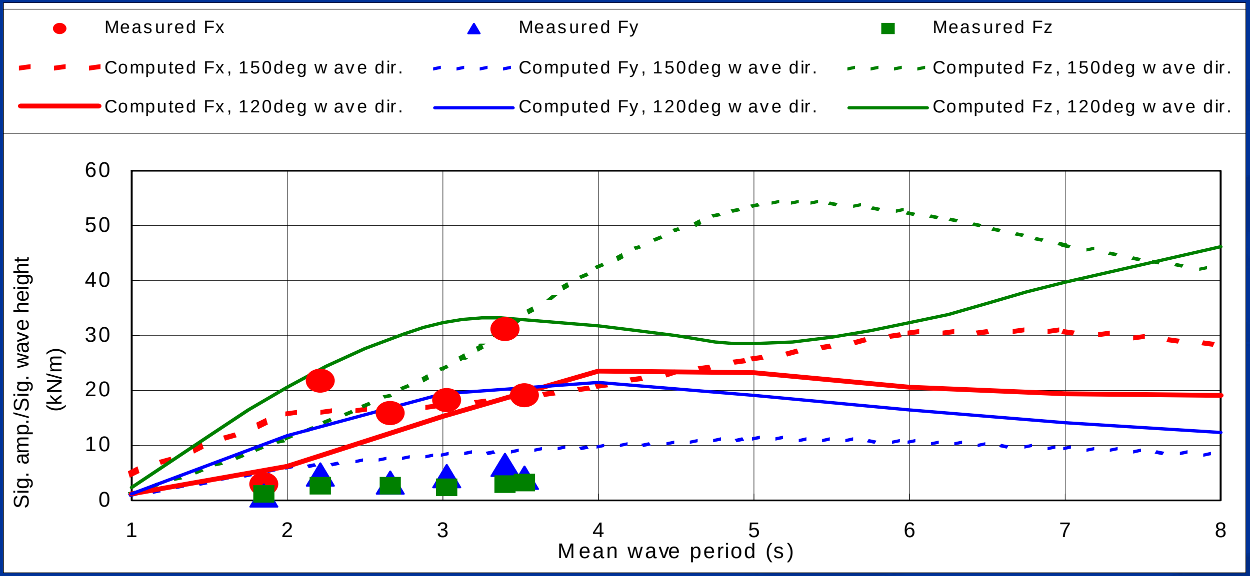
Floating body
- 2 units
- L=12m,B=4.5m

Mooring
- Chain mooring
- Yoke mooring

Materials of sliding parts
- Phenolic resin
- PA resin

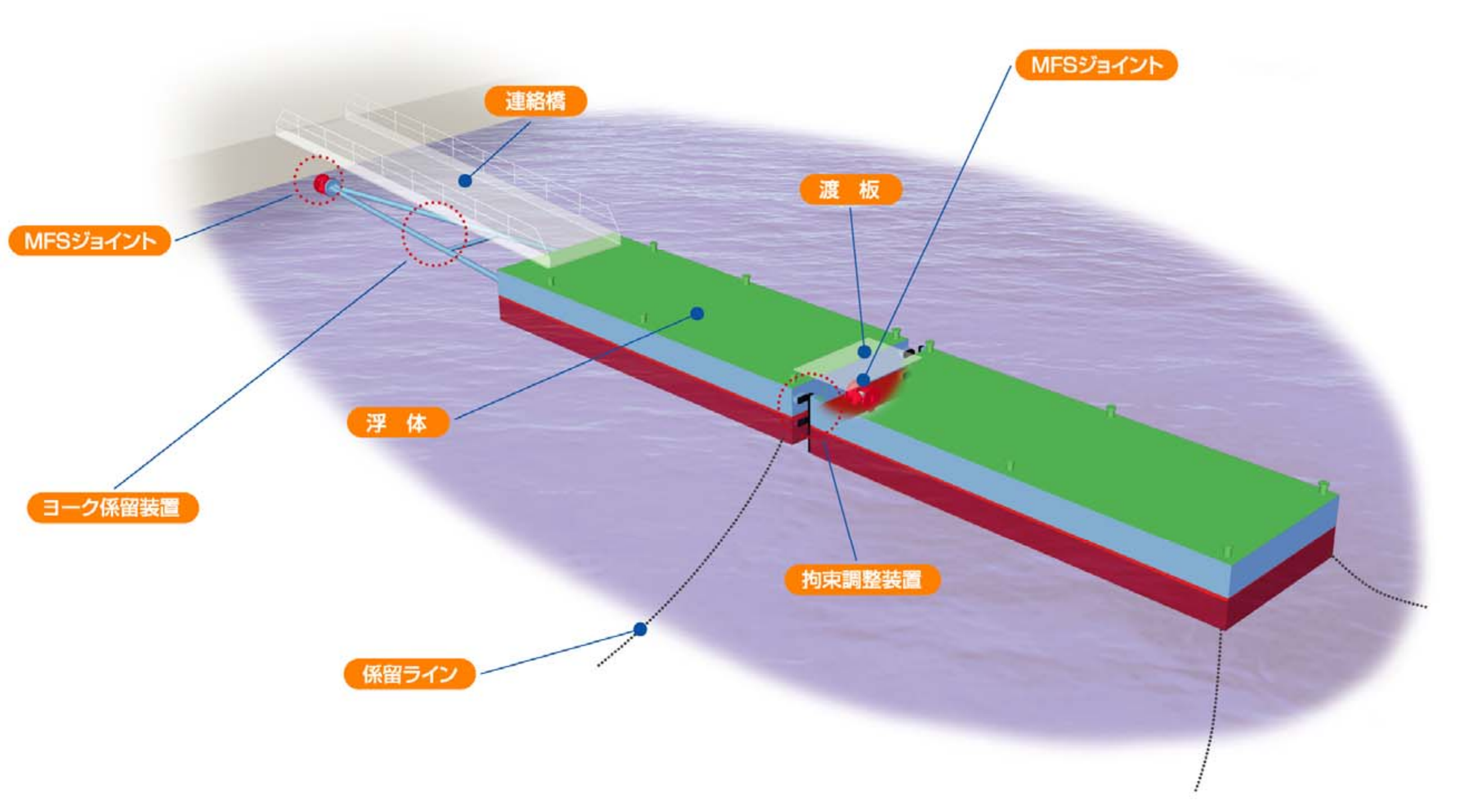
MOTION AND CONNECTING FORCE





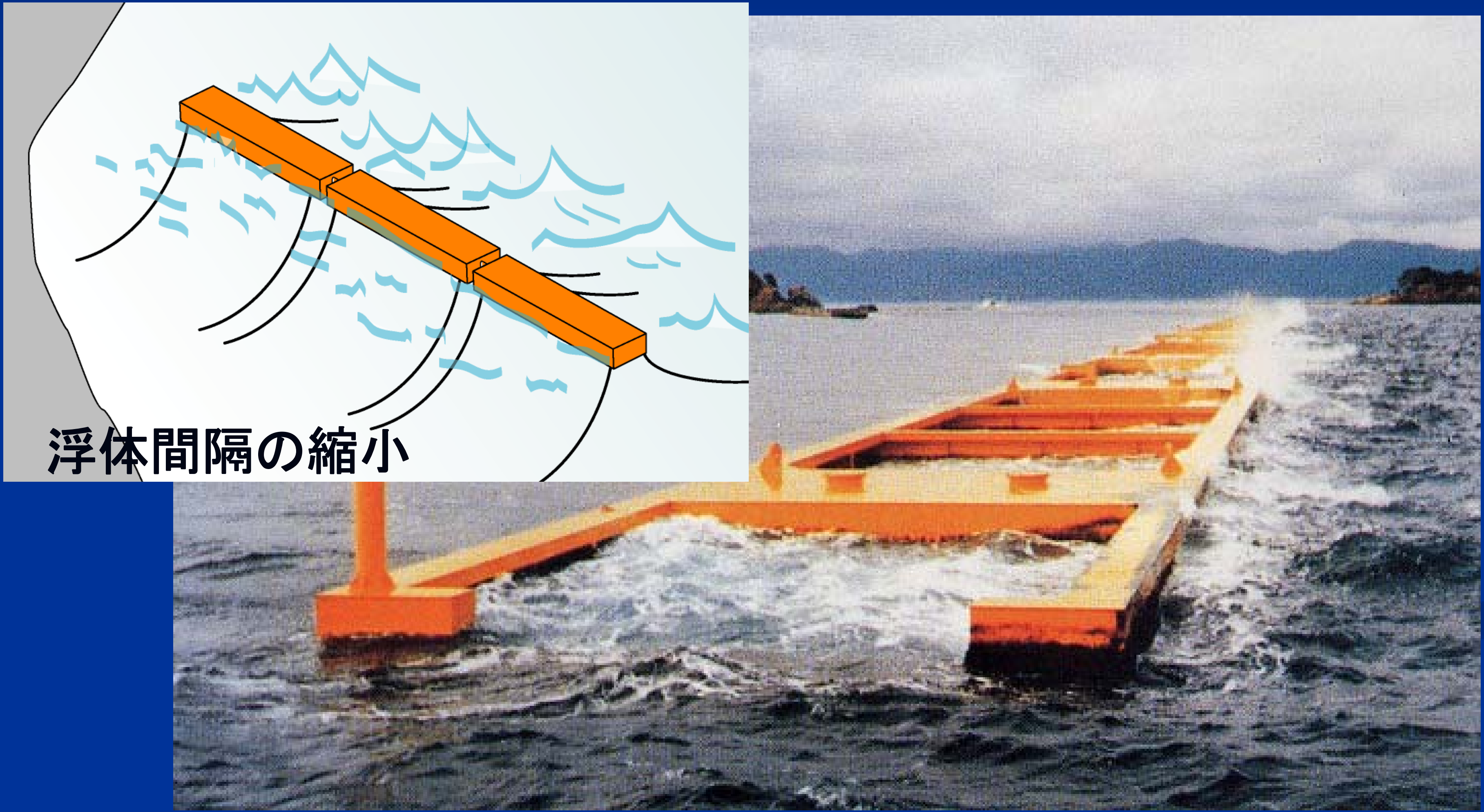
Field Test : No unique phenomenon was observed.
The mechanical connecting device displayed the required function.

MFSジョイントの適用例
（従来浮体の性能向上：浮桟橋）



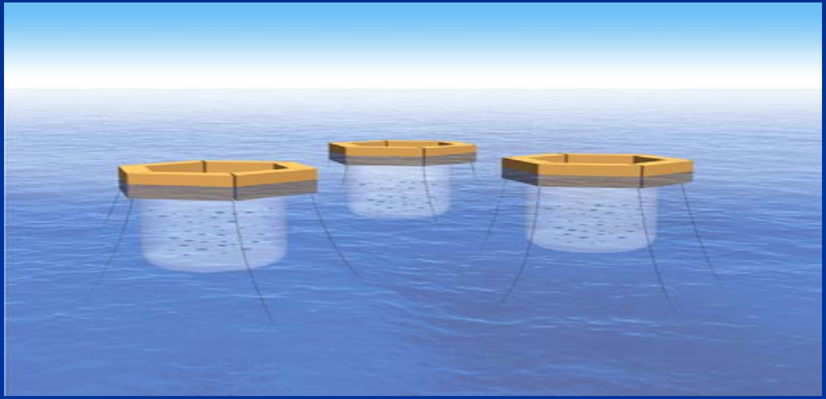
MFSジョイントの適用例

（従来浮体の性能向上：浮防波堤）

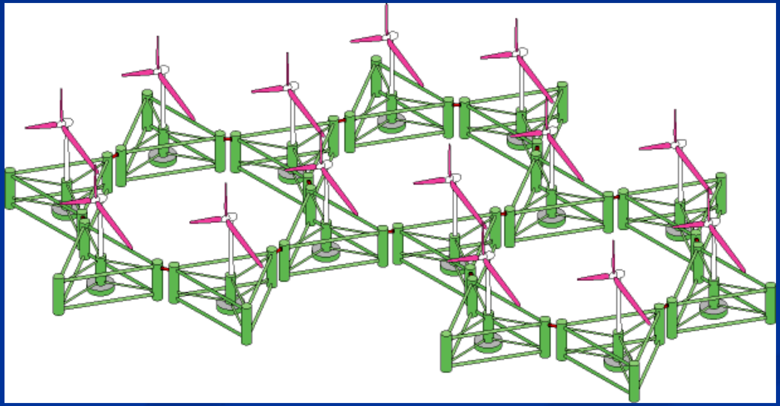


MFSジョイントの適用例
（新しい浮体構造物）

外洋型いけす



洋上浮体式風力発電設備



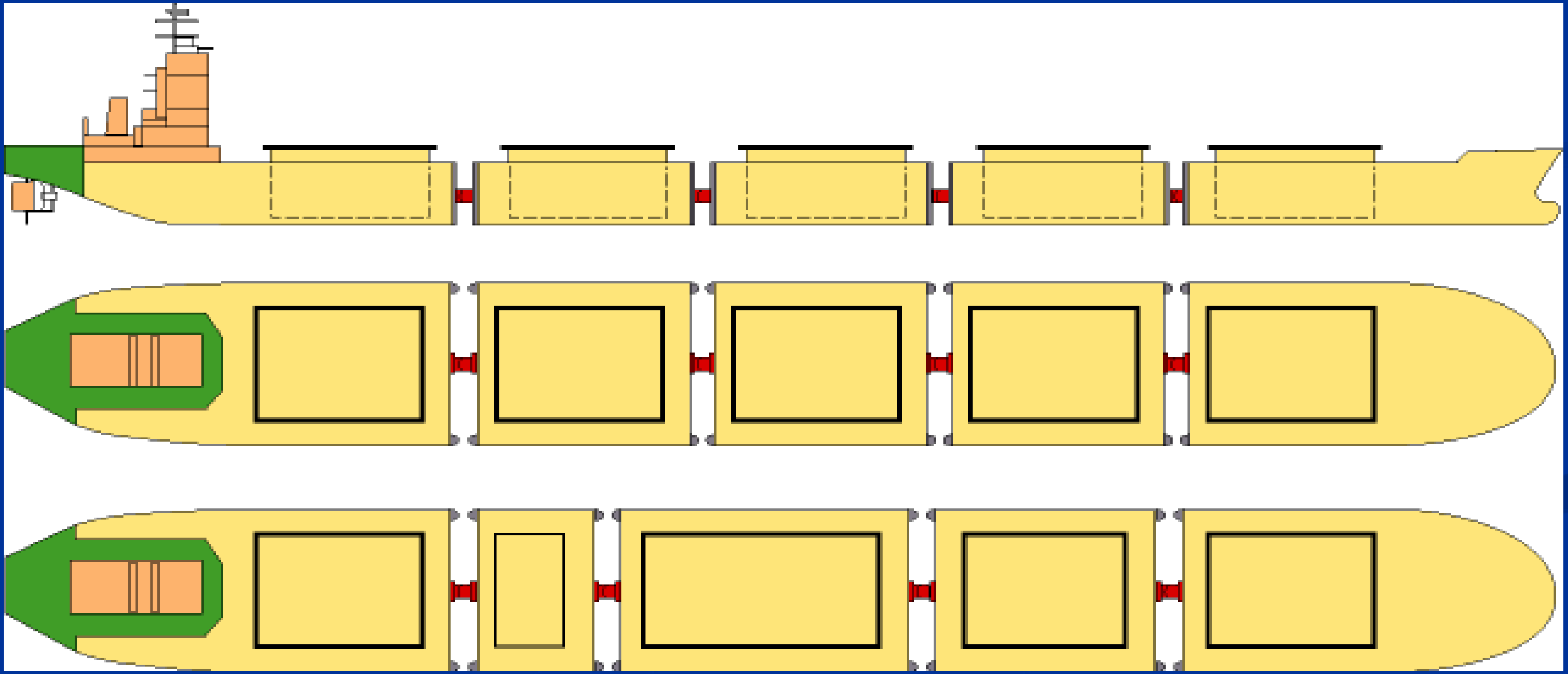
浮体式アクセス設備

親水環境保全施設

MFSジョイントの適用例
（新しい浮体構造物）

多連結バージ

新しい海運物流システムの構築



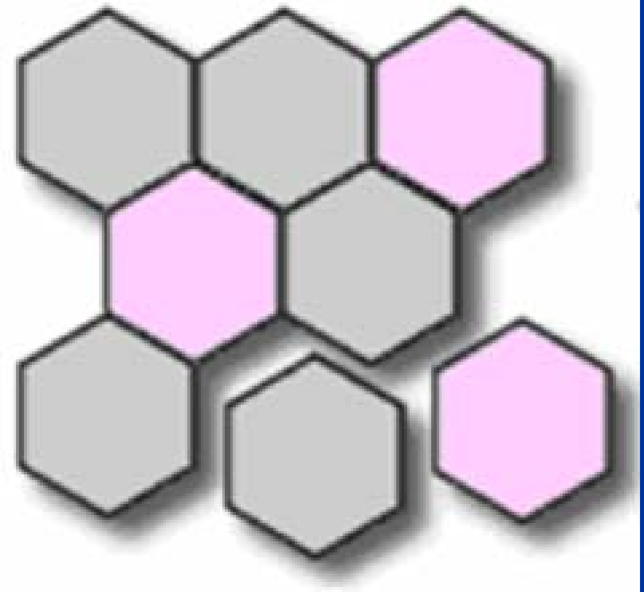
適用法に関する検討

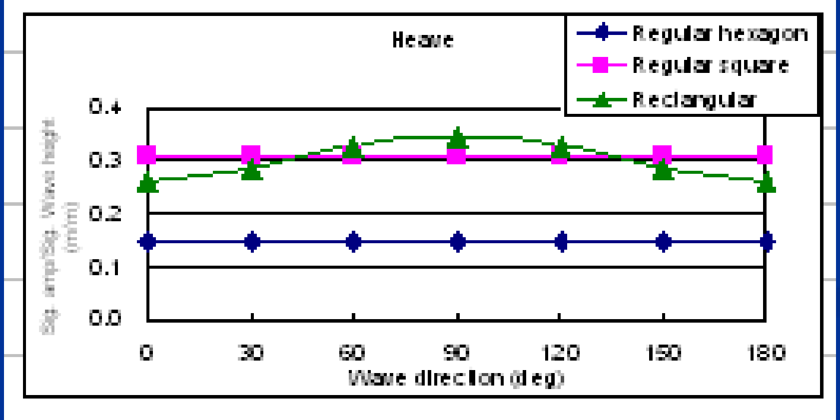
六角形浮体による多連結浮体システム

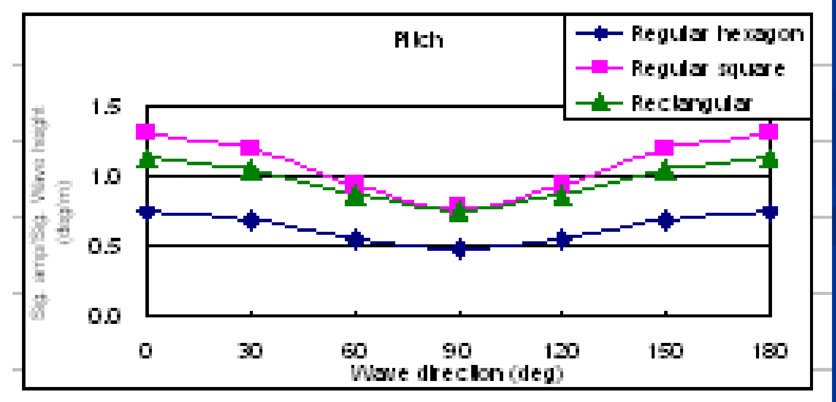
FLOATING BODY UNIT

congruent regular polygonal water plane arrangement to fill the surface of water without gaps

The regular hexagon



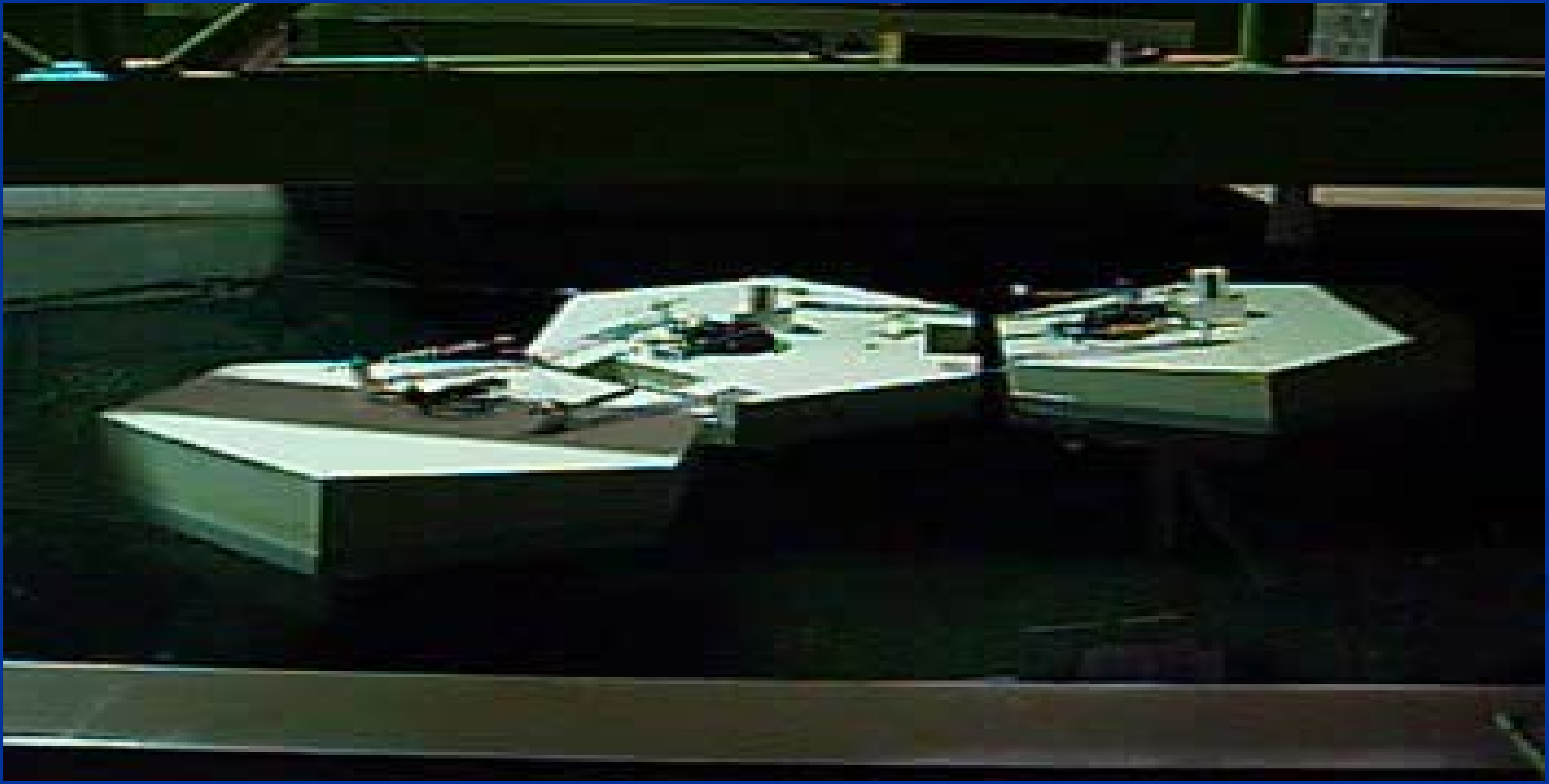




MODEL BASIN TEST

to investigate the response characteristics

to confirm the applicability of calculation method



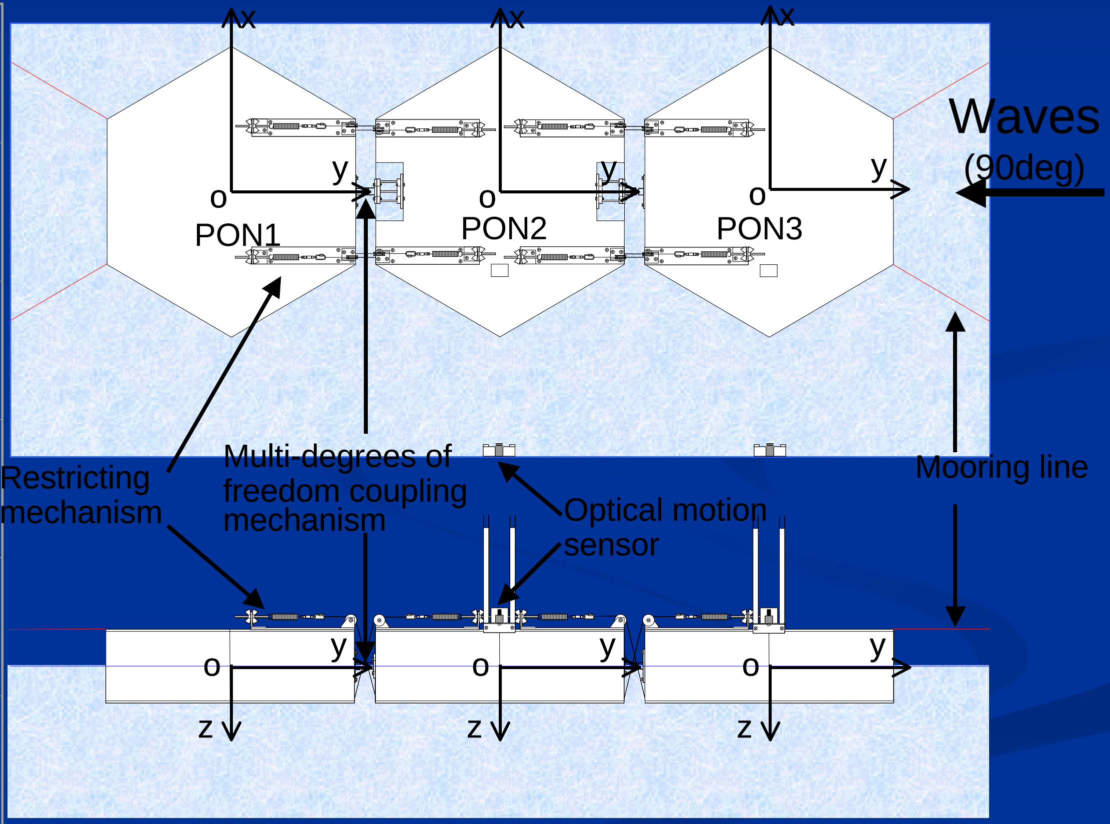
TEST PROCEDURE

Main dimensions of the floating body unit

1/S = 1/50

Items	Full Scale	Model Scale
Length	40.0 m	800 mm
Breadth	34.64 m	693 mm
Depth	10.0 m	200 mm
Draft	5.0 m	100 mm
Displacement	2,078 ton	41.56 kg

Test arrangement



Restricting mechanism

Multi-degrees of freedom coupling mechanism

Optical motion sensor

Mooring line

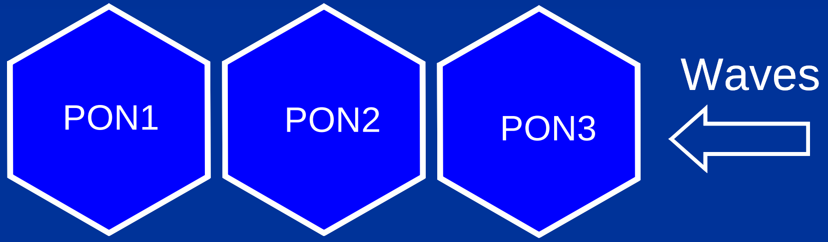
TEST CONDITION

Waves : Regular beam waves

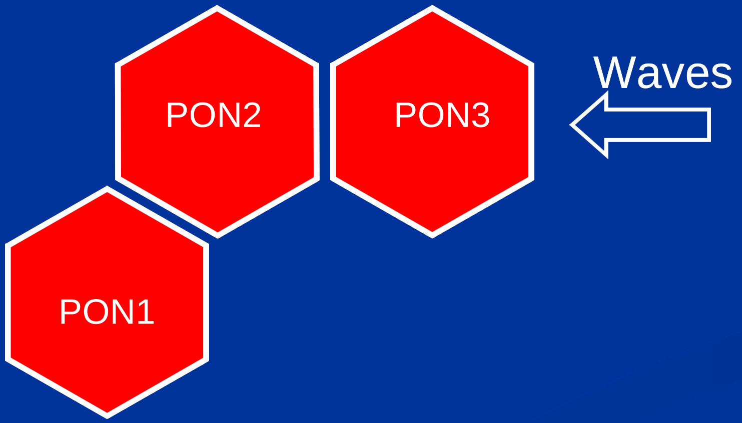
Number of floating body units : Single, Three

Arrangement of floating body units

Straight-line

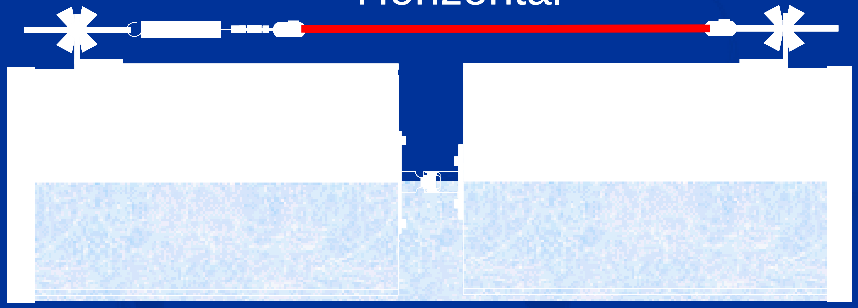


L-shape

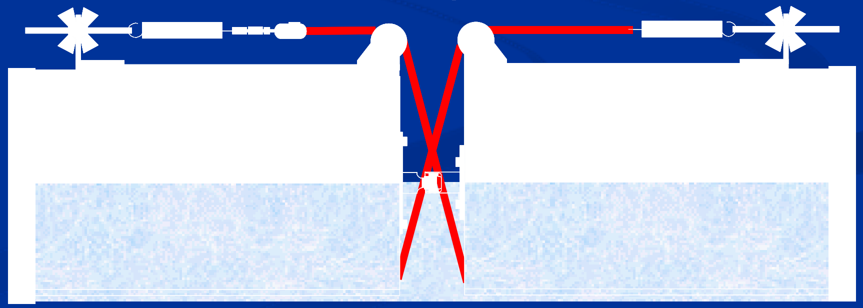


Direction of stretch of connecting line

Horizontal



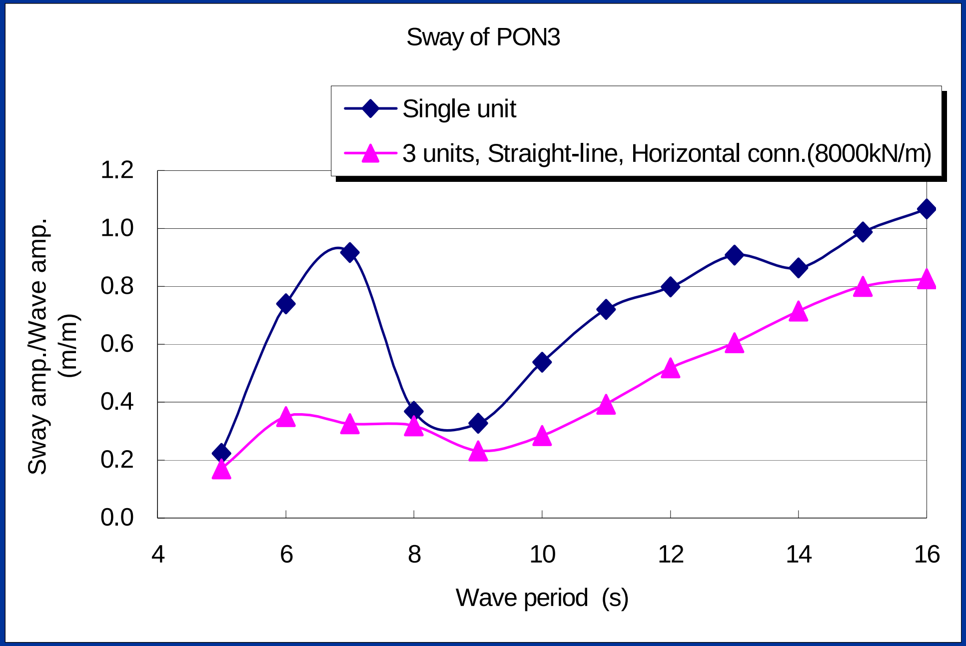
Oblique



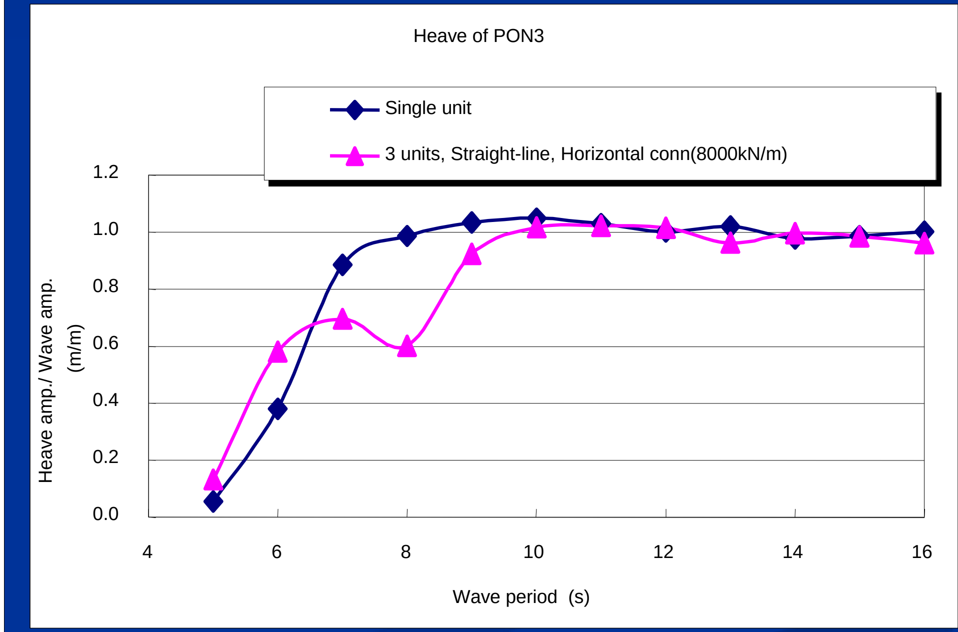
TEST RESULTS

Comparison of Motions
Single Floating Body Unit and Connected Ones

Sway



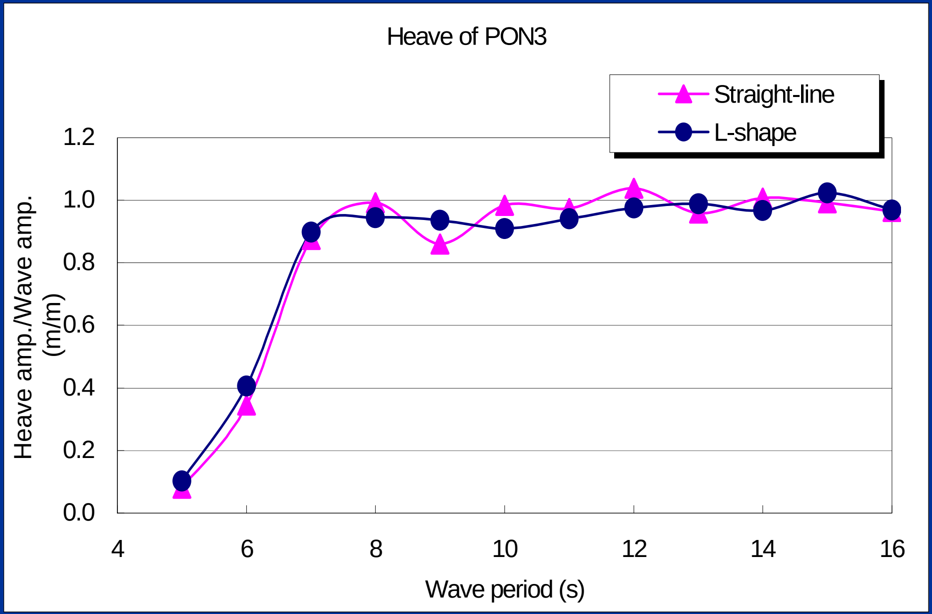
Heave



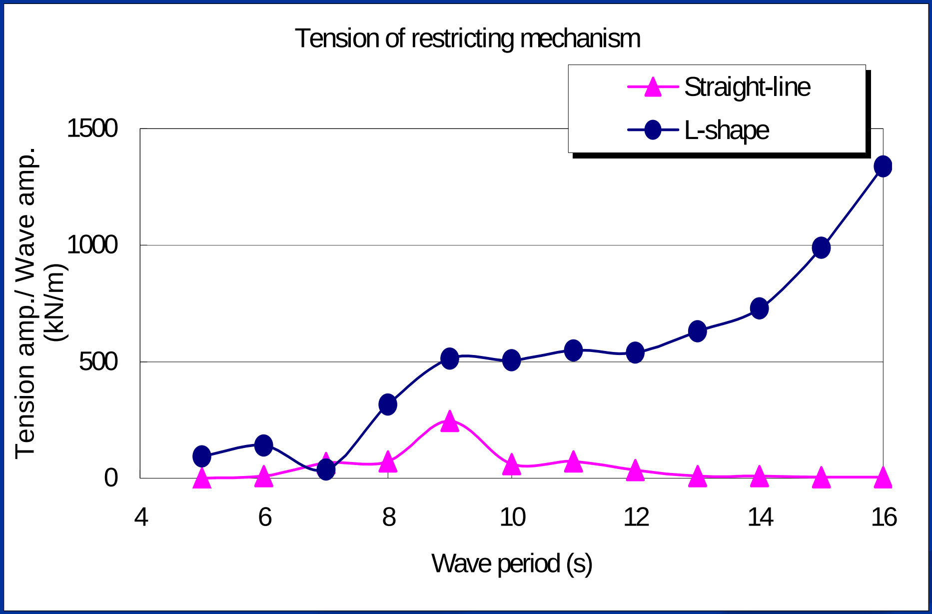
TEST RESULTS

Comparison of motions and connecting forces
Arrangements of Floating Body Units

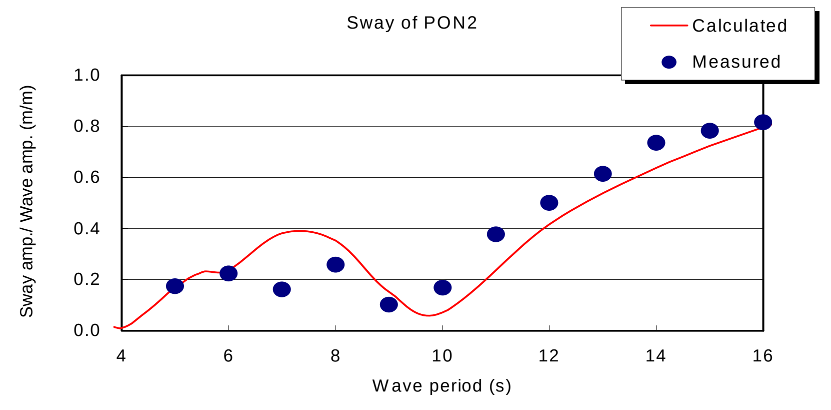
Heave

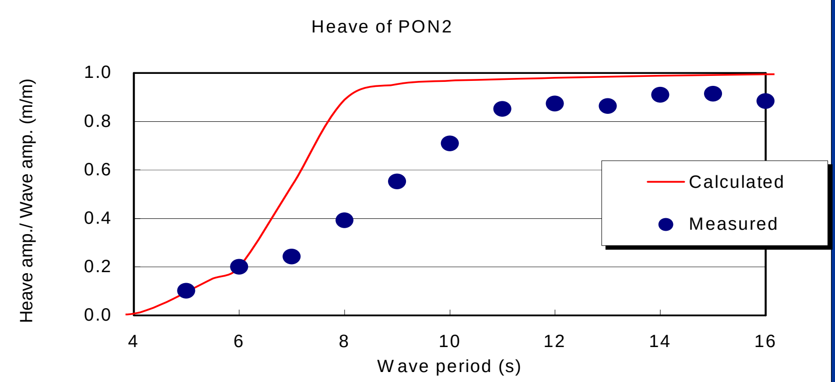


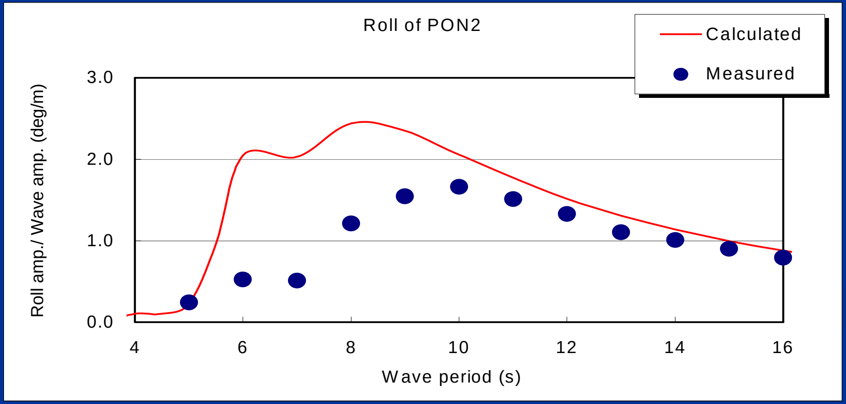
Restricting force

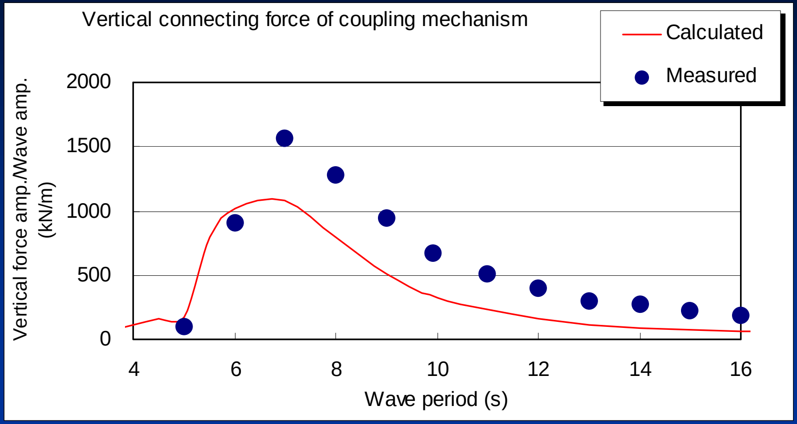


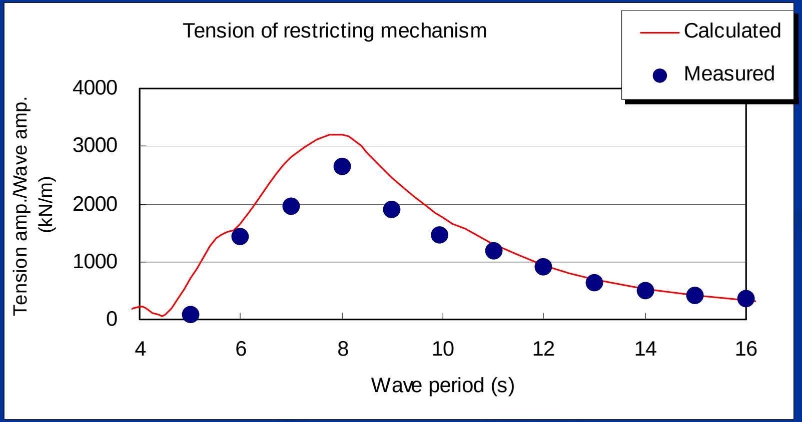
APPLICABILITY OF THE CALCULATION METHOD



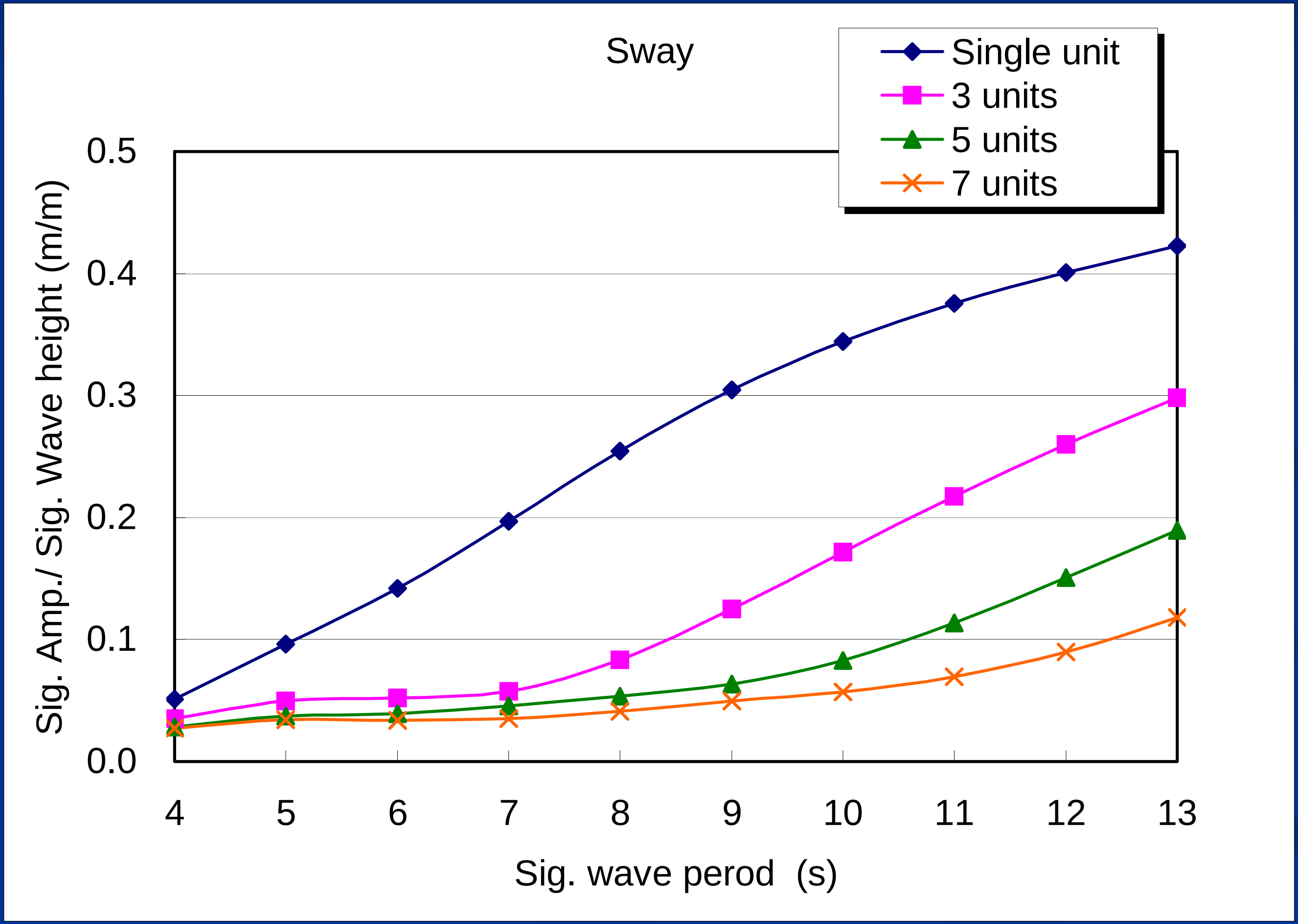




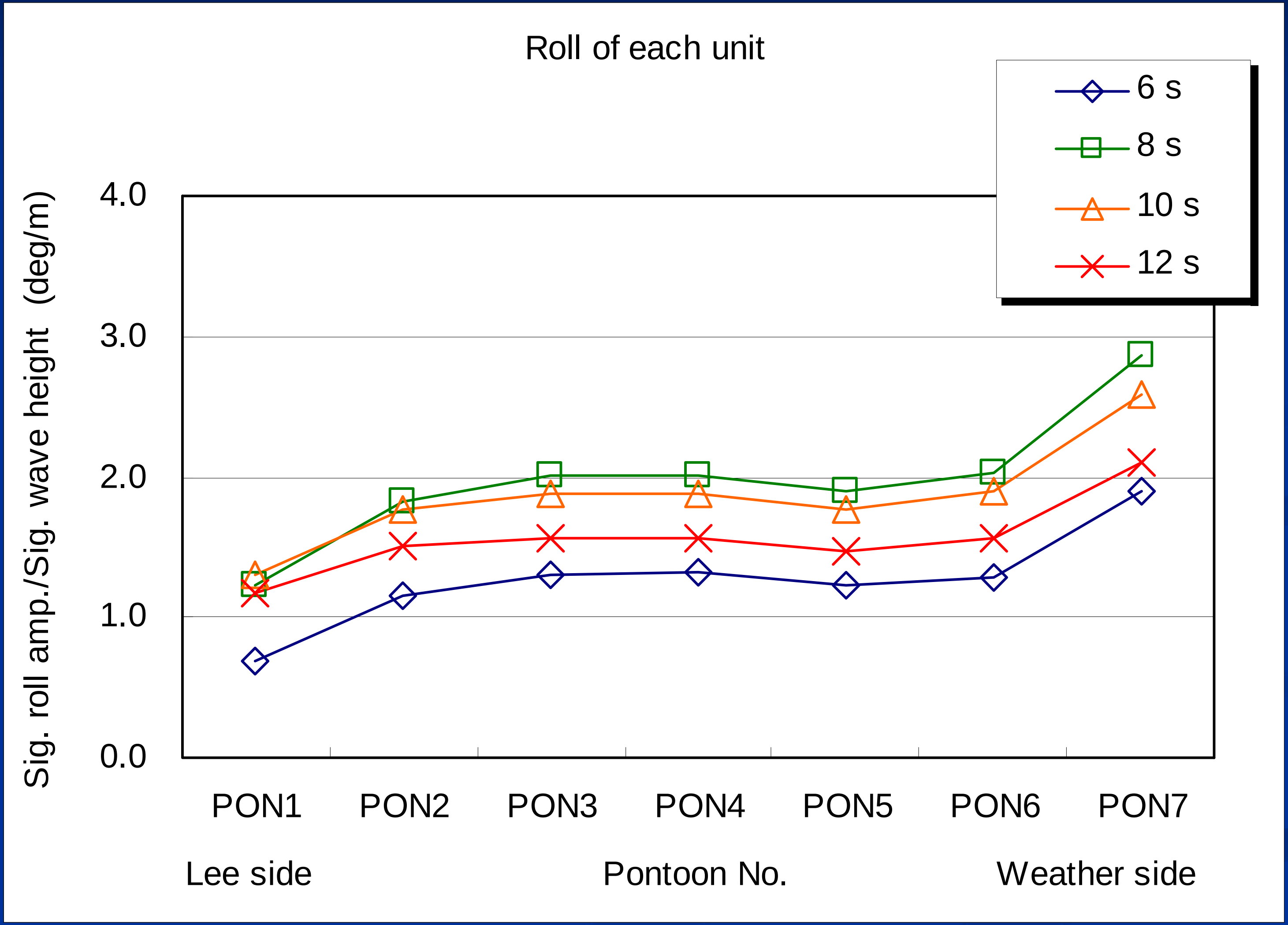




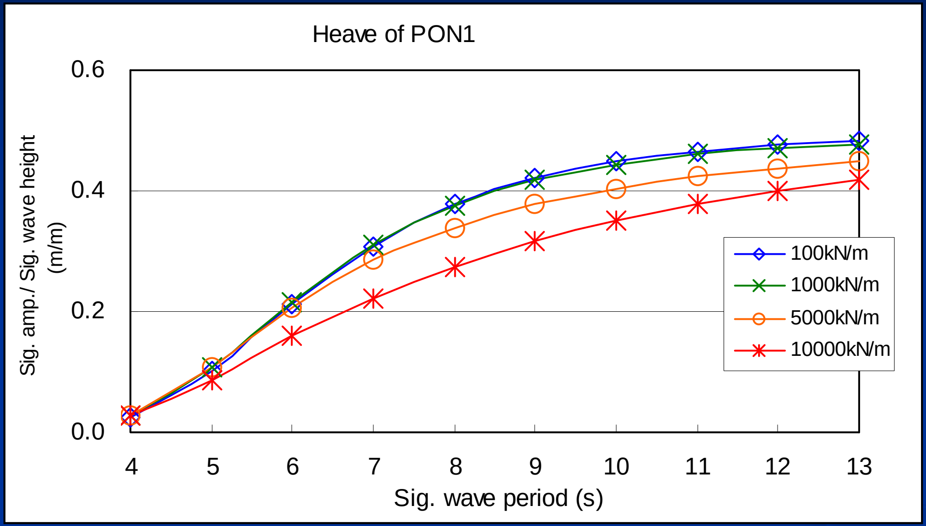
EFFECT OF NUMBER OF FLOATING BODY UNITS

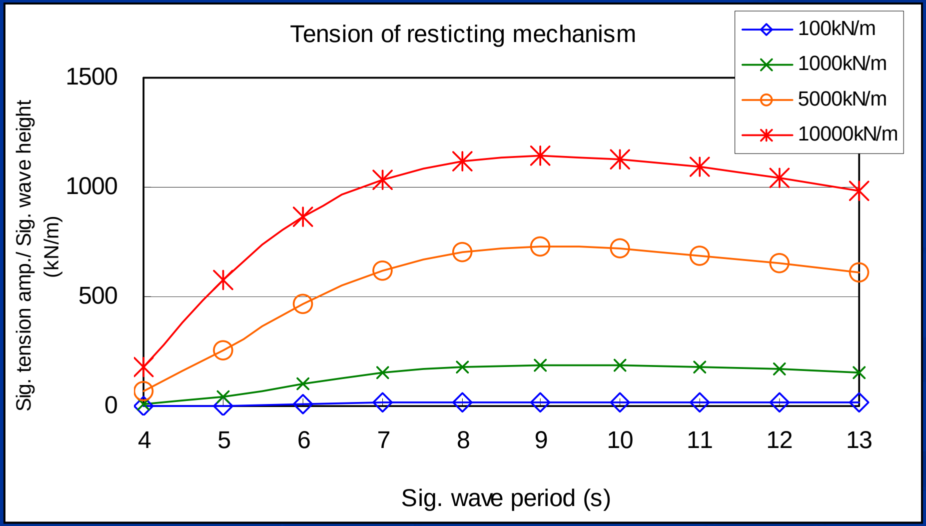


DISTRIBUTION OF ROLL MOTION



EFFECT OF SPRING CONSTANT OF CONNECTING LINE

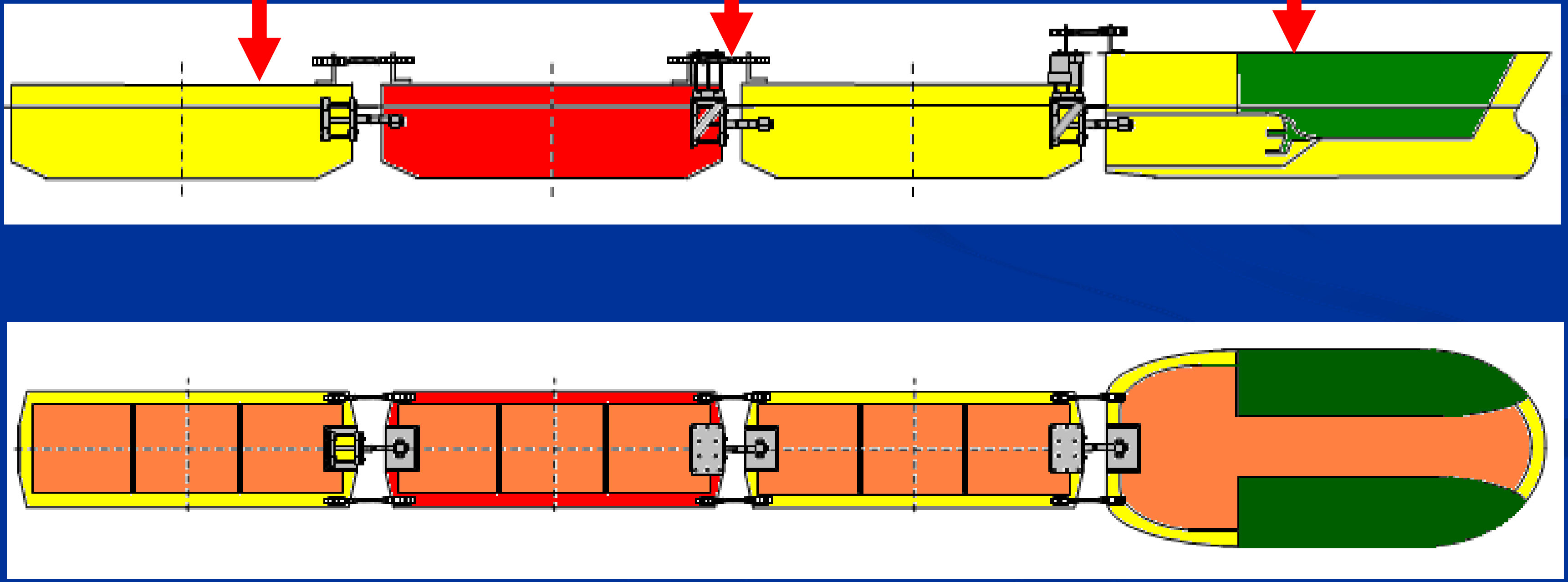




適用法に関する検討

トレーラー式多連結バージシステム

トレーラー式多連結バージシステム

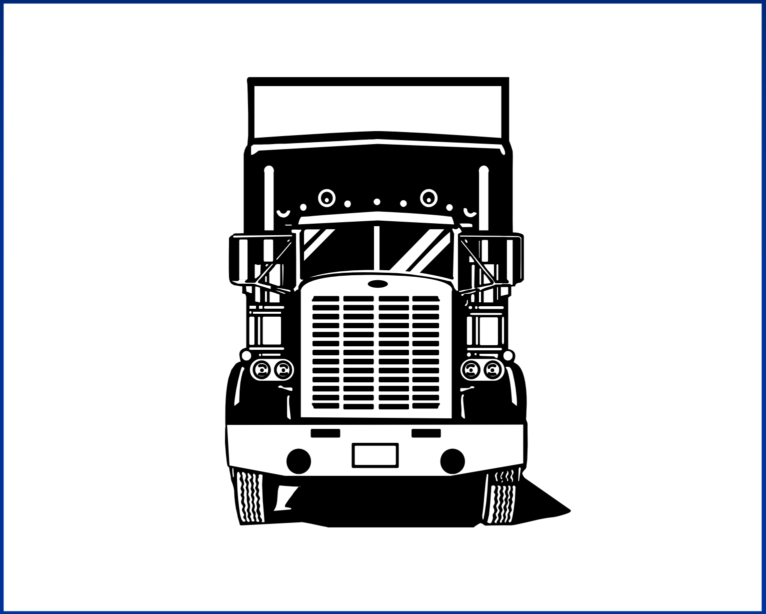


バージ

連結装置

曳船

地球温暖化の対策



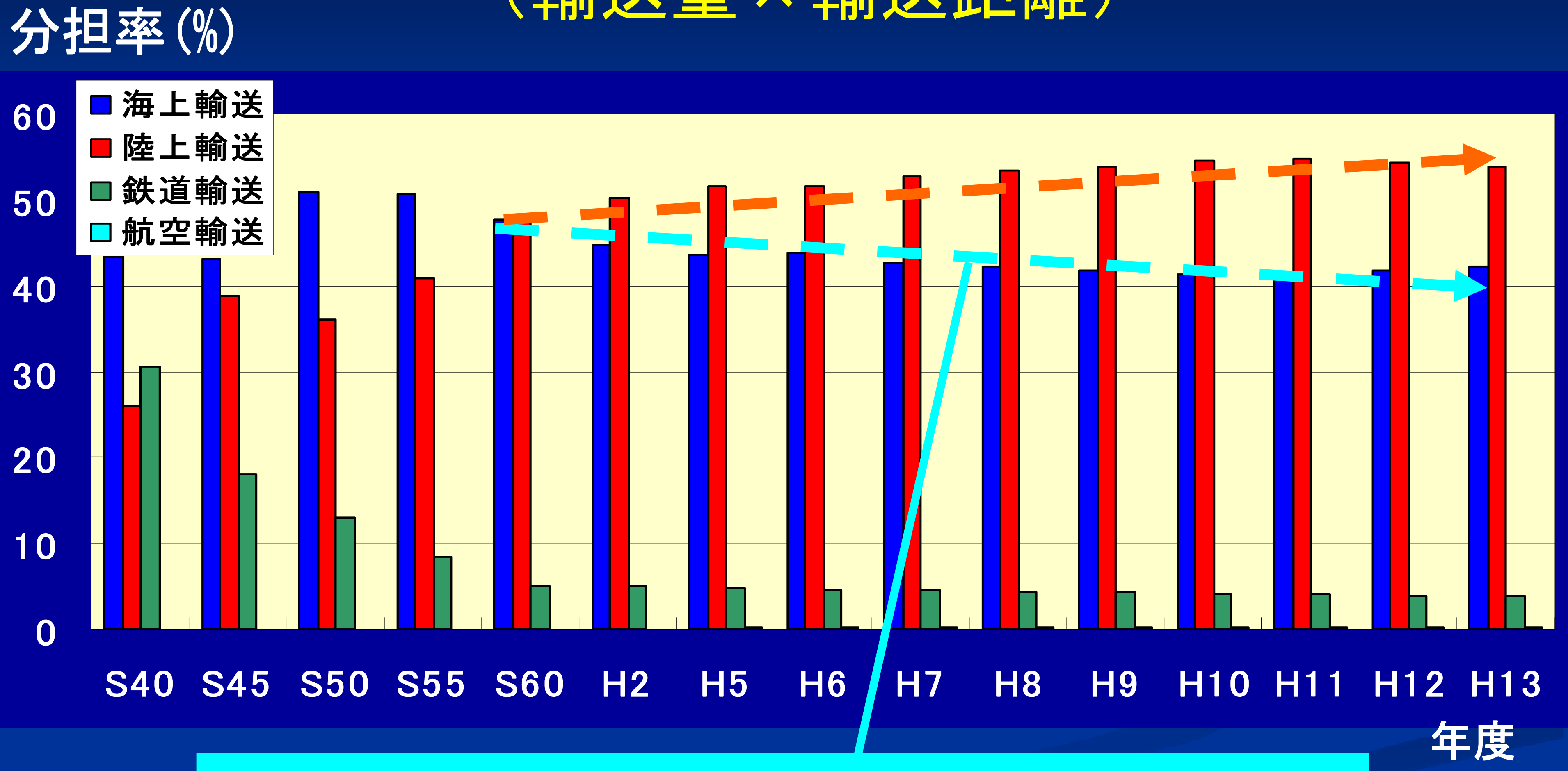
陸上輸送
（環境負荷が大きい）

海上輸送
（環境負荷が小さい）

モーダルシフトの推進

国内貨物の輸送分担率

（輸送量×輸送距離）

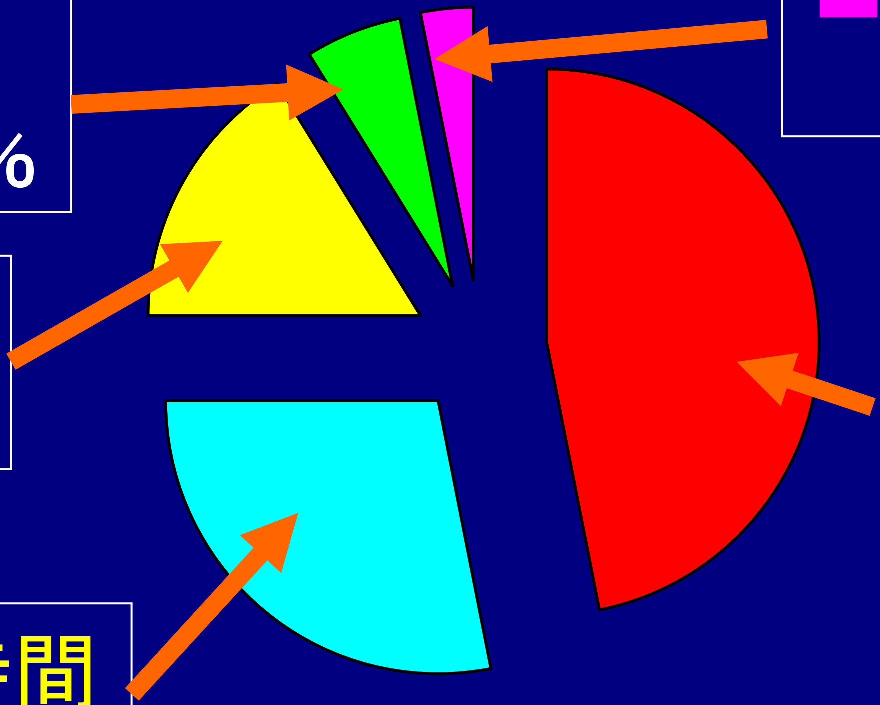


海上輸送がやや減少している

海上輸送（内航海運）の利用が増加しない原因

運航時間の長さ

運航時間内訳



🟪出港準備時間
３％

🟩航海中の
待機時間６％

🟨荷役時間
16％

🟥航海時間
47％

🟦荷役待機時間
28％

短縮 ⇒ 有効な対策になる

トレーラー式多連結バージシステムの利点

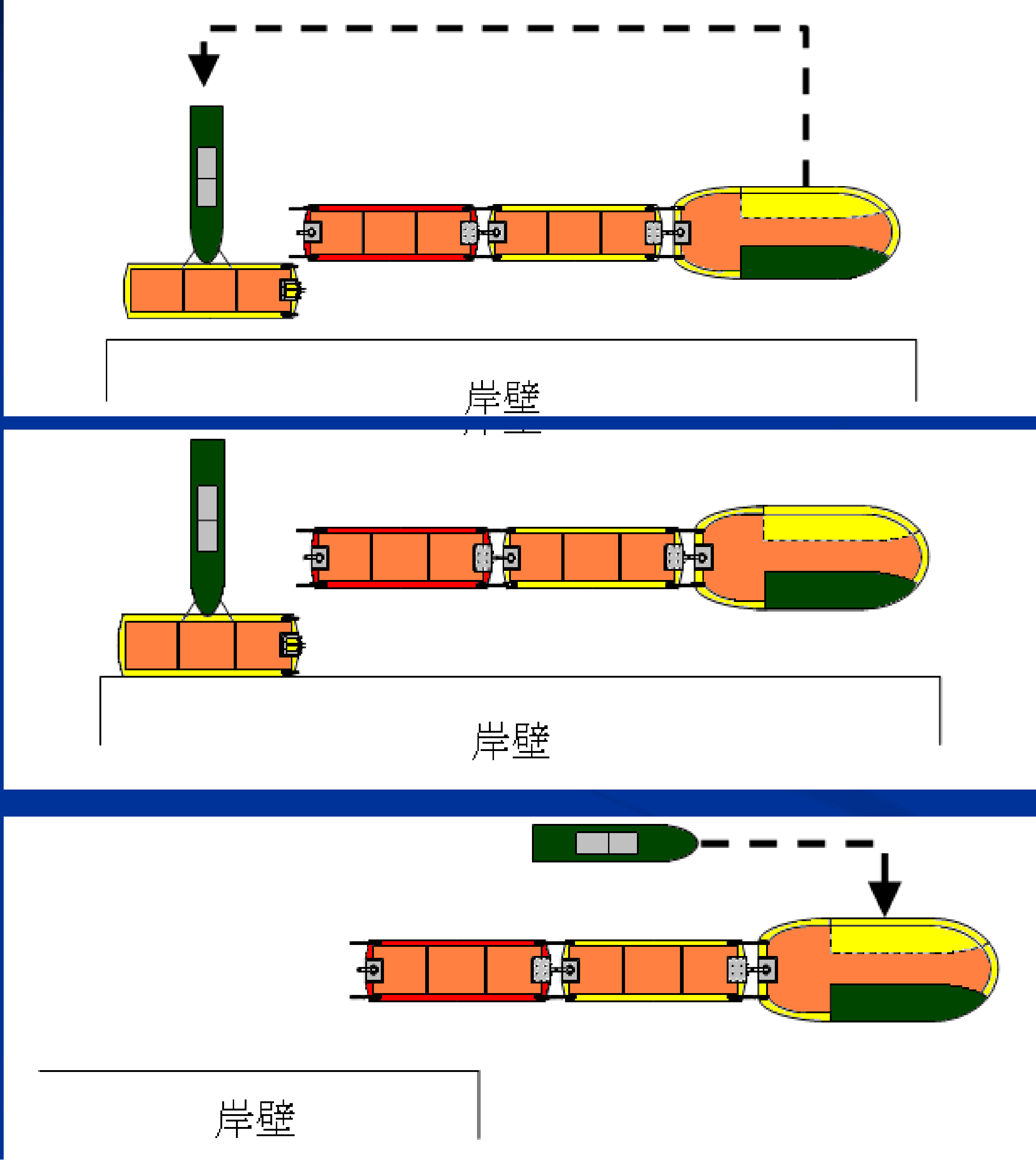
各港を回りながらバージ
を分配・回収

必要なバージだけを

切り離して出航

荷役待機時間の短縮
経済性の向上

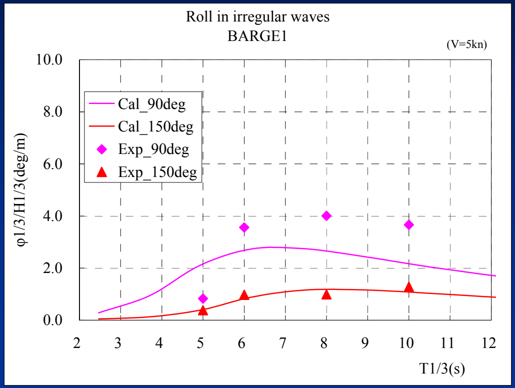
画期的な
海上輸送システム

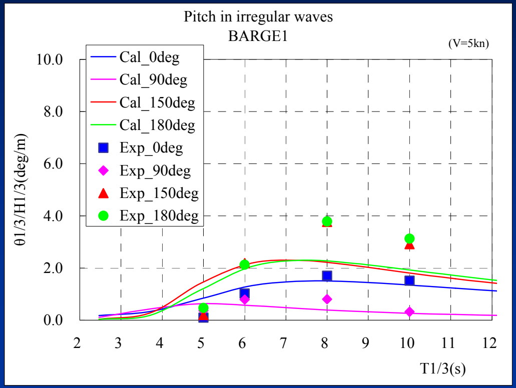


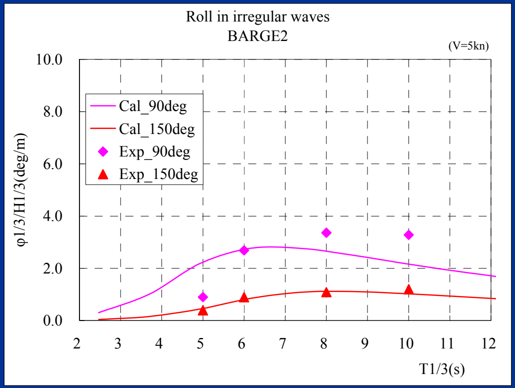
FUNDAMENTAL MODEL BASIN TEST

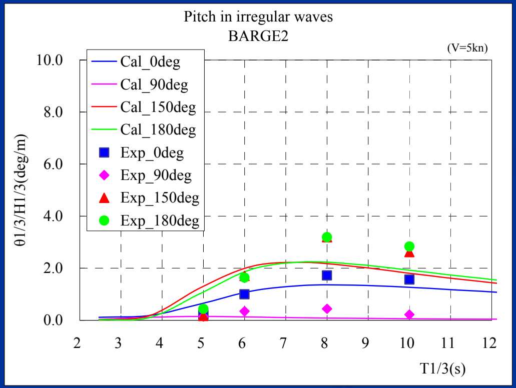
MEASURED RESULTS

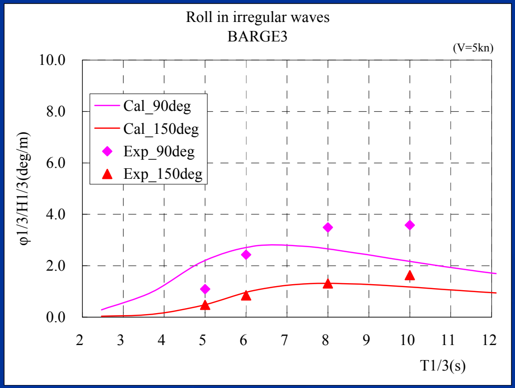
Ship Motion of Each Barge

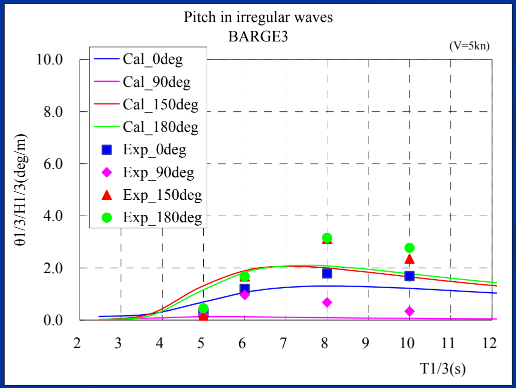






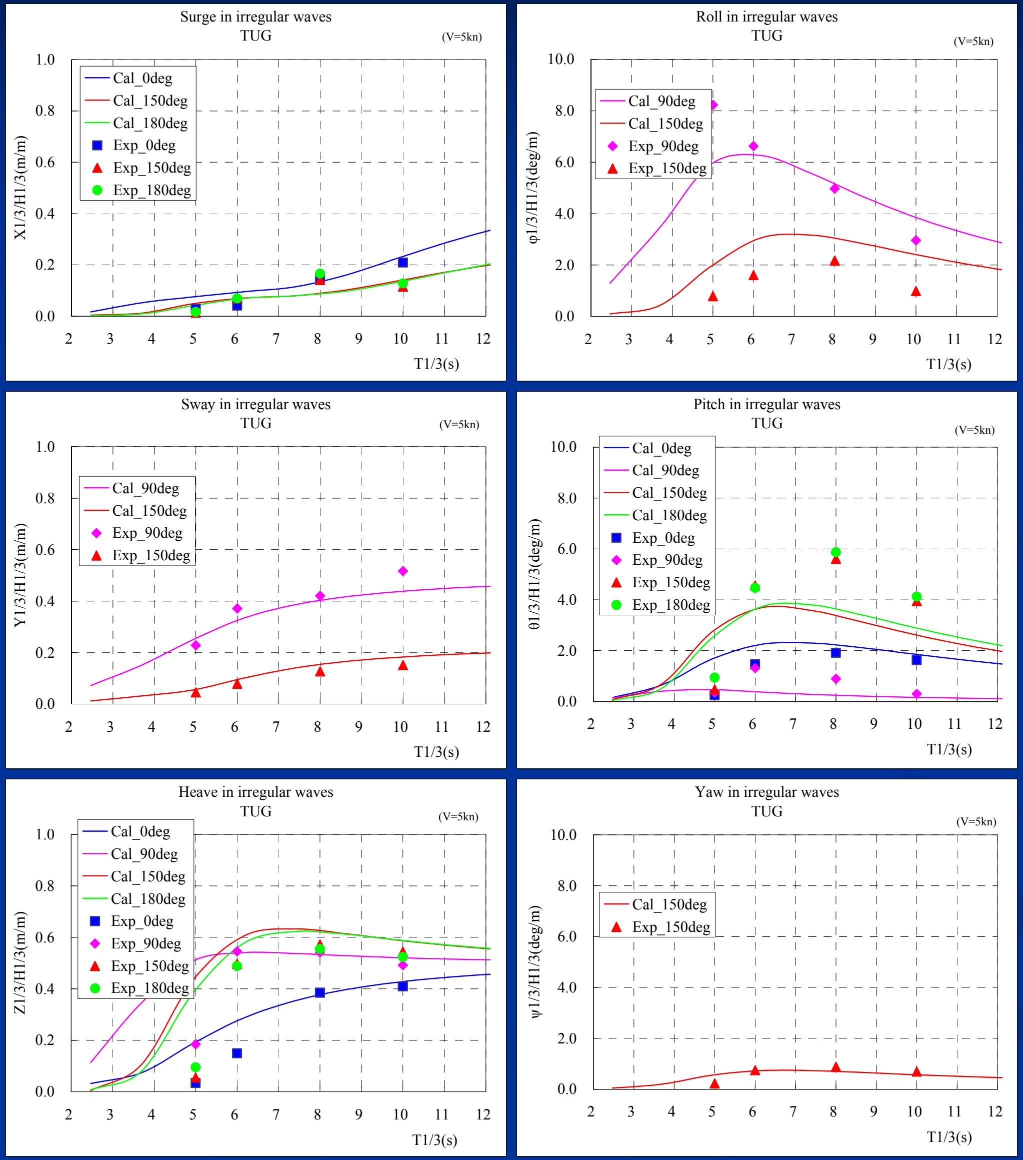






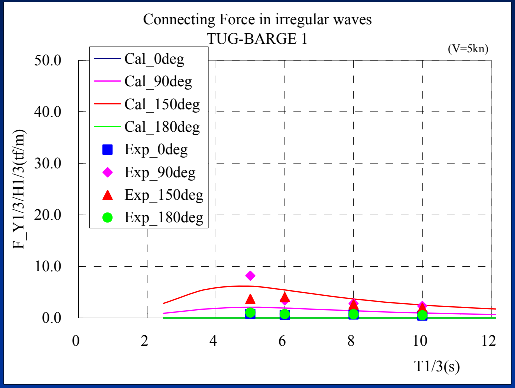
MEASURED RESULTS

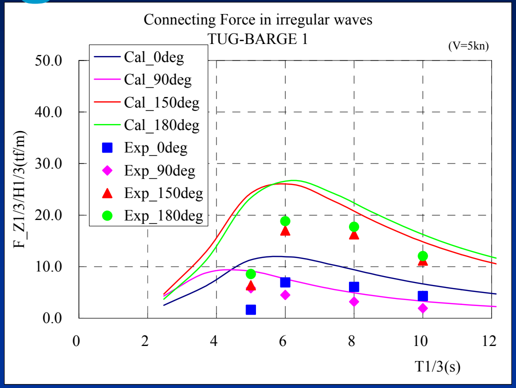
Ship Motion of the Tug Ship

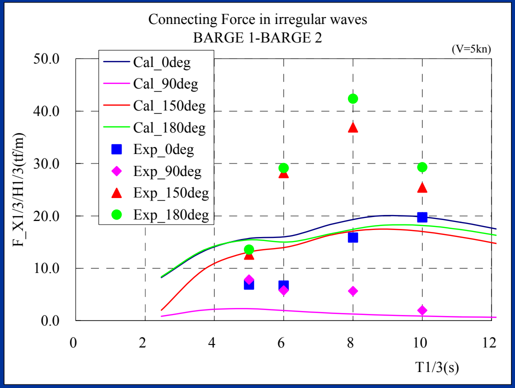


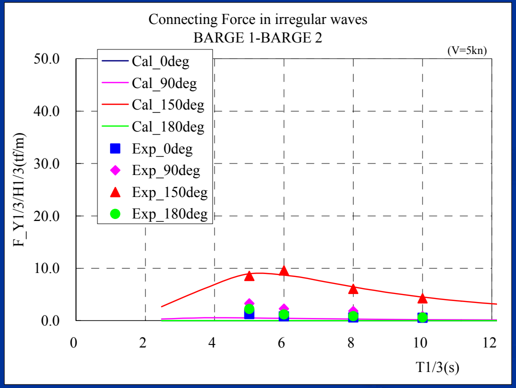
MEASURED RESULTS

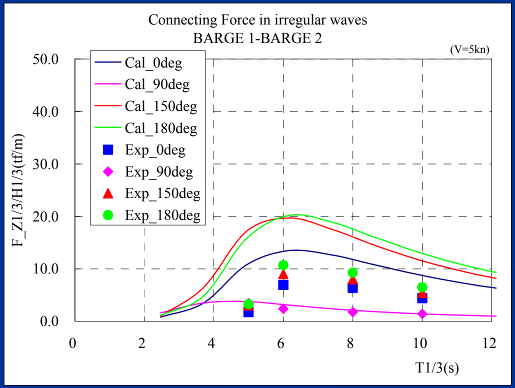
Connecting Forces


Connecting Force in irregular waves
TUG-BARGE 1


Connecting Force in irregular waves
TUG-BARGE 1


Connecting Force in irregular waves
BARGE 1-BARGE 2

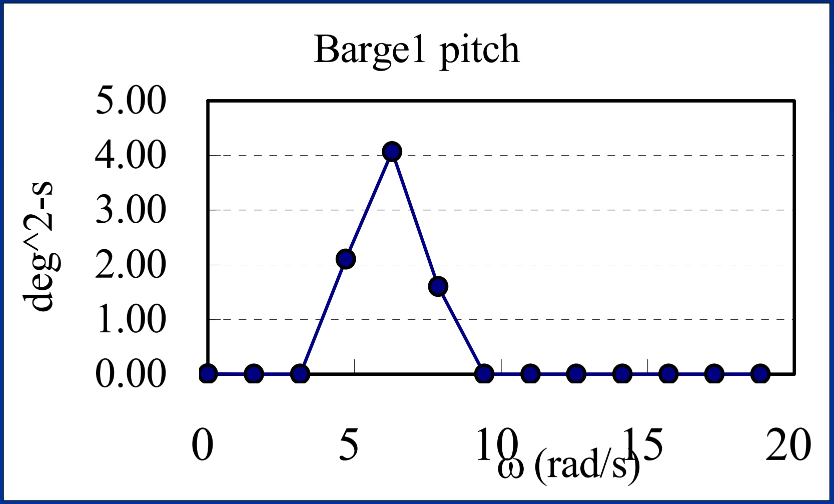

Connecting Force in irregular waves
BARGE 1-BARGE 2

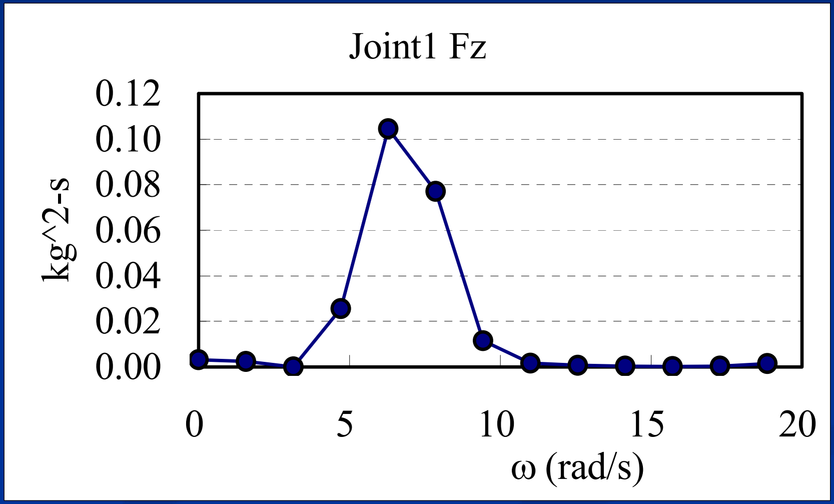

Connecting Force in irregular waves
BARGE 1-BARGE 2

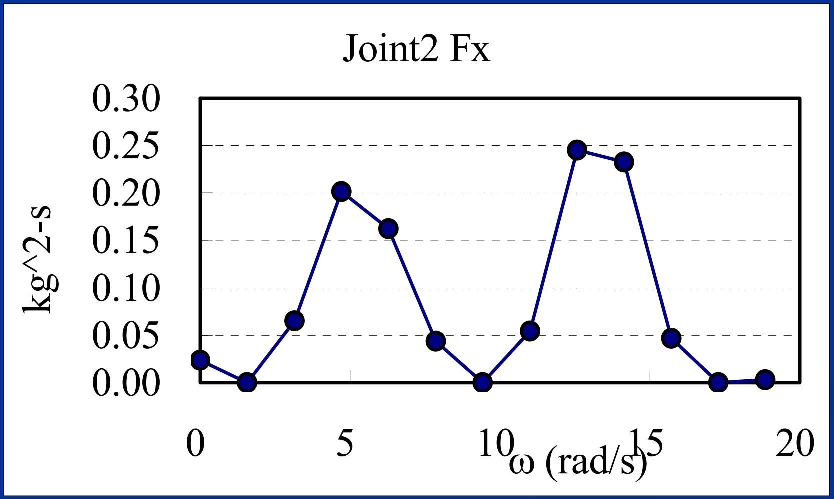
SPECTRUM

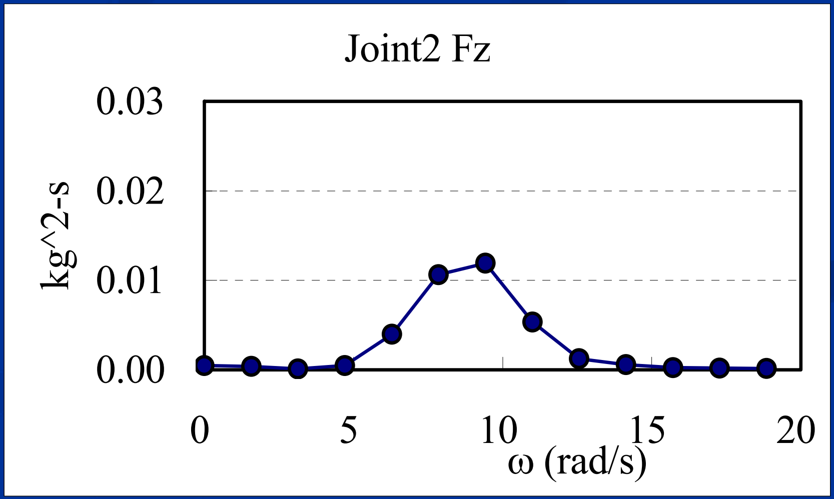
Barge Motion and Connecting Forces

($T_{1/3}$= 6 s)


Barge1 pitch

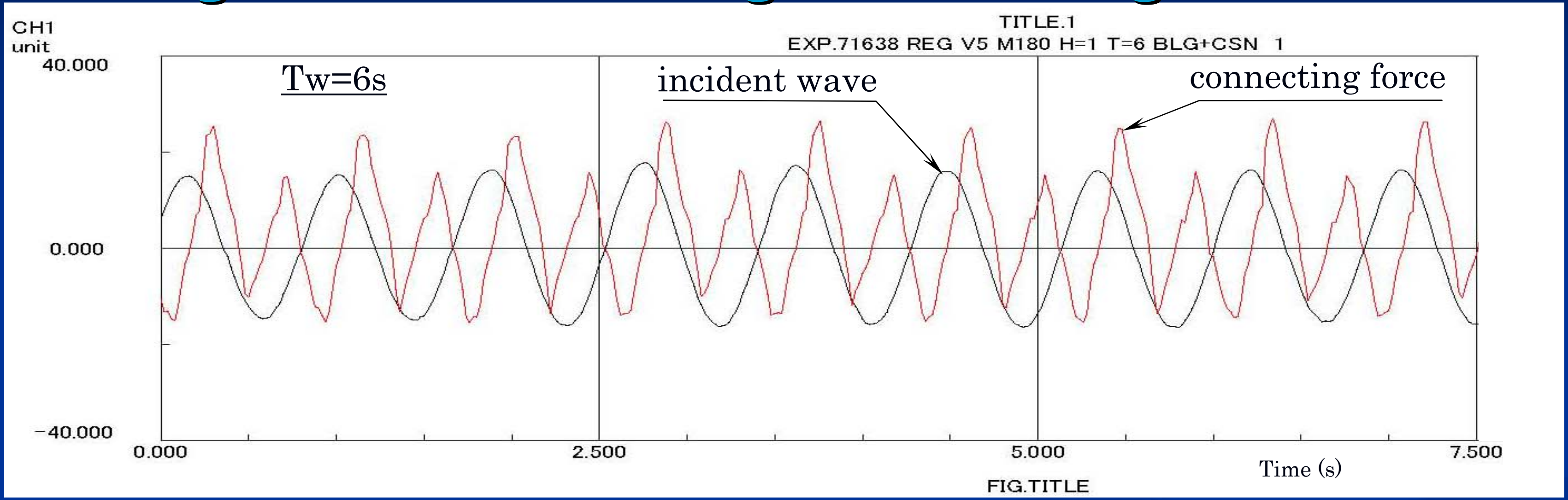

Joint1 Fz

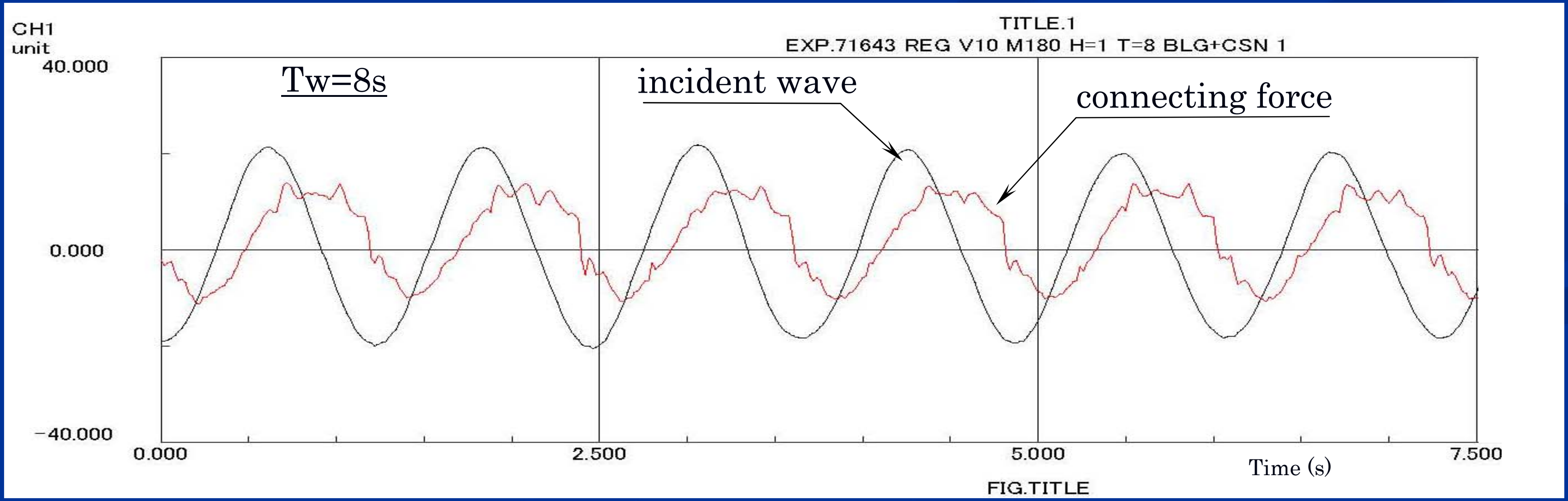

Joint2 Fx


Joint2 Fz

MEASURED RESULTS

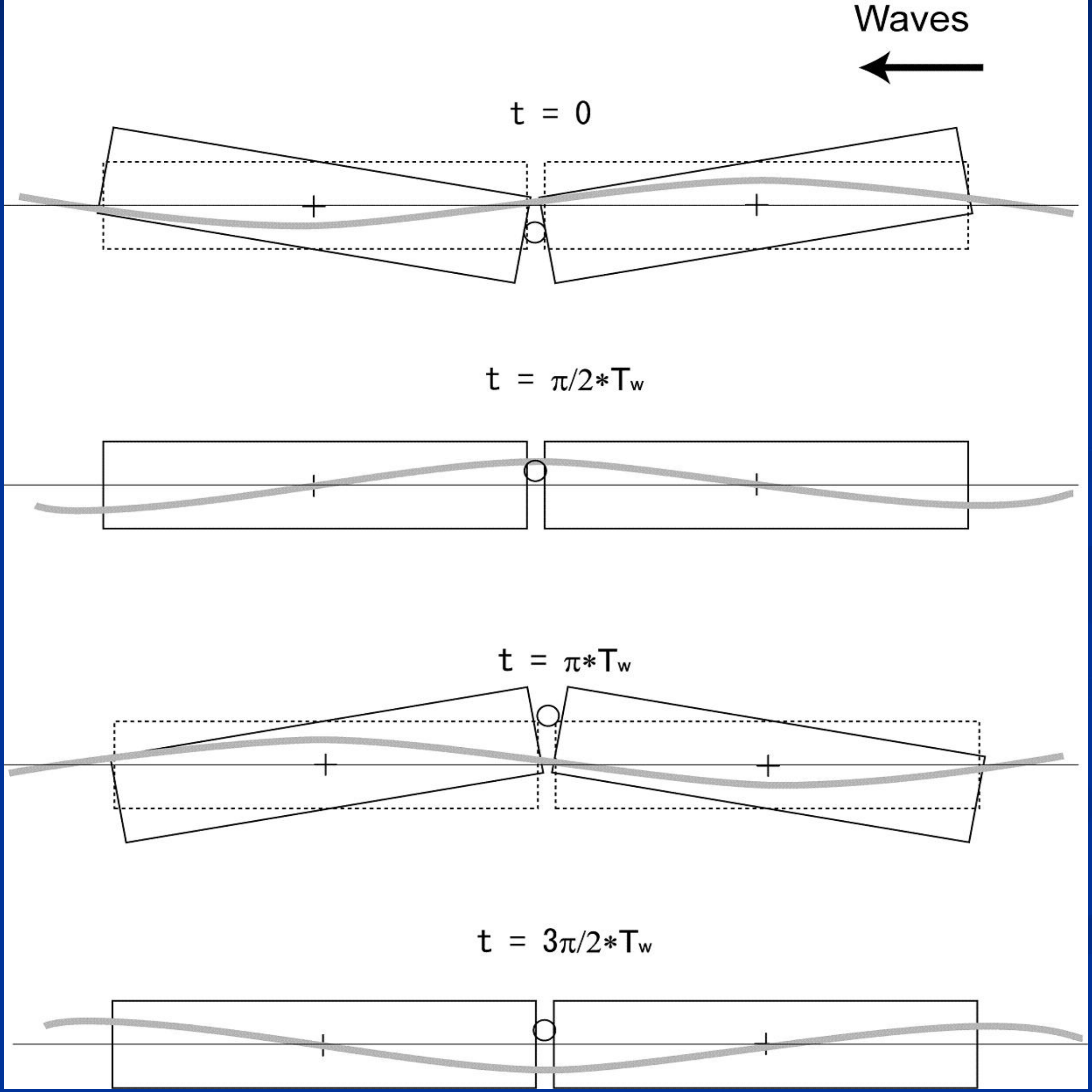
Longitudinal Connecting Force in Regular Waves





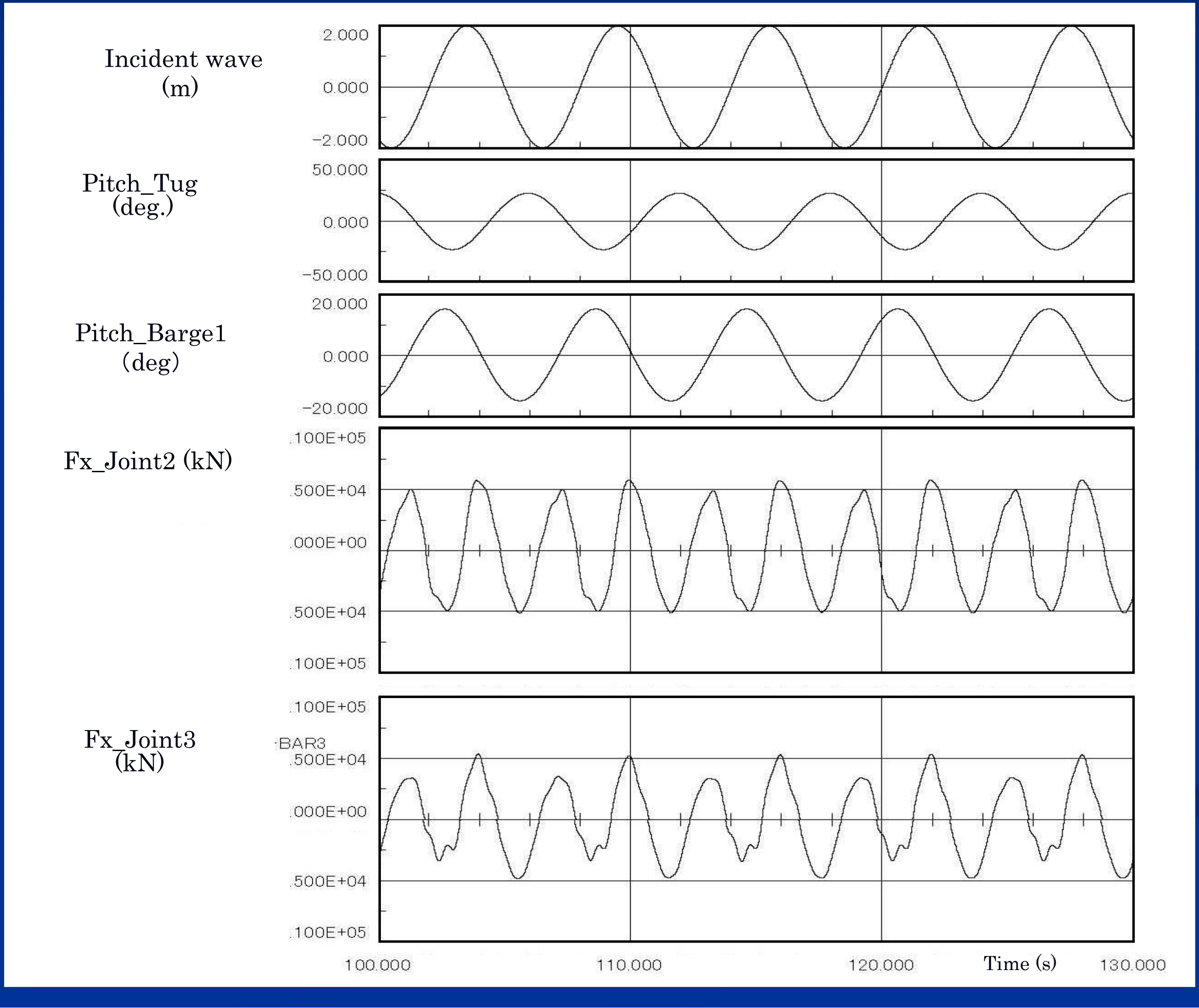
RELATION BETWEEN WAVE AND BARGE MOTION

(Tw = 6 s)



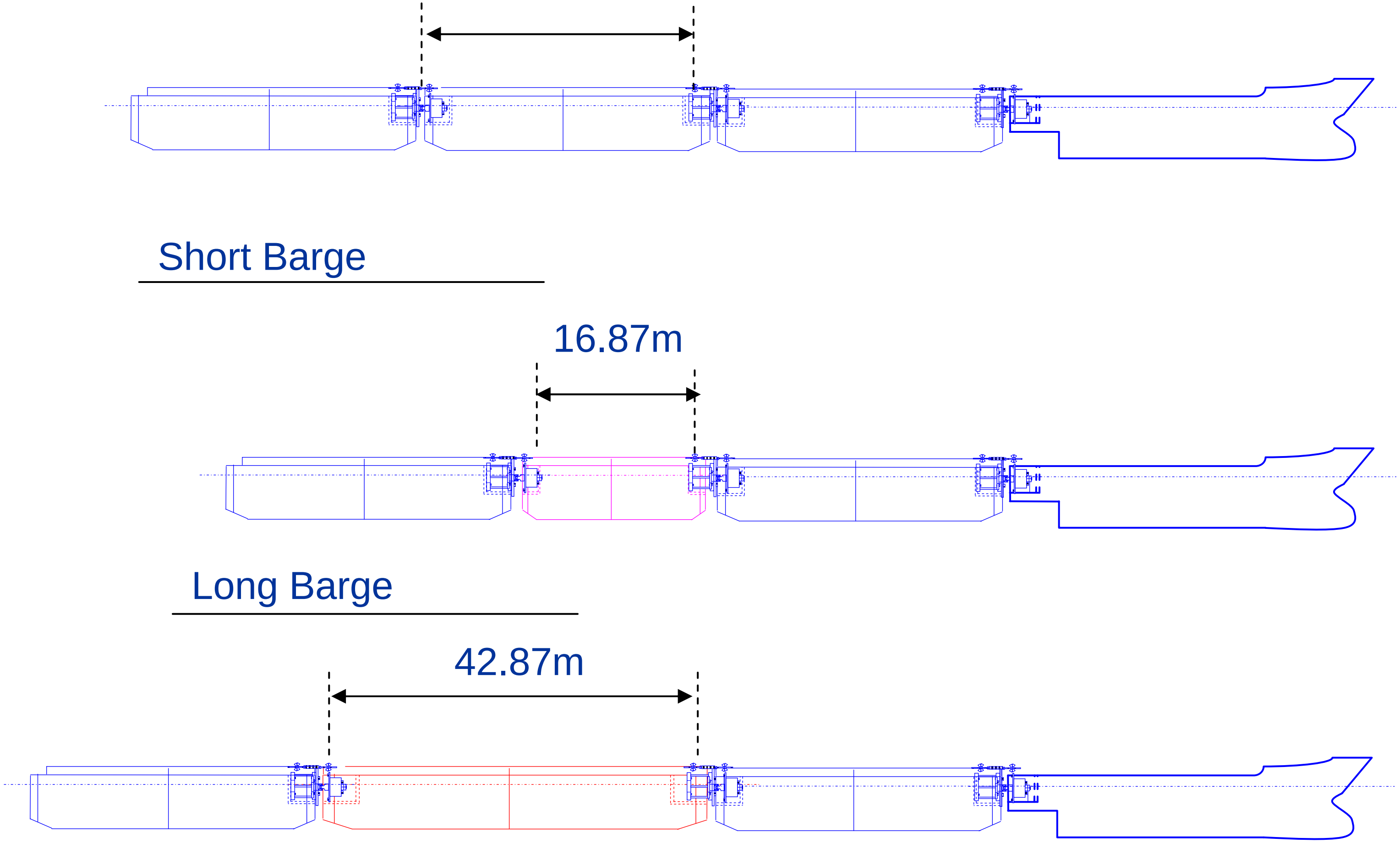
CALCULATED RESULTS

Ship Motion and Longitudinal Connecting Forces



COUNTERMEASURE

Varying the Length of Middle Barge



Original Barge

29.87m

Short Barge

16.87m

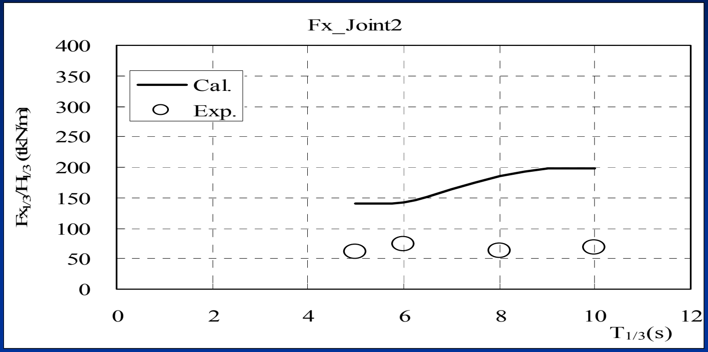
Long Barge

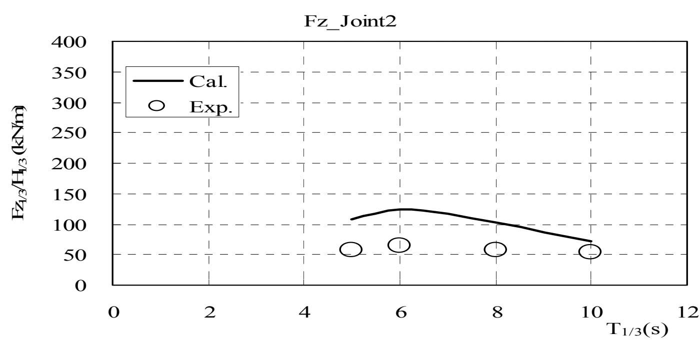
42.87m

MEASURED RESULTS

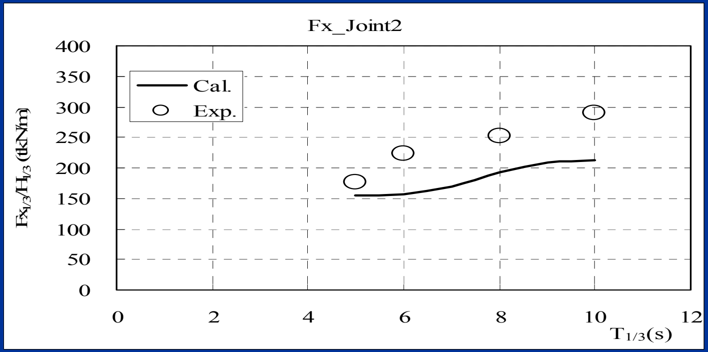
Connecting Forces while varying the length of middle barge

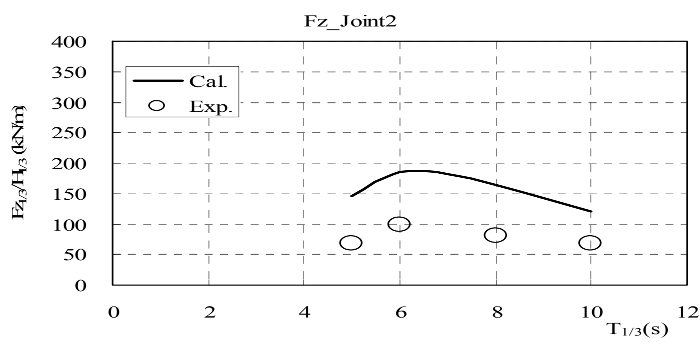
Short Barge



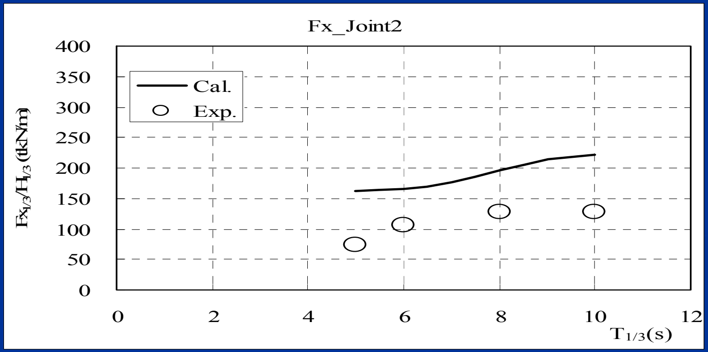


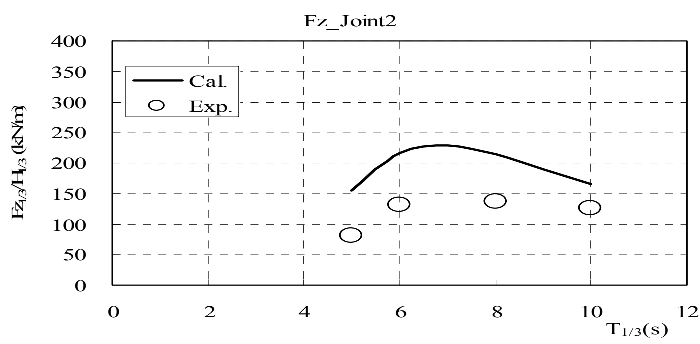
Original Barge





Long Barge

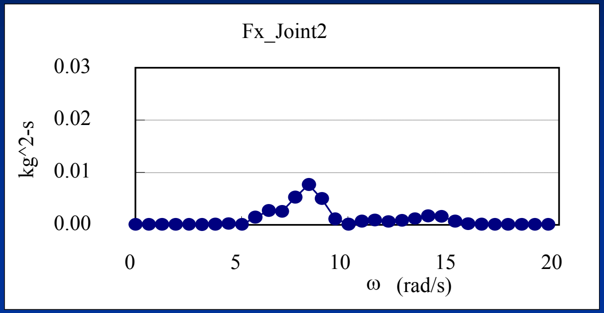


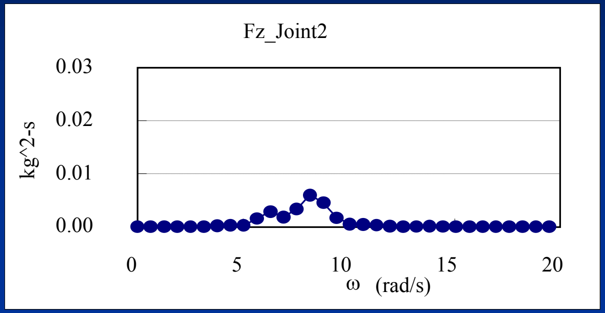


SPECTRUM

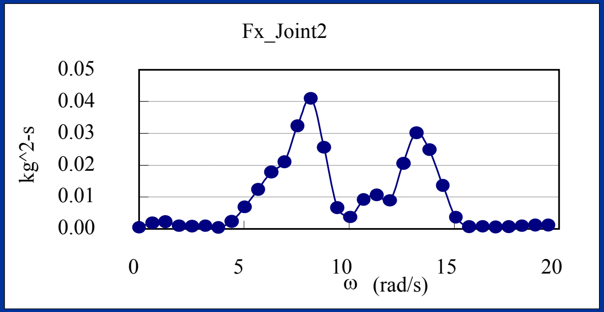
Connecting Forces while varying the length of middle barge

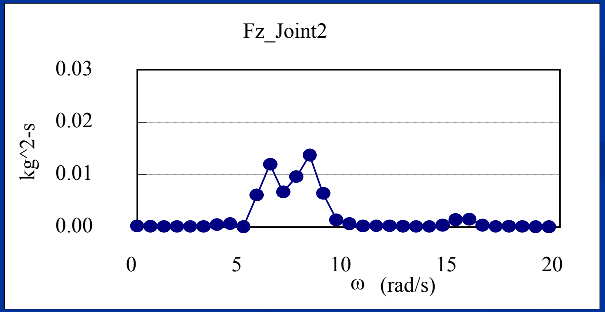
Short Barge



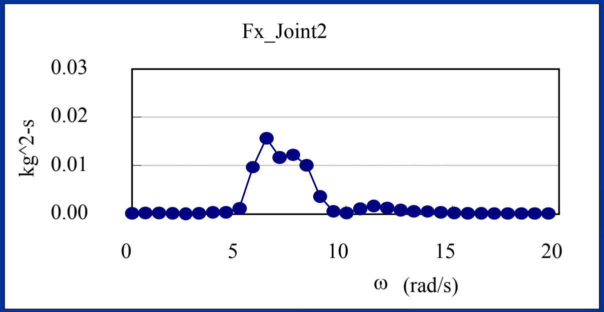


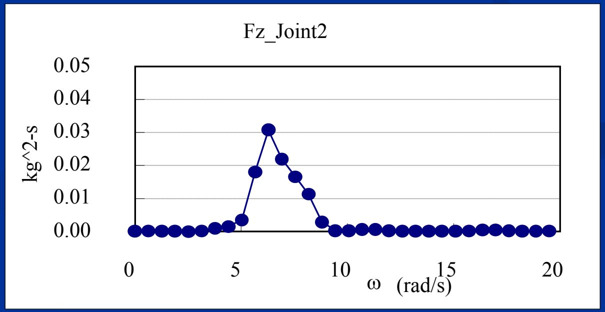
Original Barge



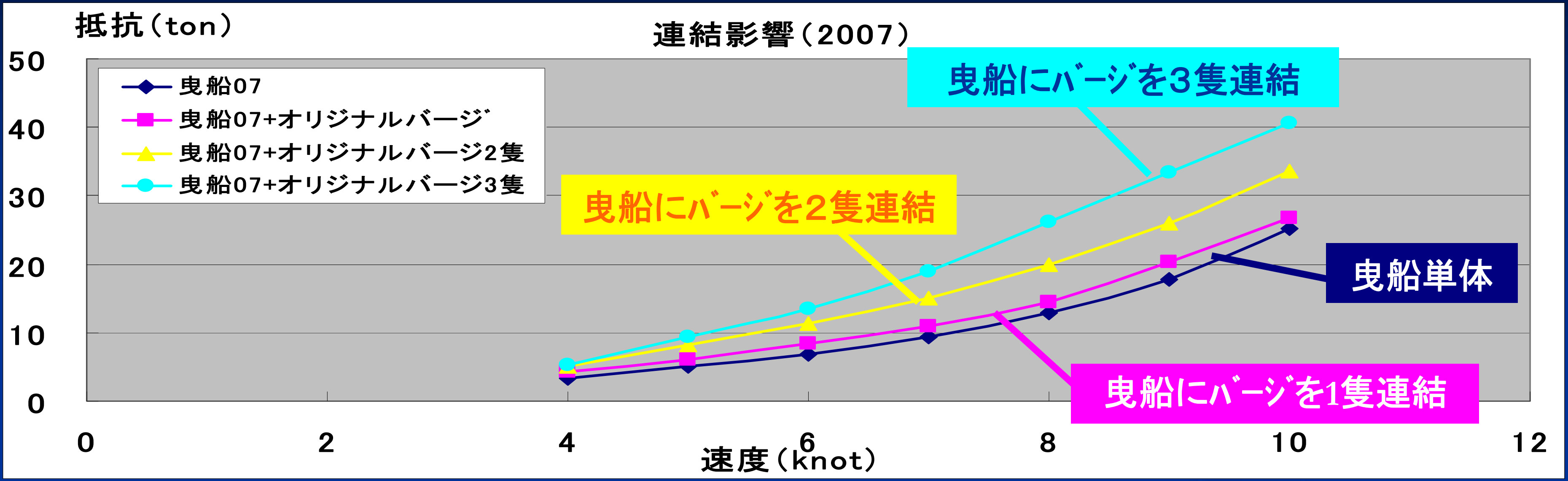


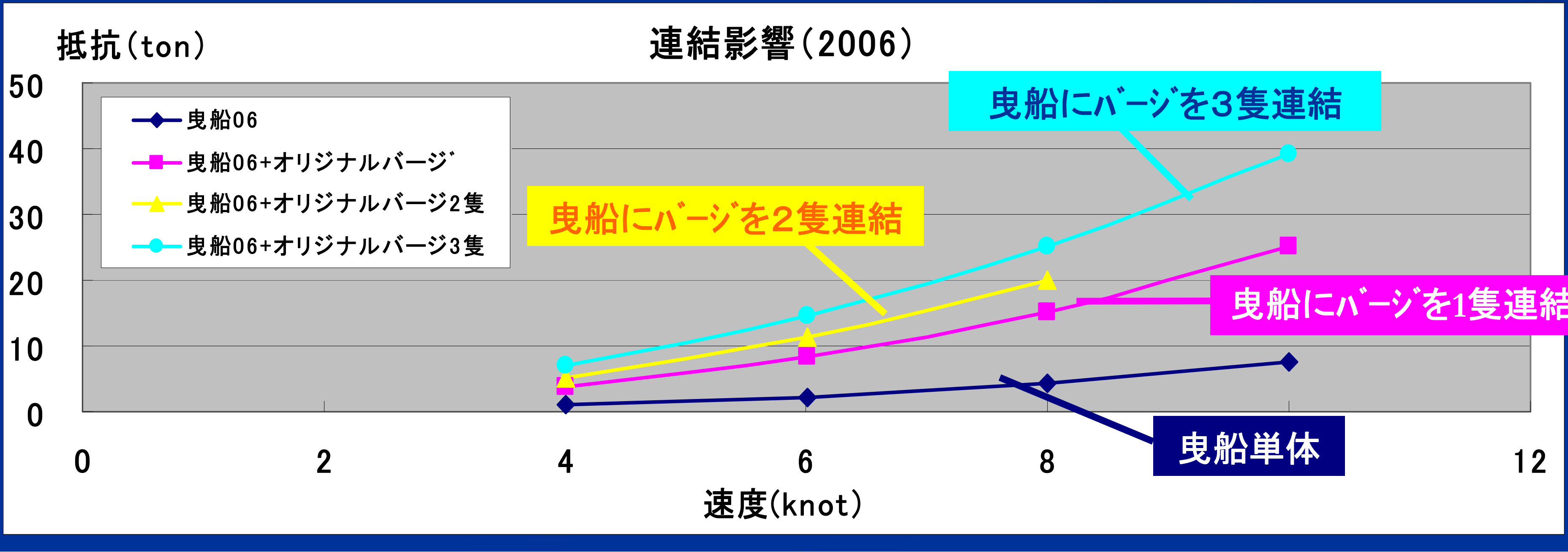
Long Barge





連結影響


抵抗（ton）
連結影響（2007）
50
40
30
20
10
0
0
2
4
6
8
10
12
速度（knot）
曳船07
曳船07+オリジナルバージ゛
曳船07+オリジナルバージ2隻
曳船07+オリジナルバージ3隻
曳船にバージを3隻連結
曳船にバージを2隻連結
曳船単体
曳船にバージを1隻連結


抵抗(ton)
連結影響(2006)
50
40
30
20
10
0
0
2
4
6
8
12
速度(knot)
曳船06
曳船06+オリジナルバージ゛
曳船06+オリジナルバージ2隻
曳船06+オリジナルバージ3隻
曳船にバージを3隻連結
曳船にバージを2隻連結
曳船にバージを1隻連結
曳船単体

まとめ

- 多連結浮体システムは、規模、構造、機能等の変化への対応や小規模施設での建造可能等、多くの利点を有しており、浮体構造物建造の促進が期待できる。
- 多連結浮体システムの実現のキーとなる新しい浮体連結技術を開発した。
- 新しい浮体連結技術を適用した種々の多連結浮体システムの開発に取り組み中である。