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갑판타입수의 유입에 따른 Ro/Ro선 안정성 연구

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Stability of Ro/Ro Ship due to Deck Inflow

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KEY WORDS: Stability, Ro/Ro ship, A.R.T(Anti Rolling Tank)

ABSTRACT: *Intensive experimental investigations were carried out to provide informations of the effects of inflow on the rolling characteristics and stability of ships, which becomes great concern in relation to ship's capsizing. A series of systematic experiments have been performed considering the effects of combined motions of roll-heave-sway and relevant parameters, such as roll angle and period, tank water height etc. To accommodate this type of experiments with 3-degree of freedom of motion, a bench tester has been developed and verified using existing data. Also, theoretical application of anti-roll tank has been incorporated to support the process of investigation. A model of Ro-Ro ships is used in the present study as this type of vessels, as well as fishing vessels, with large open decks, can loose stability rapidly when there is inflow on the decks.*

1. INTRODUCTION

The safety of ship is directly related to the stability of the vessel subjected to various environmental conditions. To improve the stability, there have been various approaches to analyse the dynamic motion of vessel by either numerical or experimental methods and many innovated devices such as bilge keels, fin stabilizers, passive and active type anti roll tanks have been developed (Chadwick (1955) and Lloyd (1989)). Although substantial efforts have undergone on to the issue, the complexity of liquid motions hindered from complete understanding of the nature. In this research, extensive experiments accompanied by mathematical analysis are conducted to examine the vessel motion and resultant moment with different phase angle due to water of free surface. In the context, effects of contributing factors such as water depths and modes of roll motion are investigated.

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For large vessels, the water trapped on deck effects on their stability and the green water as in head seas, would result in structural damage. For smaller vessels with water on deck, particularly in beam seas, is of great danger in terms of stability with higher probability of deck flooding. The ratio of volume of water trapped to the volume of the vessel is greater compared with that of a large ship. Inflow on deck may sometimes be 20 to 30 percent of the initial displacement, which apparently causes an unfavorable change in the vessel stability (Caglayan and Storch (1982)).

It is noted that pseudo-static heel is larger in the higher-frequency range, which naturally means there is more water on deck in this range. This is caused by the increased asymmetry in wave heights between the windward and leeward sides and the decreased roll period, allowing more time to flood the deck. The mechanism of water on deck has been used for passive tank stabilizers to reduce ship rolling at the beginning of researches (Bosh and Vugts (1966)). Bosch and Vugts (1966), in particular, revealed from systematic experiments that the most important parameters are the amount of water in the tank, characterized by the water level and the frequency of the roll motion. Additional parameters are breadth of the tank, amplitude of the motion etc, which are effective on the water accumulation.

In 90s, various researches numerically and experimentally have investigated coupling of ship and liquid motions, non-linear damping and restoring terms (Francescutto and Contento (1994), Contento (1992), Cardo et al. (1992), Armenio (1993), Contento and Cardo, (1993)). Lee and Vassalos (1996) studied on the anti-roll tank effects. However, Most of existing mathematical approaches modelling the sloshing and accumulation of water, provide limited solutions for certain conditions. These models cannot provide accurate solutions over a wide range of important parameters. Also solutions are based on a single degree of freedom motion, therefore the behaviour of the inflow on deck in the case of more than one degree of freedom has to be investigated.

2. THEORY OF DYNAMIC MOTION

The dynamic equations for ships with tank can be expressed as below according to Chadwick (1955).

$$J_s\ddot{\theta}+B_s\dot{\theta}+K_s\theta+J_{st}\ddot{\Phi}+K_{st}\Phi=M_\omega$$
$$J_{st}\ddot{\theta}+K_{st}\theta+J_t\ddot{\Phi}+B_t\dot{\Phi}+K_t\Phi=0 \quad (1)$$

From the characteristic of two tank motions, $K_{st}=K_t$ and in the variable of J_{st} the characteristic of the position in the tank is included. The solution of equation (1) is as below:

$$\theta=\overline{\theta}\,e^{i(\omega t-\varepsilon_s)}$$
$$\Phi=\overline{\Phi}\,e^{i(\omega t-\varepsilon_t)} \quad (2)$$

where θ = ship transverse angle
Φ = fluid transverse angle in A.R.T.
$\varepsilon_s, \varepsilon_t$ = angle difference of θ and Φ

Applying (2) to (1),

$$(-J_s\omega^2+iB_s\omega+K_s)\theta+K_t(1-\omega^2\frac{J_{st}}{K_t})\Phi=M_\omega$$
$$(-J_t\omega^2+iB_t\omega+K_t)\Phi+K_t(1-\omega^2\frac{J_{st}}{K_t})\theta=0 \quad (3)$$

$$1-\omega^2\frac{J_{st}}{K_t}=1-\frac{\omega^2}{\omega_{st}^2}\equiv a_{st} \quad (4)$$

Then the a_{st} expresses the position variation of tank and the frequency is $\omega_{st}=(K_t/J_{st})^{1/2}$. If the tank locates in the middle position, the ω_{st} becomes ∞ and $a_{st}=1$.

Putting together equations of (4) and (3),

$$K_s(1-\frac{\omega^2}{\omega_s^2}+i\frac{B_s\omega}{K_s})\theta+K_ta_{st}\Phi=M_\omega$$
$$(1-\frac{\omega^2}{\omega_t^2}+i\frac{B_t\omega}{K_t})\Phi+a_{st}\theta=0 \quad (5)$$

From the equation (5)

$$\Phi+\frac{a_{st}(a_t-ib_t)}{a_t^2+b_t^2}\,\theta=0 \quad (6)$$

and the coefficients are as follows:

$$a_t=1-\frac{\omega^2}{\omega_t^2}$$
$$b_t=\frac{B_t\omega}{K_t} \quad (7)$$

Putting equation (6) to (5), it becomes as

$$K_s(1-\frac{\omega^2}{\omega_s^2}+i\frac{B_s\omega}{K_s})\theta+\frac{K_ta_{st}^2(-a_t+ib_t)}{a_t^2+b_t^2}\,\theta=M_\omega$$

$$\left[(1-\frac{\omega^2}{\omega_s^2}+i\frac{B_s\omega}{K_s})+\frac{\frac{K_t}{K_s}a_{st}^2(-a_t+ib_t)}{a_t^2+b_t^2}\right]\theta=\frac{M_\omega}{K_s} \quad (8)$$

and the coefficients are expressed as below:

$$a_s=1-\frac{\omega^2}{\omega_s^2}$$
$$b_s=\frac{B_s\omega}{K_s}$$
$$\lambda=\frac{K_t}{K_s}\ \text{(strength ratio)} \quad (9)$$

This equation indicates that the λ, a strength ratio for tank, is located at the center of ship. Therefore the λ is called as equivalent strength factor. The tank center can be expressed by effective strength factor. Since $a_{st}=1-\omega^2/\omega_{st}^2$, a_{st} varies with λ which is dependent on the frequency.

3. EXPERIMENT APPARATUS

Series of experiments have been carried out systematically and an advanced bench tester and hydraulic control system to simulate realistic ship motions and corresponding water behaviour in the tank under investigation have been developed and applied.

3.1 Model Ship and Tank

The general characteristics of the parent ship in Table 1. The model tank was made as drawn in Fig. 1

Table 1. General Characteristics of parent ship and scaled tank

Model	Ship	Tank
Parti-culars	120m×20m×6.75m×5.5m (L×B×D×S_d) Full Displacement = 9,711 ton KG = 7.45 m GM = 1.72 m T_s = 13.15 sec (ω_s = 0.48 rad/sec) k = 0.43 × B b_s = 0.10, 0.15	(scale 1:20) 20cm×100cm×20cm (L×B×d) T_t = 11.54 sec (ω_s = 0.54 rad/sec) **inflow holes:** diameter = 1 cm numbers = 10 intervals = 1 cm

3.2 Experimental Conditions

Table 2 shows experimental conditions and input data used in numerical calculations for the series of experiments. It is seen that variations of tank simulations, such as inflow height and motion type are given to study their effects as well.

Table 2. Experimental Conditions

Item		Validation Runs	Exp.
Depth of Tank Water (cm)		10	2, 6, 10 (h/d=0.1, 0.3,0.5)
Roll	Angle (deg)	3.8	5
	Period (sec)	1.5 ~ 4.0 (0.25 interval)	
Heave	Amplitude(cm)	4	
	Period (sec)	1.6	
Sway	Amplitude(cm)	4	
	Period (sec)	1.6	
Uncoupled Motion	Roll only	○	○
Coupled Motion	Roll+Heave+Sway	○	○

3.3 Verification Test of New Bench Tester

The apparatus of bench tester as shown in Fig. 2 has been developed to simulate not only roll motion but also coupled motions including roll, heave and sway. To verify the performance of the bench tester, the results of Bosch and Vughts (1966) are used for comparison with the experimental results. Fig.3 shows comparison of the test results of moment and phase angle with those of Bosch and Vugts(1966). Also, the model tank (Vugts' model) is used to identify the characteristics of tank flow with the variations of motion mode (Jeung and Woo (1997)). Fig.4 shows the characteristics of tank flow with various modes of motion.

3.4 Effects of Pure Roll and Coupled Motions

Coupled motions in 3-degree of freedom comprising roll, heave and sway, are examined in addition to the pure roll motion. Furthermore, variations of parameters are incorporated in the study and the comparison of the results between two different modes of motion are made and discussed.

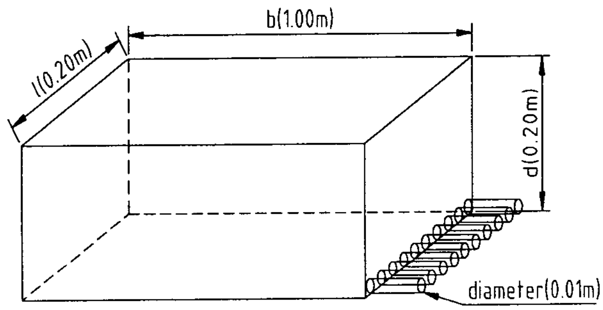


Fig.1 Features of Model Tank

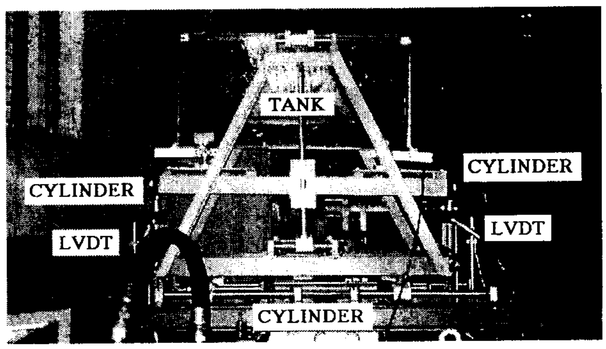
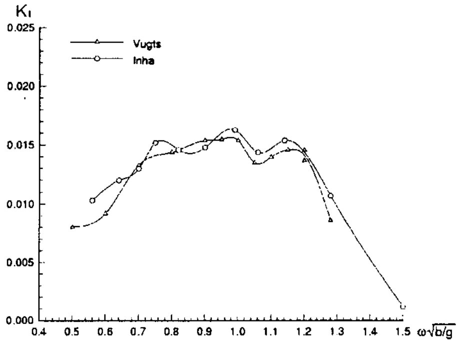
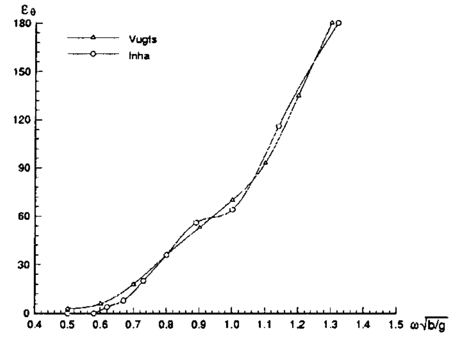


Fig.2 Apparatus of Bench Tester

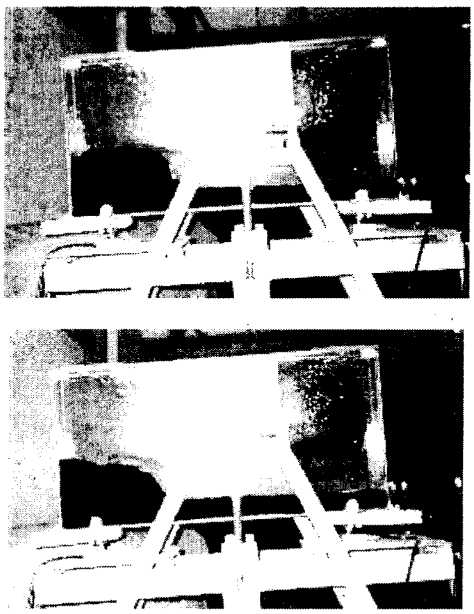


(a) K_t.(tank moment) due to $\omega\sqrt{b/g}$



(b) ε_θ(phase angle) due to $\omega\sqrt{b/g}$

Fig.3 Verification of Bench Tester (Roll Angle 3.8 Deg.)



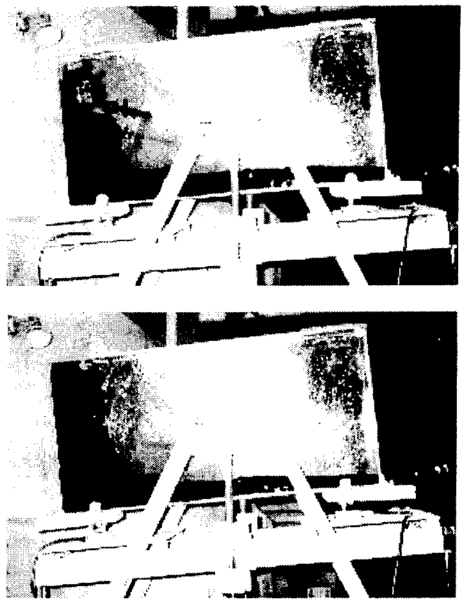
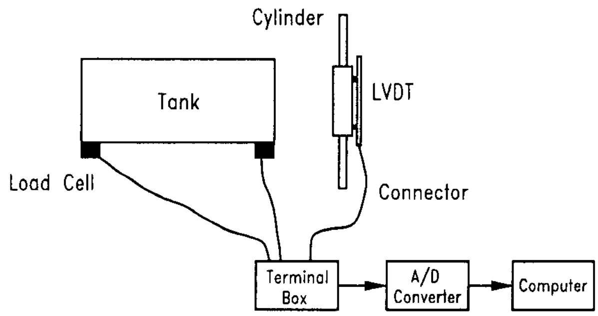


Fig.4 Example of a Flow Pattern in Experiment

3.5 Data Aquisition and Analysis

As shown in Fig. 5, the data aquisition system and its corresponding program are used to collect the electric signals from the hydraulic control system and those from load cells attached under the tank. The data is analysed to produce results, such as motions and moments with time. These informations of output are used to calculate moments and phase angles corresponding to experimental conditions.



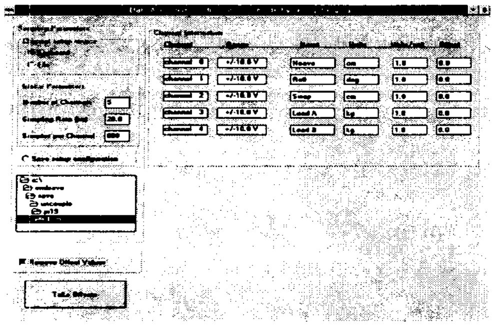


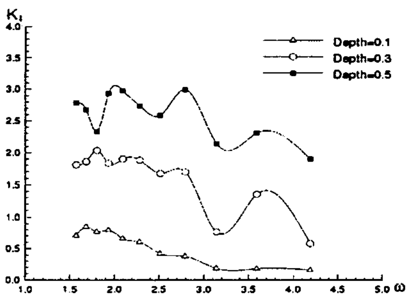
Fig.5 Data Aquisition System and Program

4. RESULTS AND DISCUSSION

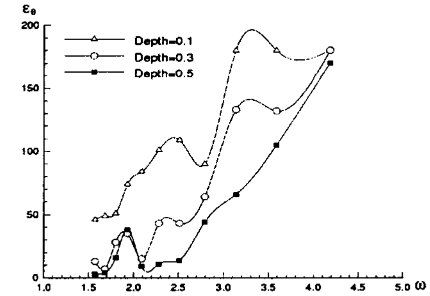
From the experimental output of tank moment and phase angle, it show that K_t due to coupled motion is greater than that of pure roll motion, particularly in low wave frequencies. It is demonstrated that coupled motion causes complex and non-linear characteristics of flow. The differences of ε_θ between pure roll and coupled motions would not show any persistent trends. It would confirm that phase angle is very sensitive, depending on the parameters, such as volume, frequency, mode of motion, etc of the flow.

4.1 Effect of Water Depth

The effects of inflow depth on K_t and ε_θ are evident and show persistent trend in either motion mode. As inflow depth increases, corresponding magnitudes of K_t increase, whereas those of ε_θ decrease. Figs. 6 and 7 show the effects of inflow depth to moment and phase angle for coupled and roll motions at roll angle 5° .

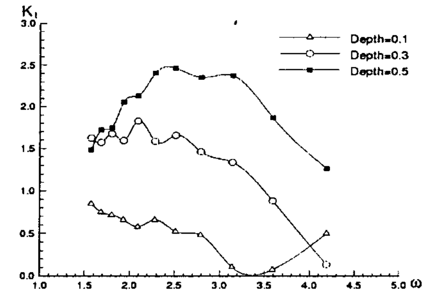


(a) Tank moment due to wave frequency

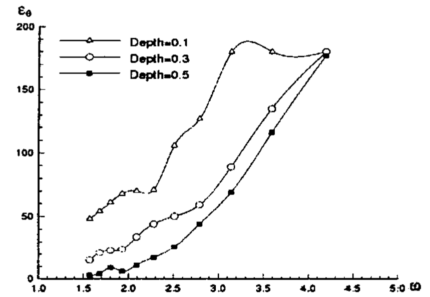


(b) Phase angle due to wave frequency

Fig.6 Pure Roll Motion: Moments and Phase Angles



(a) Tank moment due to wave frequency

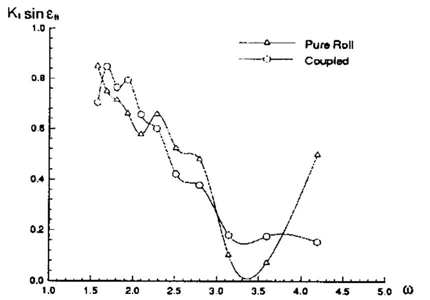


(b) Phase angle due to wave frequency

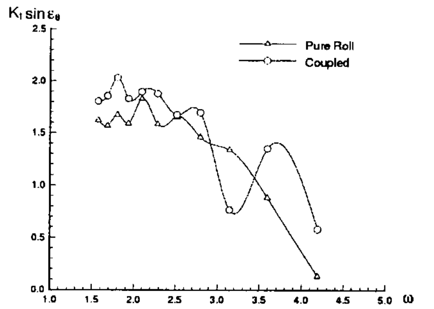
Fig.7 Coupled Motion: Moments and Phase Angles

4.2 Comparison of $K_t \cdot \sin\varepsilon_\theta$

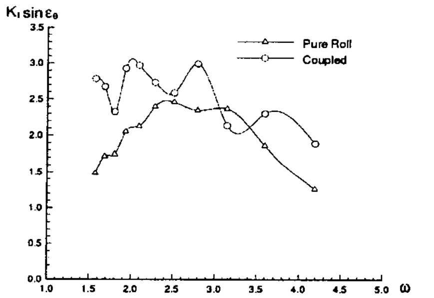
The difference of $K_t \cdot \sin\varepsilon_\theta$ can be seen in Fig.8 for the variations of water depth. It is observed that phase angle ε_θ, plays important role in the analysis. The value of $K_t \cdot \sin\varepsilon_\theta$ increases significantly with water depth at high frequencies at roll angle 5° . In particular, coupled motion gives rather fluctuating results at low frequencies.



(a) h/d = 0.1



(b) h/d = 0.3



(c) h/d = 0.5

Fig.8 Comparison of $K_t \cdot \sin\varepsilon_\theta$ between pure roll and coupled motion

5. CONCLUSIONS

An experimental investigation has been carried out on the dynamic effect of inflow onboard to the stability of vessel. To generate and investigate the coupled motions, a bench tester, which can accommodate roll, heave and sway, has been developed for the present research. The device is found quite effective in application to this type of tests. The conclusions can be drawn as follows:

(1) It is confirmed that coupled motion causes the tank flow to be of complexity and non-linearity. The phase angle as well as moment are very sensitive to the variations of parameters in coupled motion.

(2) The moment due to coupled motion is generally greater than that of pure roll motion, particularly in low wave frequencies. Also the moment increases as the inflow depth increases as well.

(3) The difference of phase angles between the results of pure roll and coupled motions is significant when the inflow depth is shallow.

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