EXPERIMENTAL STUDY ON FLOODING OF A CRUISER IN WAVES

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ABSTRACT

To study the motions and flooding process of a damaged cruiser, a series of experiment have been performed in calm water and in waves. Two damaged parts are selected to investigate damage effects; mid section and fore section. The flooding process in calm water is tested for the transient process. The effects of flow in/out through opening and internal water motion are investigated in waves. The experimental results are analyzed and compared.

Keywords: *cruiser, damaged, flooding, experiment, sloshing*

1. INTRODUCTION

The evaluation of the motions and flooding process of a damaged ship in waves is very important for assessment of survivability and ship safety. Many efforts have been also made for the development of numerical methods for the behaviour of damaged ship. These numerical methods have been validated and improved by the international benchmark studies such as those done by ITTC and HARDER project. Up to now it is believed that the numerical methods are able to predict the overall tendency of the damaged ship motions and flooding process to an extent when compared with experiments. But reliable prediction is difficult because the underlying phenomena are very complicated and highly nonlinear due to the various factors such as geometry of damaged compartment, flooding process and waves etc. To improve the accuracy of the numerical methods and the understanding of the mechanism of flooding process, data of various damaged scenario need more through numerical methods and experiments. Also it is generally believed that the physics of damaged ship can be analyzed by experiments more realistically.

In this study a series of experiment have been carried out for the behaviour of a damaged cruiser in waves. Two damaged configurations are selected to study the damage effects. The one is mid section part which has 6 compartments. The second is fore section part which has 4 compartments. The position of damage is starboard in both damage conditions. The flooding tests were performed for the transient process and the flooding water height was measured by 19 water height sensors. The flooding test results can also be used for the validation data of numerical codes and the enhancement of understanding. To study the effect of flooding water and damage compartment, model tests were carried in various wave conditions. The motion tests in waves were carried out after the compartments are completely flooded. The results of the present paper are preliminary and the experiments will be compared with the numerical results in the future works.

2. MODEL EXPERIMENTS

The model tests were performed in MOERI ocean engineering basin (L×B×D: 56×30×4.5 m). The model ship is a cruiser and the hull data of cruiser is provided by SSRC. The contents of model test are as follows.

▪ Motion in regular and irregular waves

Intact, damaged

▪ Flooding process in calm water

Intact, damaged

▪ Free decay in calm water

Intact, damaged (opened, closed)

2.1 Ship model

The target ship is a cruiser. The main particulars are summarized in Table 1 and Figure 1 and Figure 2 show lines and model of cruiser. The model was fitted with bilge keels. Its length is 75 m and height is 0.50 m in prototype. They are symmetrically located about the mid ship at half the bilge girth. The inclination with the vertical is 45 deg. The model was around 5 m long corresponding to a scale of 50.

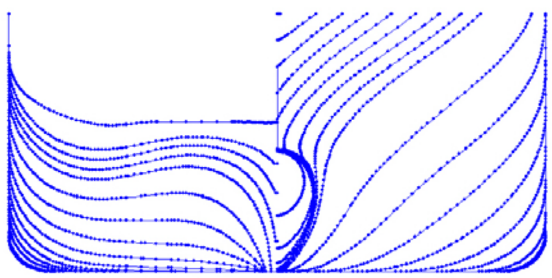

Fig 1 Lines of cruiser

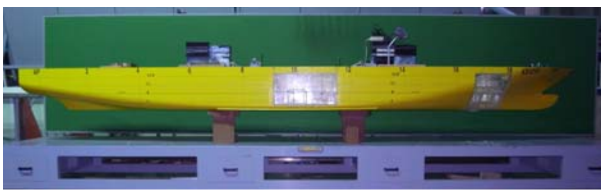

Fig 2 Cruiser model

Table 1 Particulars of cruiser

Length, Lpp (m)	247.2
Beam, B (m)	35.5
Draft, T (m)	8.3
Displaced weight (ton)	56541.5
KG (m)	16.393
GM (m)	2.388
Natural roll period (sec)	21.07
Gyration of roll (m); 0.42B	14.814
Gyration of pitch (m); 0.25Lpp	61.925

2.2 Damage compartment

Two damaged scenarios were chosen. The one (DAM1) is that mid section part is damaged which has 6 compartments. The second (DAM2) is that fore section part is damaged which has 4 compartments. These damaged parts are little different with original inner compartment of the cruiser. The compartments were simplified for model test. The opening of damaged compartment is located starboard side, the length is 6 m and the height is 5 m. The general arrangement of the damaged compartment is shown in Figure 3.

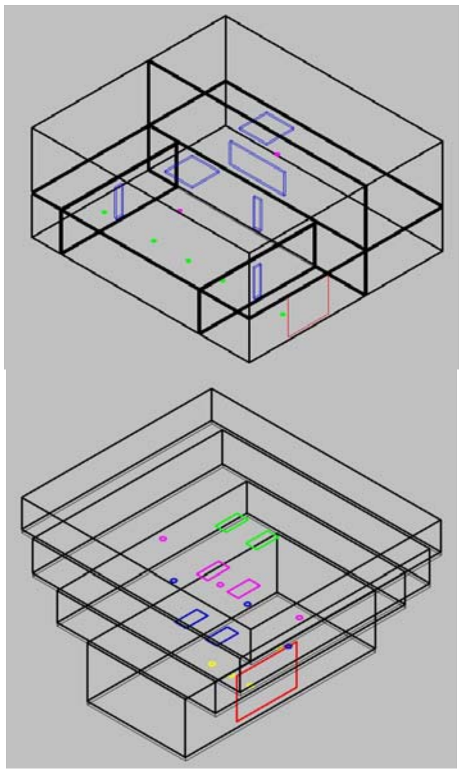

Fig 3 Arrangement of damage compartments (CP10/11, CP17)

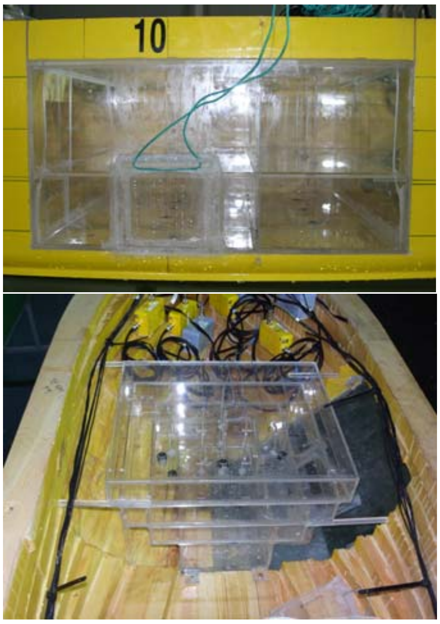

Fig 4 Damage compartment model

The damage model is shown in Fig 4. The material of damaged model is acryl and thickness is 5 mm. The coordinates of compartments and inner connection are listed in Table 2 & 3. The origin is midship (10 St.) in x, center in y and baseline in z direction. The opening of DAM1 is located above free surface, 8.3 m. The top of opening from the keel is 8.4 m. The top of DAM2 opening from the keel is 8.05 m. The opening is pulled out in an instant for flooding test. The coordinate of wave probes in each compartment is listed in Table 4.

Table 2 Coordinates of compartments

Compartment	X1	X1	Y1	Y2	Z1	Z2
CP10-R1S	-10.750	6.275	-7.250	-14.500	2.900	8.425
CP10-R1C	-10.750	6.275	-7.000	13.125	2.900	8.425
CP10-R1P	-10.750	6.275	13.375	17.500	2.900	8.425
CP10-R2	-10.750	6.275	-14.500	17.500	8.675	16.875
CP11-R1	6.525	17.750	-14.500	17.500	2.900	8.425
CP11-R2	6.525	17.750	-14.500	17.500	8.675	16.875
CP17-R1	82.050	99.450	-3.000	6.000	3.900	8.550
CP17-R2	82.050	99.450	-5.750	8.750	8.800	11.350
CP17-R3	82.050	99.450	-8.000	11.000	11.600	14.325

Table 3 Coordinates of inner connections and opening

Connection	X1	X1	Y1	Y2	Z1	Z2
CP10-opening	-4.613	1.388	17.500	17.750	3.400	8.400
CP10-R1S CP10-R1C	-2.238	-1.238	-7.000	-7.250	3.400	7.400
CP10-R1C CP10-R1P	-2.238	-1.238	13.125	13.375	3.400	7.400
CP10-R1C CP10-R2	2.275	6.275	6.500	10.500	8.425	8.675
CP10-R1C CP11-R1	6.775	7.025	1.000	2.000	3.400	7.400
CP10-R2 CP11-R2	6.775	7.025	-2.500	5.500	9.675	12.650
CP11-R1 CP11-R2	13.250	17.250	6.500	10.500	8.425	8.675
CP17-opening	86.750	92.250	-3.250	-3.000	4.400	8.050
CP17-R1 CP17-R2	87.500	89.500	-0.395	0.605	8.550	8.800
CP17-R1 CP17-R2	87.500	89.500	2.395	3.395	8.550	8.800

Table 4 Coordinates of wave probes

Wave probe	X	Y	Z
RBM 1 (CP10-R1S)	-1.613	-10.800	2.900
RBM 2 (CP10-R1C)	-1.738	-2.075	2.900
RBM 3 (CP10-R1C)	-1.738	3.000	2.900
RBM 4 (CP10-R1C)	-1.738	8.075	2.900
RBM 5 (CP10-R1P)	-1.738	15.375	2.900
RBM 6 (CP11-R1)	12.625	-4.250	2.900
RBM 7 (CP11-R1)	12.625	10.250	2.900
RBM 8 (CP11-R1)	12.625	3.000	2.900
RBM 9 (CP10-R2)	-1.738	4.250	8.675
RBM 10 (CP11-R2)	12.625	4.250	8.675
RBM 11 (CP17-R1)	90.750	-0.250	3.900
RBM 12 (CP17-R1)	90.750	1.500	3.900
RBM 13 (CP17-R1)	90.750	3.250	3.900
RBM 14 (CP17-R1)	95.100	1.500	3.900
RBM 16 (CP17-R2)	92.250	1.500	8.800
RBM 17 (CP17-R2)	90.750	6.750	8.800

2.3 Environmental conditions

The characteristics of damaged cruiser in waves are investigated. To study the effects of flooding water and in/out flow through opening, motions in regular and irregular waves are measured. In order to study the effects of wave height, 4 heights (1, 3, 5, 7 m) of regular waves are used. The wave conditions are as follows.

▪ Regular waves

Frequency: 0.2 rad/s ~ 1.1 rad/s

Height: 1, 3, 5, 7 m

▪ Irregular waves: JONSWAP(γ: 3.3)

Irreg1: $H_{1/3}$=1 m, T_p=5sqrt($H_{1/3}$)

Irreg2: $H_{1/3}$=3 m, T_p=5sqrt($H_{1/3}$)

2.4 Measurement system

To analyze the behaviours of damaged ship, the motions of ship and water in compartment must be measured. The 6 dof motion of ship are measured by non-contact optical system (RODYM6D). The flooding flow is measured by capacity type wave probe. The number of wave probe used is 10 in CP10/11 and 6 in CP17. Video cameras are used to record the flow of flooding process. The RBM1 is in CP10-R1S next to damage opening. The location of wave probes is as follows.

▪ CP10

CP10-R1S: NRBM1

CP10-R1C: NRBM2, 3, 4

CP10-R1P: NRBM5

CP10-R2: NRBM9

▪ CP11

CP11-R1: NRBM6, 7, 8

CP11-R2: NRBM10

▪ CP17

CP17-R1: NRBM11, 12, 13, 14

CP17-R2: NRBM16, 17

3. TEST RESULTS & DISCUSSION

3.1 Experimental results

The flooding test was performed in calm water for DAM1 and DAM2. Fig 5 and Fig 6 shows the results for DAM1. The flooding through the opening starts at CP10-R1S(RBM1) and continues to CP10-R1C (RBM2,3,4) and CP10-R1P(RBM5). The water instantly fills up CP10-R1S. After filling of CP10-R1S, water propagates into other compartments. The RBM6, 7 and 8 show the flow from CP10 to CP11. The required time for flooding second floor, CP10/11-R2 is about 240 sec and the steady state value of roll angle is 5.14 deg. Fig 6 shows the motions with flooding. Roll motion begins at the same time with flooding and reaches the steady state (~400 sec) after filling of CP10-R1S/C/P. The flooding process of DAM2 is shown in Fig 7 & 8. The flooding process and motions are quite simple due to simple geometry and configuration. The flooding starts at CP17-R1 and flooding water reaches to the bottom of CP17-R2. The amount of water in CP17-R2 is small.

The motion tests in waves were carried out in the condition that the compartments were flooded. This gives the same situation at initial condition. The results of motions in waves are shown in Fig 9~12. The wave amplitudes are 1, 3, 5, 7 m to assess the effect of nonlinearity of the incident waves. The heave RAO shows there is no effect of wave amplitude and damage. But the roll motion is significantly influenced by wave amplitude and damage conditions. Interestingly enough, the effect of wave amplitude on roll motion also appears in intact condition. The peak value of roll RAO decreases at resonance frequency when wave amplitude increases. In case of DAM1, roll RAOs are changed due to internal water motion and inflow/outflow. The resonance frequency moved from 0.3 rad/s to 0.33 rad/s due to sloshing. The effect of internal water motion appears for wave amplitude 3, 5, 7 m and sloshing occurred in CP10/11-R2. This is sloshing in low filling ratio. When wave amplitude is 1m, the internal water motion is small and sloshing doesn't occur. In order to excite sloshing in a considerable level, waves more than 3 m should be incident because the ship heels 5.14 deg to starboard. Fig 14 shows the sloshing by roll motion. In case of DAM2, roll RAOs is similar to intact RAOs. Although sloshing in CP17-R2 occurs, there is no significant influence of flooding because of small amount of water. Fig 13 shows the effect of opening and in/outflow.

Fig 15, 16 & 17 show the roll motion and internal water motion in CP10/11-R2. The position of water height measurement (RBM9/10) is in the middle. The initial value of water height is zero in flooded situation. The positive value stands for increasing and negative value decreasing. When wave height is 1 m, flooding water doesn't reach to port side wall and sloshing doesn't occur. But in case wave height 5 m, flooding water reached to port side wall. When wave frequency is 0.33 rad/s, the coupling of sloshing and roll is strong. Because the water height is measured at middle, the phase with roll motion is carefully analyzed.

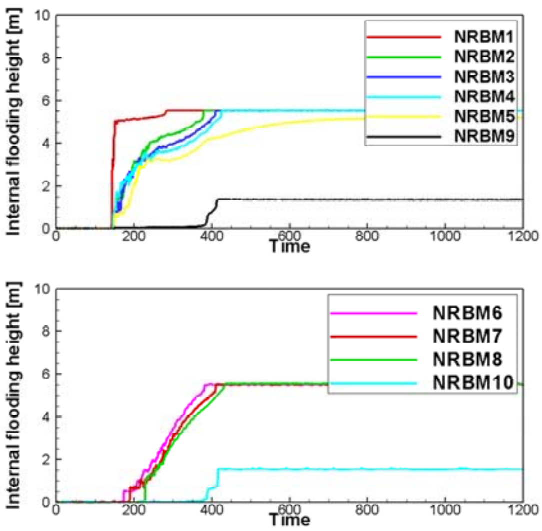

Fig 5 Flooding process of DAM1

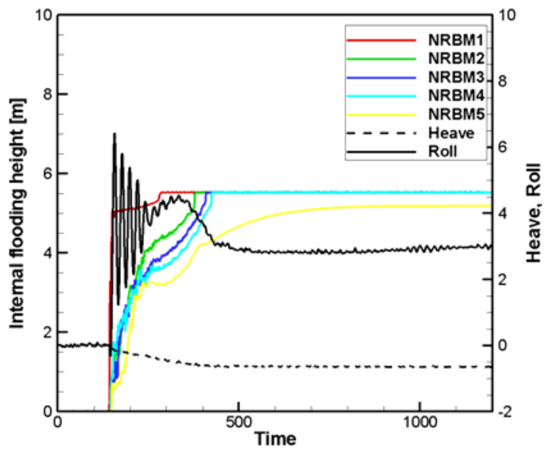

Fig 6 Motions with flooding of DAM1

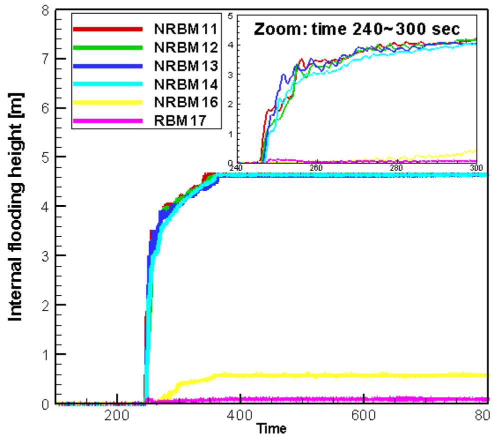

Fig 7 Flooding process of DAM2

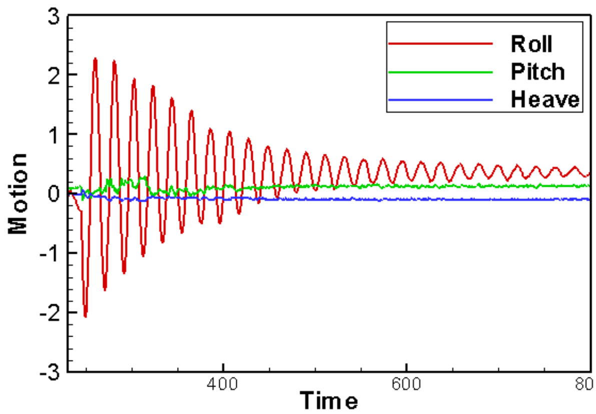

Fig 8 Motions of DAM2

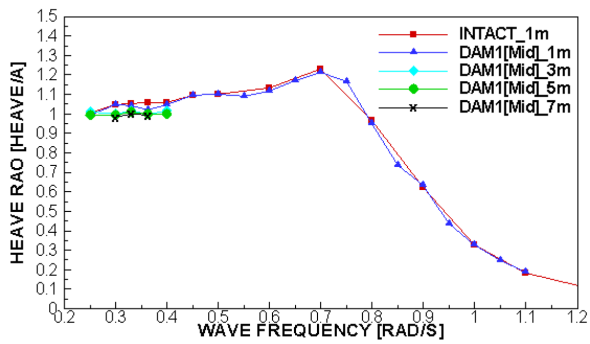

Fig 9 Heave RAO of DAM1

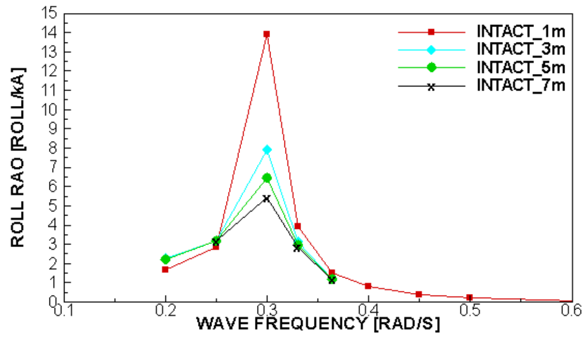

Fig 10 Roll RAO of intact

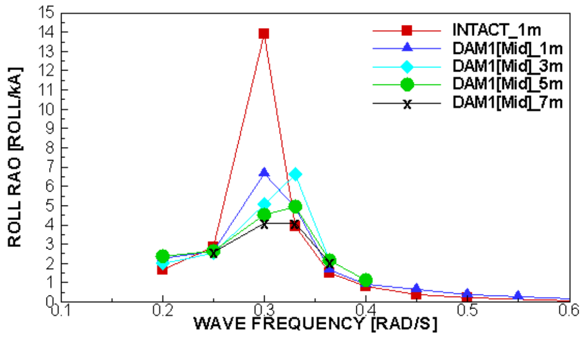

Fig 11 Roll RAO of DAM1

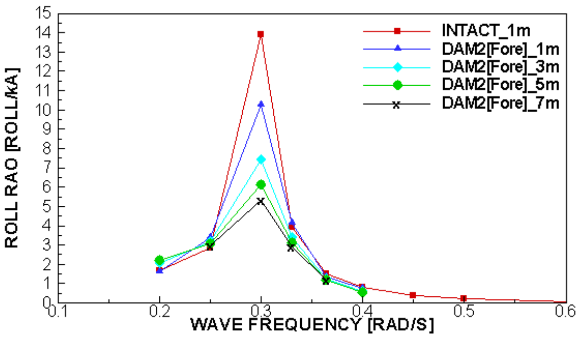

Fig 12 Roll RAO of DAM2

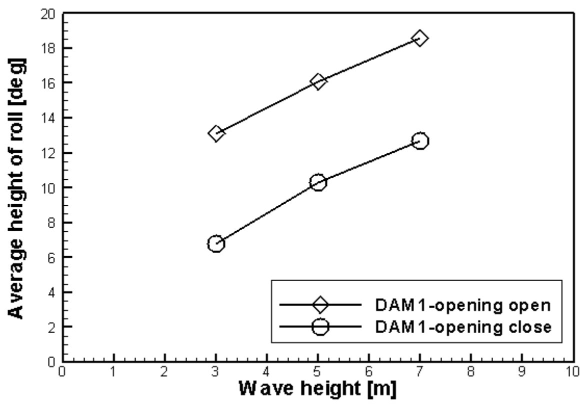

Fig 13 Effect of opening on the roll motion(DAM1, ω=0.33 rad/s)

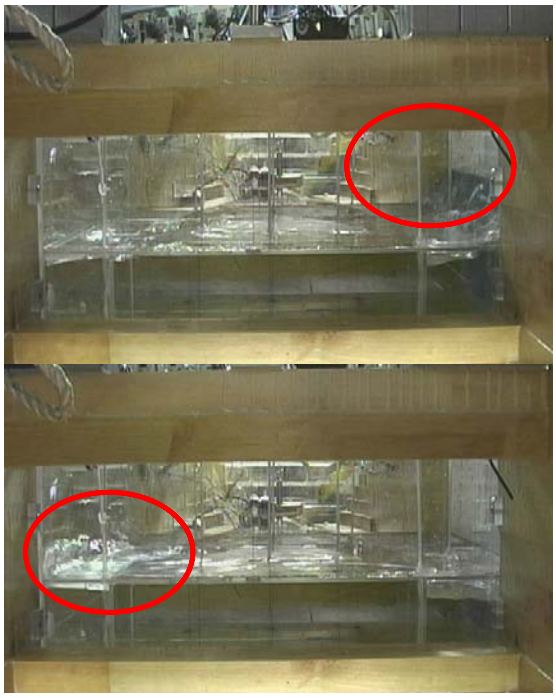

Fig 14 Sloshing in CP10/11-R2

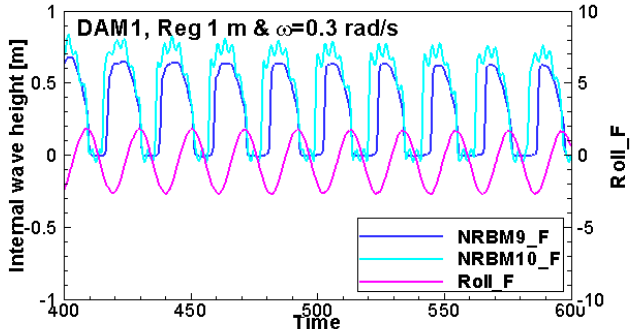

Fig 15 Motion and flooding of DAM1(wave height 1m, ω=0.3 rad/s)

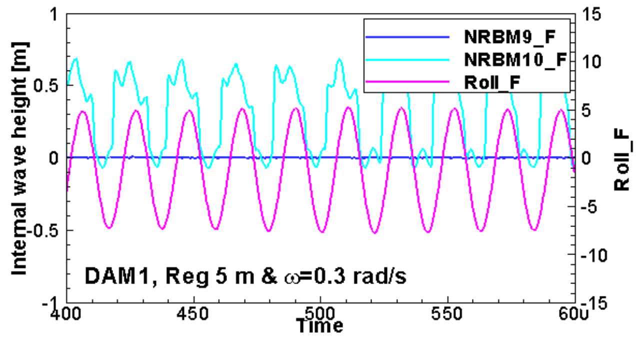

Fig 16 Motion and flooding of DAM1(wave height 5m, ω=0.3 rad/s)

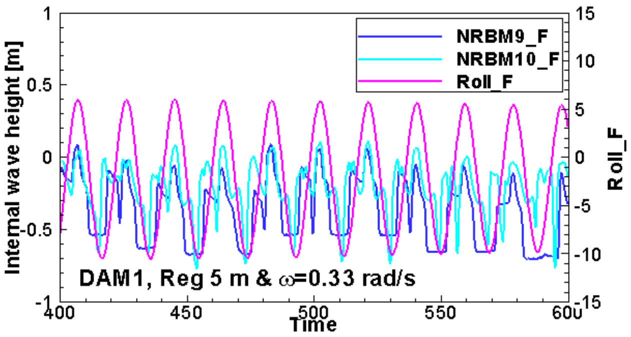

Fig 17 Motion and flooding of DAM1(wave height 5m, ω=0.33 rad/s)

The closed condition is flooded with closed opening. So, there is no flow in/out through opening. The motions are affected by only internal water motion. Roll of close condition is smaller than open condition. When opening is open condition, damaged part is not symmetric and flow in/out occurs in the CP10-R1S. Reduction of roll will be investigated with numerical analysis in the future.

The results of the present paper are preliminary. The detail analysis of internal water motion and the numerical analysis is in progress. The results will be compared and analyzed with numerical analysis afterwards.

4. CONCLUSIONS

The experiments have been performed for the behaviour of damaged cruiser in waves. The influences of damage configuration, internal water motion, wave height and flow in/out are considered. The transient process and motion behaviour in waves are analyzed. The transient flooding process is measured in each compartment. The effect of flooding on the ship motion appeared in roll motion. Although the amount of water in upper compartment is small, the sloshing is occurred and the effect is significant. The more precise analysis will be done by comparing with numerical results.

5. ACKNOWLEDGMENTS

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