Study on the motions and flooding process of a damaged ship in waves

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ABSTRACT

To study the motions and flooding process of a damaged cruiser, a series of experiment and numerical calculation have been performed in calm water and in waves. Two damaged parts are selected to investigate damage effects; mid section and fore section. The results of the experiment, quasi-static model and quasi-dynamic model are compared. The numerical simulation is conducted using quasi-static model and quasi-dynamic model. The quasi-dynamic model adopts the mass-spring system for internal water motion description. The model considers the dynamics of free surface as ship motion.

KEYWORDS

Cruiser, Damaged, Flooding, Experiment, Sloshing

INTRODUCTION

The ship accidents occurred due to various reasons; collision, running a ground, malfunctioning of an engine, attack, etc. When a ship is damaged for certain reason, she loses her function and safety. So, the evaluation of the motions and assessment of stability is very important. 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 and numerical analysis 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 experiments indicate that the internal compartment influences the transient flooding process and roll motion. When there is shallow water in compartment and the ship moves as natural frequency of internal water in compartment, the coupling of internal water and ship motion occurs. The numerical simulation is conducted using quasi-static model, quasi-dynamic model and CFD. The quasi-dynamic model adopts the mass-spring for internal water motion description. The model considers the dynamics of free surface as ship motion. This mass-spring equation is explicitly coupled with ship motion equation. The quasi-dynamic model shows the intermediate results of CFD and quasi-static model.

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)

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.

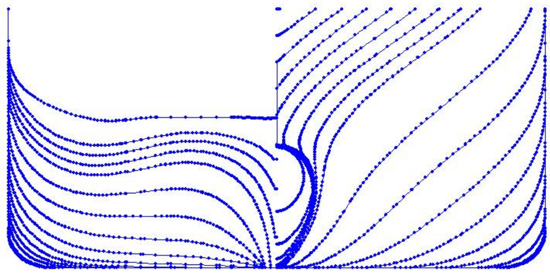


Fig. 1: Lines of cruiser

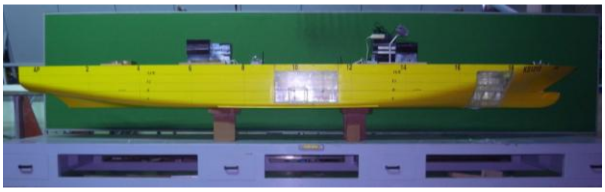


Fig.2: Cruiser model

Table 1: Particulars of cruiser

Items	
Length, Lpp	247.2 m
Beam, B	35. 5 m
Draft, T	8.3 m
Displaced weight	56541.5 ton
KG	16.393 m
GM	2.388 m
Natural roll period	21.07 m
Gyration of roll	14.814 m
Gyration of pitch	61.925 m

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.

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.

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($H_{1/3}$)

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 can be found in Cho et al (2009).

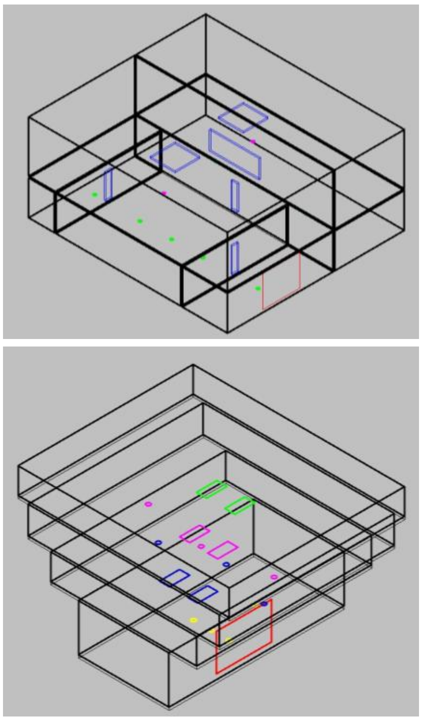


Fig.3: Arrangement of damage compartments (CP10/11, CP17)

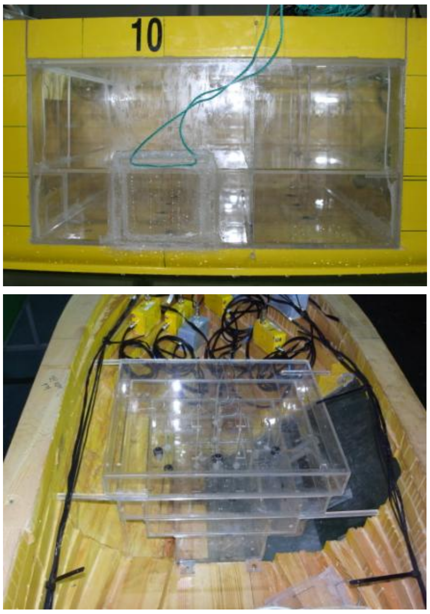


Fig.4: Damage compartment model

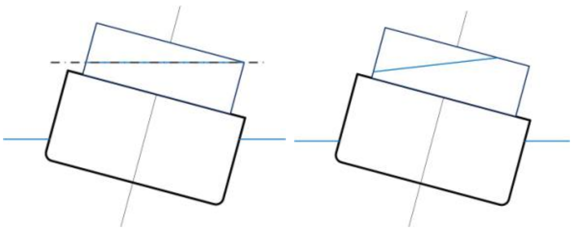
NUMERICAL METHOD

In order to analyze the flooding, use the quasi-static model (Cho et al, 2009) and quasi-dynamic model. The quasi-dynamics model is lumped mass-spring system for free surface. This model calculate the free surface angle which is flat, that is mean sense as the ship motion. Fig 5 shows the concept of quasi-static, quasi-dynamic and CFD model. The quasi-dynamic model equation coupled with ship motion is flows. The 4th order Runge-Kutta method is used for time integration.

$$a_1\ddot{y} + a_2\dot{y} + a_3 y = -b_1\ddot{x} - b_3 x \qquad (1)$$

where y is free surface angle, x ship roll, a and b equation coefficients.

$$v = \dot{y}$$
$$\dot{v} = \frac{-b_1\ddot{x} - b_3 x - a_2 v - a_3 y}{a_1} \qquad (2)$$



Quasi-static Quasi-dynamic

Fig 5: Free surface model

TEST RESULTS & DISCUSSION

Experimental results

Fig 5 shows the roll free decay test results. The natural roll period for DAM1 decreases about 1 sec due to flooding, heeling, free surface etc. The quadratic damping for DAM1 is different with intact. When opening is open condition, damaged part is not symmetric and flow in/out occurs in the CP10-R1S. This indicates that the estimation of damping is difficult when a damaged part is severe. 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 similar with intact.

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 port side wall. When wave frequency is 0.33 rad/s, the coupling of sloshing and roll is strong. Table 2 shows the phase of roll and incoming wave due to sloshing.

Table 2: Phase of wave and roll

Frequency	0.2~0.25 rad/s	0.3~0.36 rad/s	0.4 rad/s ~
Intact	90 deg	0 deg	-90 deg
DAM1	90 deg	180 deg	-90 deg

Fig 15 and 16 show the irregular test results for intact and DAM1. The flooding affects the roll motion and the roll motion decrease. Also the motion of flooding water is clear at 0.3 rad/s.

Numerical simulation results

Fig 17~21 show the results for ITTC tanker model. The free decay results of quasi-dynamic model are pretty similar to experiments and CFD. This indicates that the quasi-dynamic model can calculate the dynamics of free surface. Also regular wave test shows the reasonable results. The merit of quasi-dynamic model is fast calculation. The required time is almost same as quasi-static model.

The damaged problem is calculated by quasi-dynamic model. The results are shown in Fig 23~26. The transient flooding process is represented by the model. The flooding heights are compared and the numerical results agree with experiments. But the roll is different at flooding beginning. This difference is due to the different amount of flooding water in CP10R1S. The increase of numerical result in CP10R1S is almost step and CP10R1S is full. But experiment shows CP10R1S is not filled once and is full after 150 sec. This lag may by occurred by air compression and numerical model limit. Fig 25 and 26 show the regular wave results. Roll RAOs show similar tendency of experiments.

CONCLUSIONS

The experiments and numerical analysis 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. Quasi-dynamic model show quite good results. For more precise estimation, the improvement of model is needed.

ACKNOWLEDMENTS

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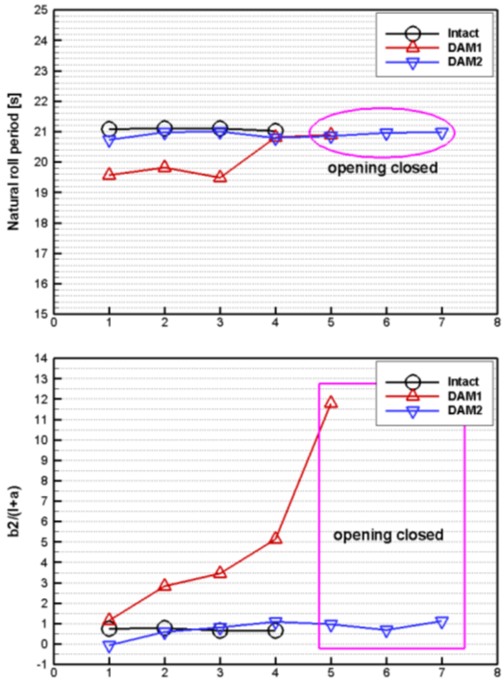

Fig 6: Results of free decay

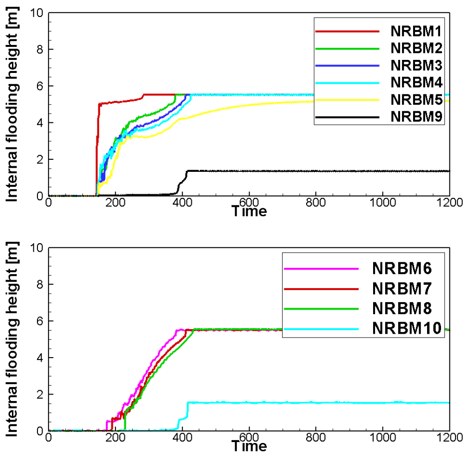

Fig 7: Flooding process of DAM1

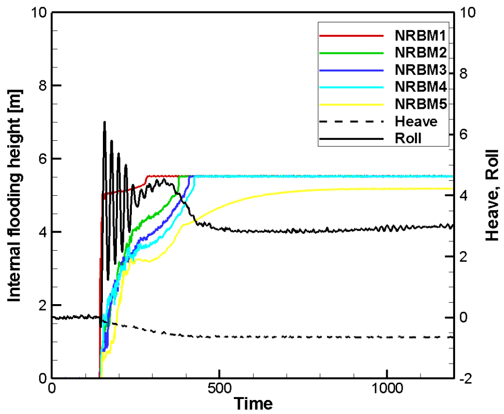

Fig 8: Motions with flooding of DAM1

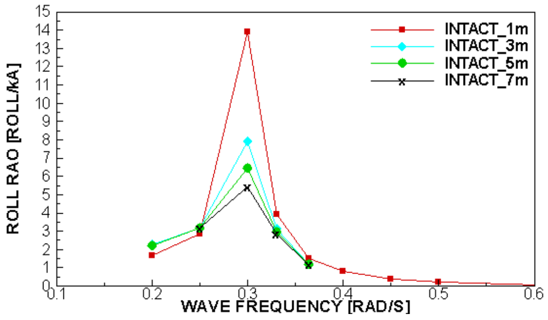

Fig 9: Roll RAO of intact

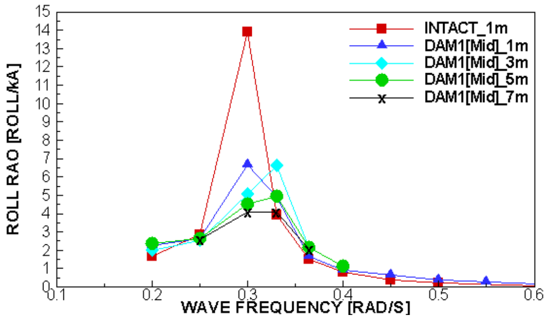

Fig 10: Roll RAO of DAM1

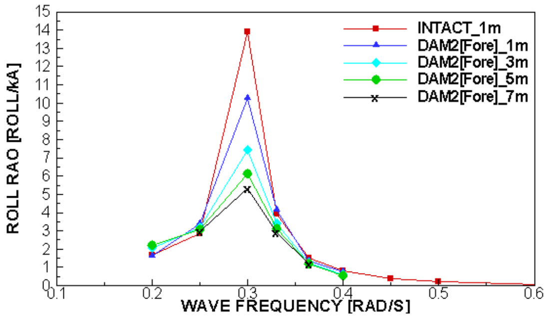

Fig 11: Roll RAO of DAM2

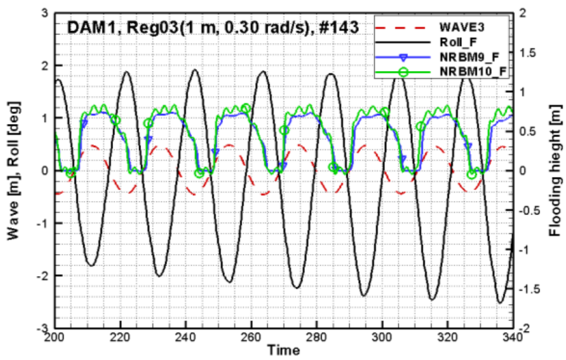

Fig 12: Motion and flooding of DAM1(wave height 1m, ω=0.3 rad/s)

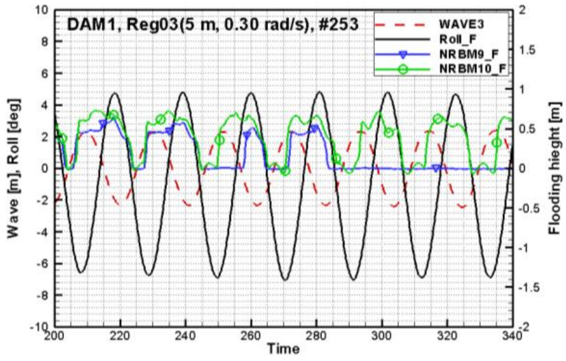

Fig 13: Motion and flooding of DAM1(wave height 5m, ω=0.3 rad/s)

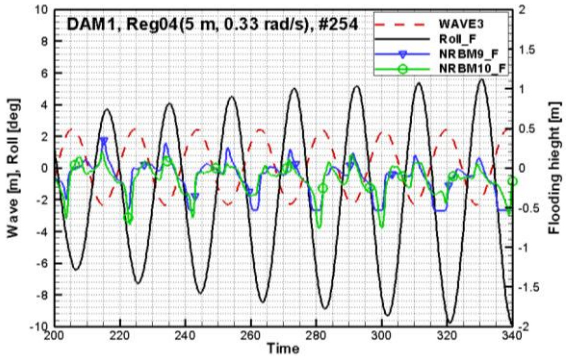

Fig 14: Motion and flooding of DAM1(wave height 5m, ω=0.33 rad/s)

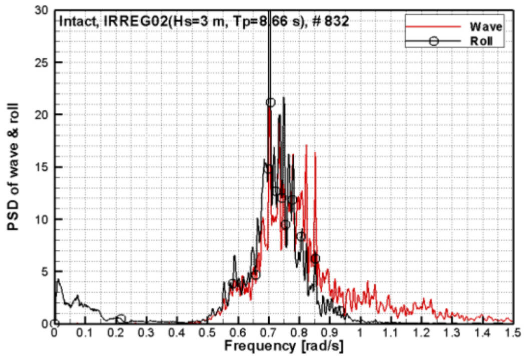

Fig 15: PSD of intact in irregular wave(Hs=3 m)

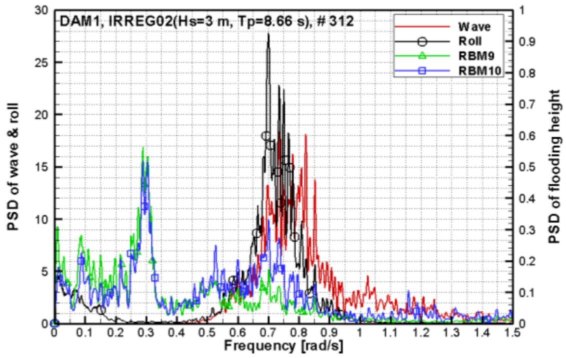

Fig 16: PSD of DAM1 in irregular wave(Hs=3 m)

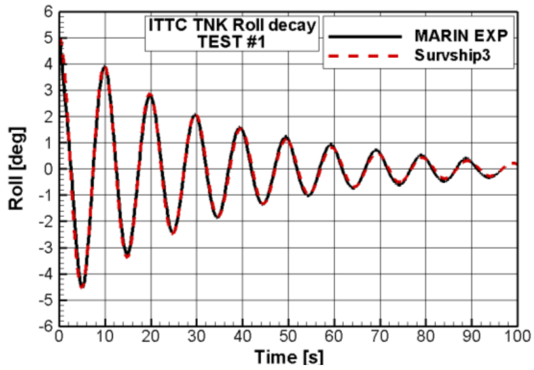

Fig 17: Free decay(h=0m)

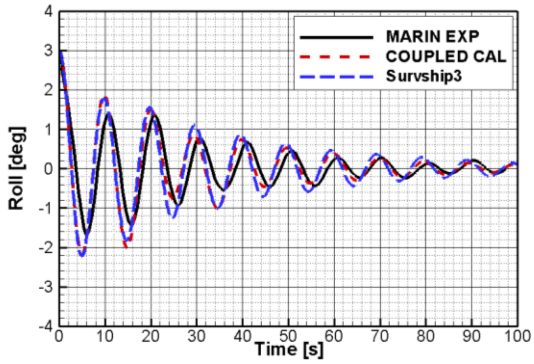

Fig 18: Free decay-sub resonance(h=3m)

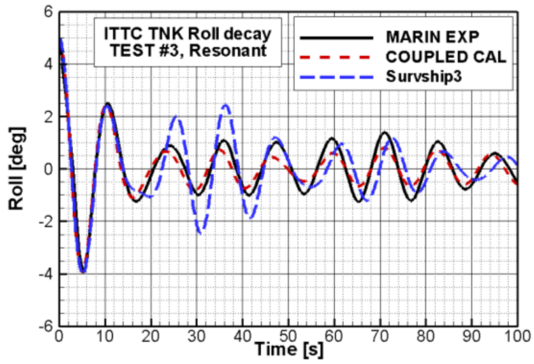

Fig 19: Free decay-resonance(h=4m)

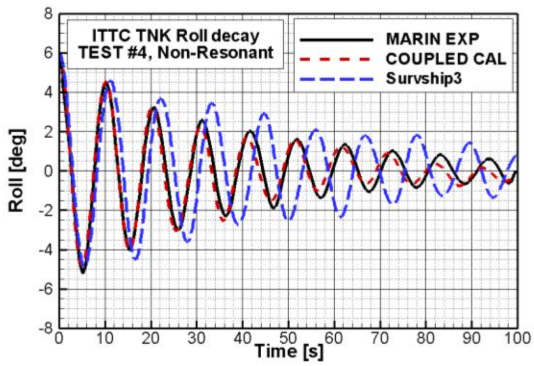

Fig 20: Free decay-non-resonance(h=16m)

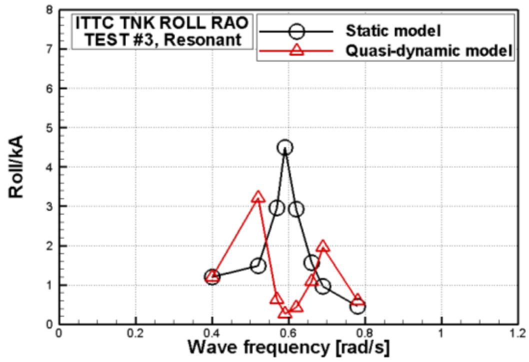

Fig 21: Roll RAO-resonance(h=4m)

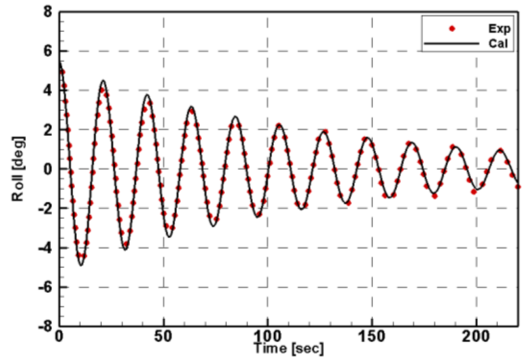

Fig 22: Roll free decay of cruiser

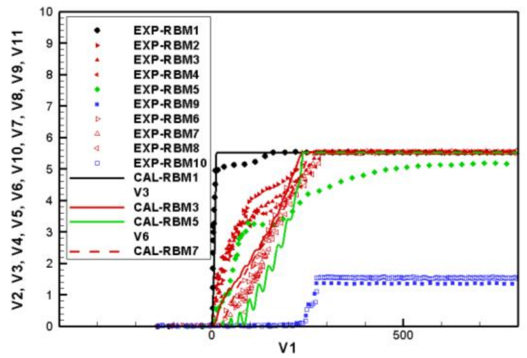

Fig 23: Comparison of flooding height for DAM1

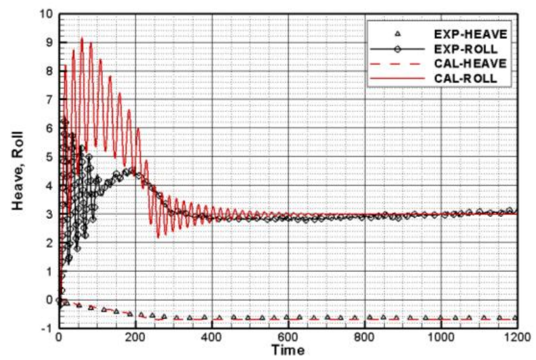

Fig 24: Comparison of motions for DAM1

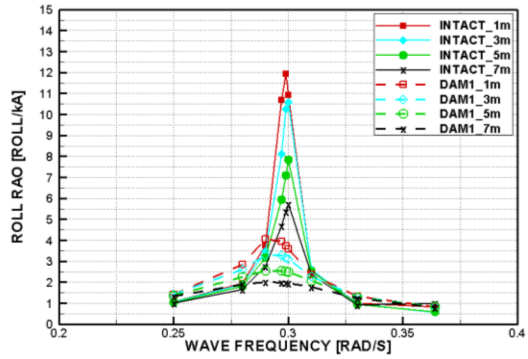

Fig 25: Roll RAO for intact and DAM1-Quasi-dynamic model

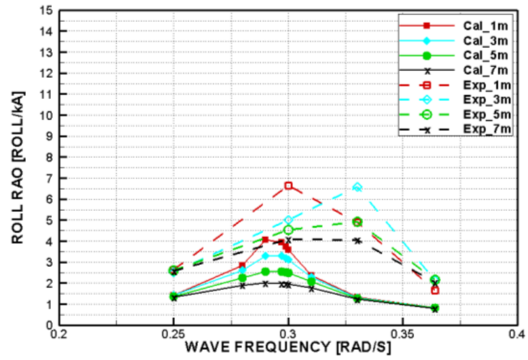

Fig 26: Roll RAO comparison for DAM1-Quasi-dynamic model

REFERENCES

Cho, S., Sung, H., Nam, B., Hong, S. and Kim, K., 2009, “Experimental Study on Flooding of a Cruiser in Waves”, Proc. 10th International Conference on Stability of Ships and Ocean Vehicles, St. Petersburg, pp. 747~753.

Palazzi L. and De Kat J., 2004, “Model Experiments and Simulations of a Damaged Ship With Air Flow Taken Into Account”, Marine Technology, Vol. 41, No. 1, pp. 38-44.

Papanikolaou, A. and Spanos, D., 2002, “On the Modelling of Floodwater Dynamics and its effects on Ship Motions”, Proc. 6th International Ship Stability Workshop, Webb Institute, New York.

Papanikolaou, A. and Spanos, D., 2005, “24th ITTC Benchmark Study on Numerical Prediction of Damage Ship Stability in Waves Analysis of Final Results”, Proc. 8th International Ship Stability Workshop, Turkey.

Ruponen, P. 2007, "Progressive flooding of a damaged passenger ship", Doctor thesis, Helsinki university of technology.

van Walree F. and N. Carette, 2008, "Benchmark study of numerical codes for the prediction of time to flood of ship-phase 2", Proc. 10th International Ship Stability Workshop, Daejeon, Korea.