BENCHMARK STUDY OF NUMERICAL CODES FOR THE PREDICTION OF THE TIME TO FLOOD OF SHIPS-PHASE II

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ABSTRACT

The paper provides an update on the progress of the ITTC-SiW benchmark study on numerical codes for the prediction of time-to-flood of damaged passenger ships. Simulation data for the flooding of a passenger ship has been provided by two developers of numerical codes. An initial analysis of results shows distinct differences in the prediction of ship motions and survivability.

KEYWORDS

Passenger ship, numerical simulations, time-to-flood.

INTRODUCTION

On request of the 48th IMO-SLF Committee, The Sub-Committee on Ship Stability in Waves (SiW) of the ITTC has agreed to carry out a systematic benchmark study of numerical codes that are currently in use for the prediction of the damaged stability of ships in waves. Several comparisons of predictions for time-to-flood and motions at calm water and in waves, obtained from running the participating numerical codes, shall be reported for progressively more complex ship motion and flooding scenarios.

The initial intention was to carry out benchmark studies for a passenger ship. Unfortunately, the data for a realistic passenger ship with a complex internal geometry were not readily available to the ITTC-SiW committee. Therefore it has been decided to split the work in two phases as follows:

I. benchmark based on a barge for which detailed model test data are available;
II. benchmark based on a realistic passenger ship with complex internal geometry.

The benchmark work for Phase I is described by Van Walree and Papanikolaou (2007). The present paper describes initial results of Phase II.

OBJECTIVE

The objective of the benchmark study is to establish current capability and weaknesses in predicting, qualitatively and quantitatively, the time-to-flood for a passenger ship with a realistic internal configuration. Besides time-to-flood, related quantities as motions and flooding volumes in compartments will be compared. Since there are no experimental results available for the ship in question, the benchmark will be performed by comparing numerical results only.

BACKGROUND

The passenger ship that is taken as the basis for the study has been kindly provided by SSRC. Table 1 shows the main particulars while Figures 1 and 2 show the internal configuration and openings respectively.

The only appendages present were a set of bilge keels with a length of 75 m and height 0.5

m. Roll damping was to be determined by the participants.

Table 1 Main particulars

Mass	56542	[ton]
Lpp	247.7	[m]
B	35.5	[m]
T	8.3	[m]
GM	2.0	[m]
k_{xx}	0.37B	[m]
k_{yy}	0.25Lpp	[m]
k_{zz}	0.25Lpp	[m]

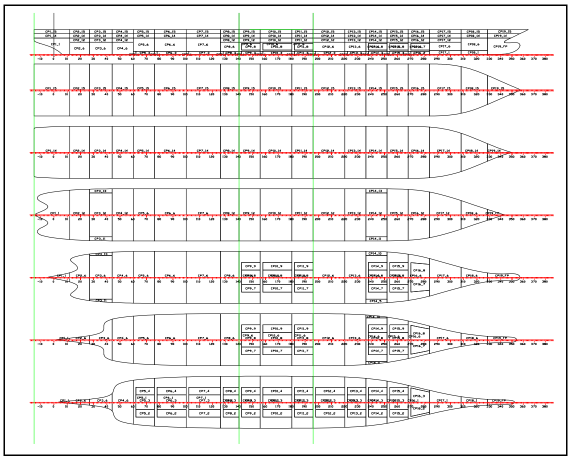

Figure 1 Passengers ship compartments

In total 142 compartments were present with 84 openings in horizontal end vertical direction.

Conditions

The ship was free drifting (with zero initial forward speed) for all simulations. No wind forces were taken into account. All six modes of motion were free, i.e. no mode was restricted. The initial position of the ship was such that the incident wave direction was on the starboard side of the ship (90 deg from stern), i.e. the damage faced the incident waves.

Damage particulars

The damage length was 0.03*Lpp+3m. The damage height equaled the depth of the ship while the damage depth was B/5 m. The shape of the damage is triangular in top view, pointing into the ship with depth B/5 m. In side view the shape is rectangular with a length and height as specified.

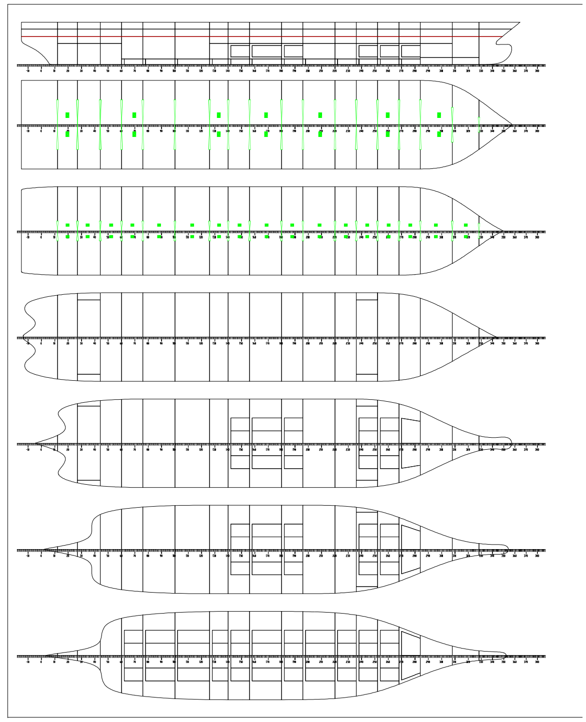

Figure 2 Passenger ship openings

Two damage positions were chosen: with centre at frame 100 (D1) and with centre at frame 180 (D2). The latter position is near mid ship. Both damage positions were at the starboard side of the ship. The damage length extended along two compartments. Discharge coefficients were to be determined by the participants.

Simulations for intact vessel

- Four sea states, long crested seas.
- Roll decay simulation.
- Ten wave seeds (wave realizations).
- Simulation duration 1800 sec.
- One loading condition.

Simulations for damaged vessel

- Two damage positions, D1 and D2.
- Five sea states with Hs varying between 2 and 4 m.
- Ten wave seeds (wave realizations).

- Simulation duration until three minute averaged heel angle is constant but at least 1800 sec.
- One loading condition.

PARTICIPATION

The following organisations participated in phase II of the benchmark study:

- Universities of Glasgow and Strathclyde
- Maritime Research Institute Netherlands (MARIN), The Netherlands

In the presentation of results the numerical simulation results from the participants are referenced to anonymously as A and B.

TYPES OF NUMERICAL MODELS

All codes incorporate time domain simulation methods and can predict motions in six degrees of freedom. The codes are applied to mono-hulls at zero or normal operating speeds.

Froude-Krylov and restoring forces are based on integration of undisturbed wave pressures over the instantaneously submerged hull and superstructure portions. Radiation and diffraction forces are generally based on strip theory or a 3D frequency domain panel method. This frequency domain information is used in the time domain by means of convolution integrals (retardation forces). The hydrodynamic force components that are influenced significantly by viscosity are generally determined semi-empirically.

The employed flooding methods use relatively simple hydraulic models. A modified Bernoulli equation is used to determine the water ingress through damage openings. The flow rate through an opening is related to a pressure head and a semi-empirical discharge coefficients. This approach is also applied to the progressive flooding between ship compartments through open doors, ducts, collapsed bulkheads, etc. Some of the codes may take into account sloshing effects, if occurring. The flooded compartment water surface is either assumed to be horizontal at all times, or movable due to the coupling with the ship motion, but still plane. Air compressibility effects can be taken into account.

RESULTS

Intact conditions

Results affecting the transverse stability are compared first, for an intact ship. Figure 3 shows a comparison between the GZ curves, for heel angles with a positive stability. It is seen that the two curves are quite close.

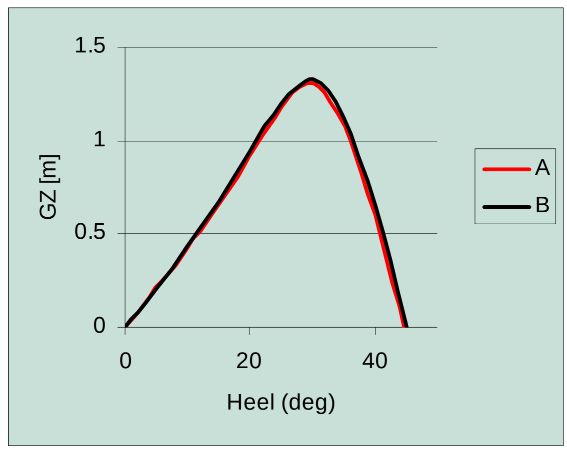

Figure 3 Comparison of righting levers

For the roll decay simulations, results are quite different though, see Figure 4.

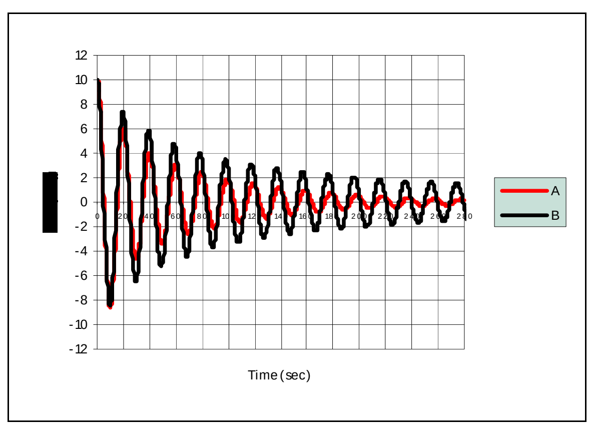

Figure 4 Comparison roll decay

The roll damping in Code A is much stronger than for Code B. Figure 5 shows the derived roll decay rates versus roll amplitude.

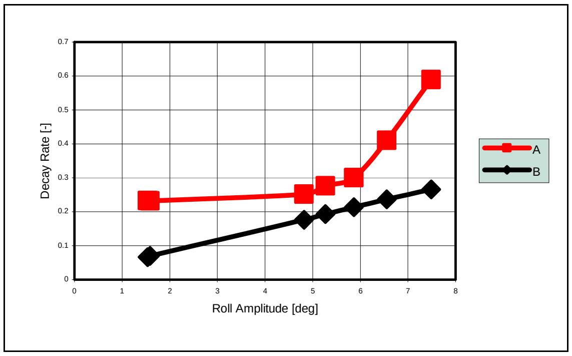

Figure 5 Roll decay rate versus roll amplitude

The intersect of the curves at a zero roll amplitude is proportional to the linear roll damping, the slope is proportional to the quadratic roll damping. Code A roll decay values clearly show higher order contributions to roll damping. Code B roll decay is linear and quadratic only.

Code A and Code B used a strip theory method to determine potential flow added mass and damping. Viscous roll damping contributions were obtained from the empirical method of Himeno (1981) and include eddy and bilge keel damping.

The potential flow roll damping is shown in Figure 6 and shows a good resemblance.

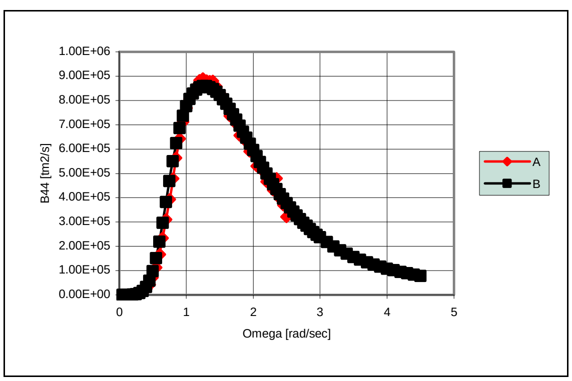

Figure 6 Comparison of potential flow roll damping

An investigation in to the discrepancy in viscous roll damping is underway and will be included in the final ITTC Report. Also, contributions from other participants may shed more light on this matter.

Standard deviations of the motions are given in Figures 7 through 10, for Hs= 4 m, Tp=8 sec and a Jonswap type wave spectrum. Note that the ship was freely drifting for all conditions shown. In each Figure, results for ten wave seeds are plotted.

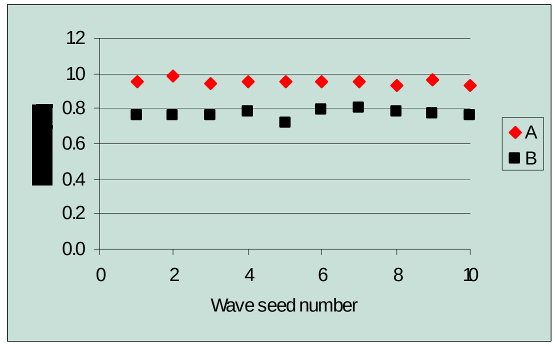

Figure 7 Heave versus wave seed number

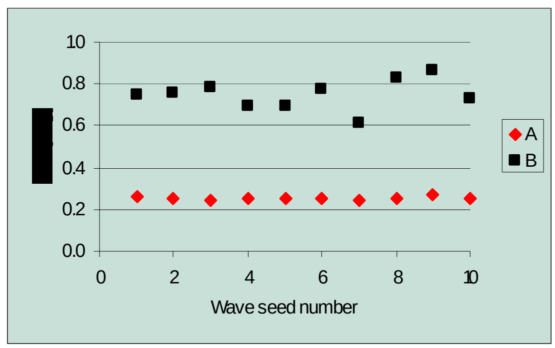

Figure 8 Roll versus wave seed number

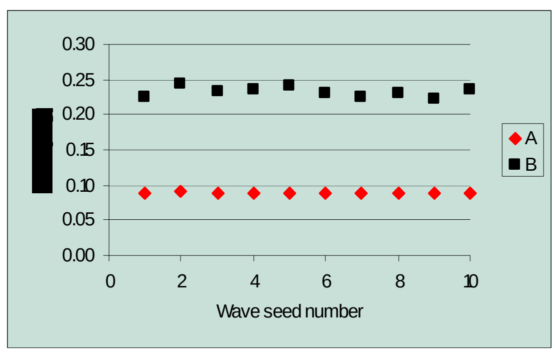

Figure 9 Pitch versus wave seed number

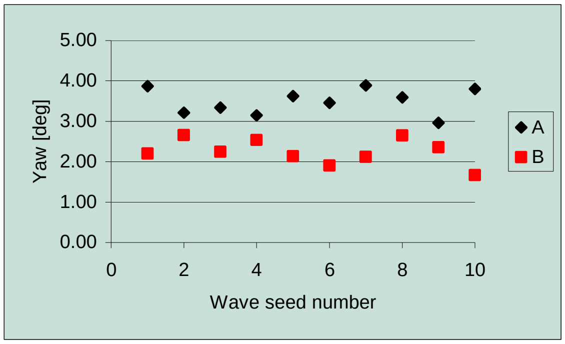

Figure 10 Yaw versus wave seed number

The difference in heave motion is about 20%. The roll motion shows a much larger discrepancy, obviously due to the difference in roll damping. The pitch motion shows a large relative difference as well, but pitch is small in magnitude and is highly dependent on the actual yaw angle. Yaw predictions are reasonably comparable.

A comparison of the drift position at the end of the 1800 sec simulations is shown in Figure 11, again for 10 wave seeds. The wave direction is in the direction of the positive x-axis in the plot, the significant wave height Hs is 4 m and the peak period Tp is 8 sec. It is seen that the ships drift in the same direction, but the drift velocity in Code B is about three times as high as for Code A (2 kt versus 0.6 kt respectively).

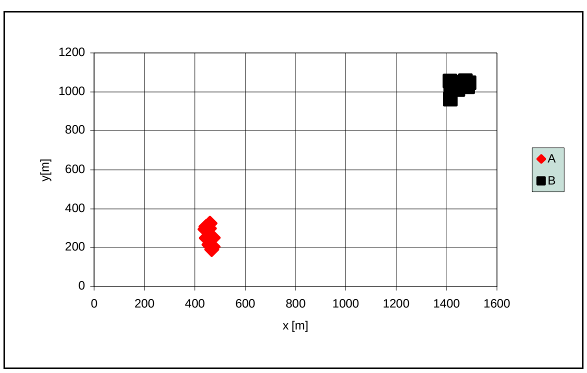

Figure 11 Drift positions for 10 wave seeds.

Damage conditions

For damage conditions appreciable differences can be expected in the mean heel angles and flood water contents since the roll behavior is quite different. Figures 12 through 15 show the average roll angles for the last three minute time interval of the 1800 sec simulation. Again, data are shown for ten wave seeds.

Clearly, average roll angles for Code A are much lower than for Code B. The most striking differences in results appear in Figure 13. Code B predicts a substantial mean heel of about 15 deg., while Code A still predicts a mean heel of about zero.

For Code B results, the ship most times rolls away from the damaged side, but for some wave seeds the ship shows a mean heel towards the other side. This behaviour is not unusual for ships with a symmetrical compartment configuration.

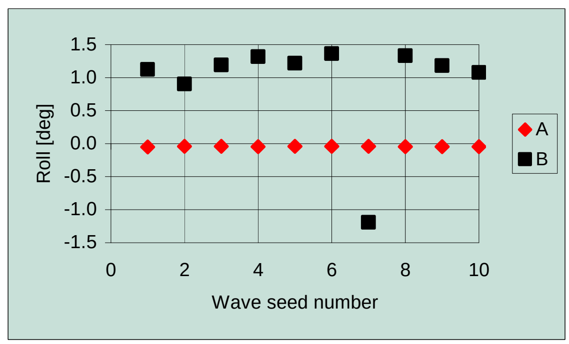

Figure 12 Mean heel for Hs=2m, damage D1

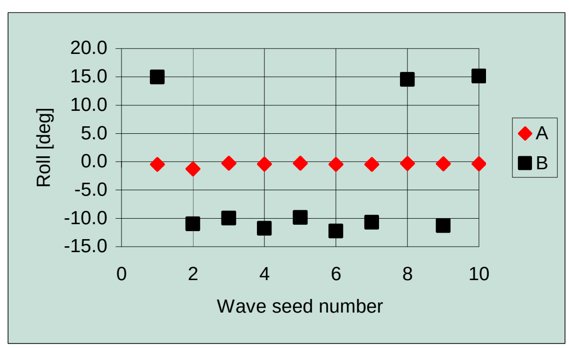

Figure 13 Mean heel for Hs=4m, damage D1

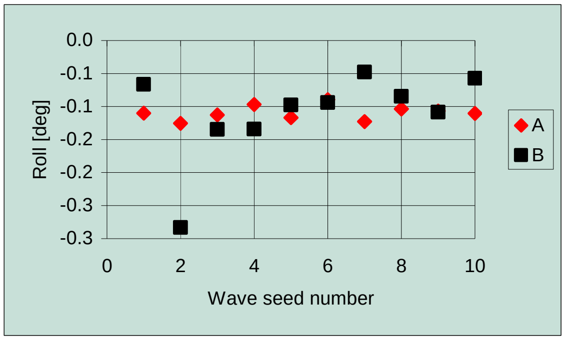

Figure 14 Mean heel for Hs=2m, damage D2

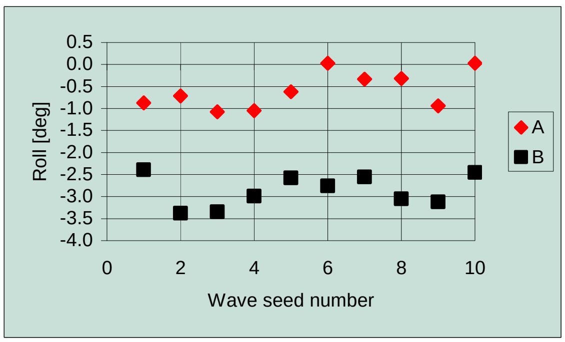

Figure 15 Mean heel for Hs=4m, damage D2

Figures 16 through 19 show the RMS values of roll for the entire simulation duration. For the first three conditions, Code A results are much lower than Code B results, in fact more than the factor four lower found for intact conditions.

However for the last condition the roll RMS values are very comparable. This is the condition with the mid ship damage and a 4m significant wave height. Possibly floodwater dynamics play a significant role here and overcome the difference in roll damping.

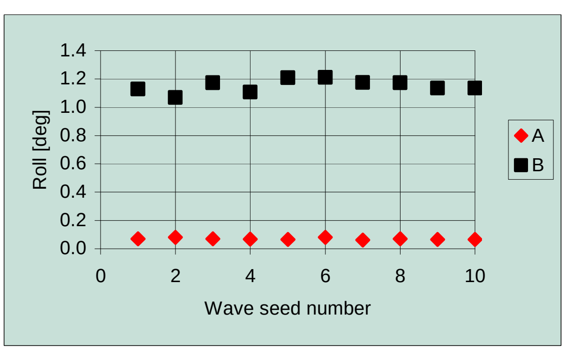

Figure 16 RMS heel for Hs=2m, damage D1

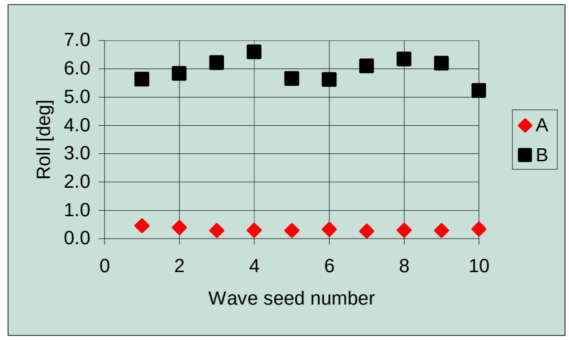

Figure 17 RMS heel for Hs=4m, damage D1

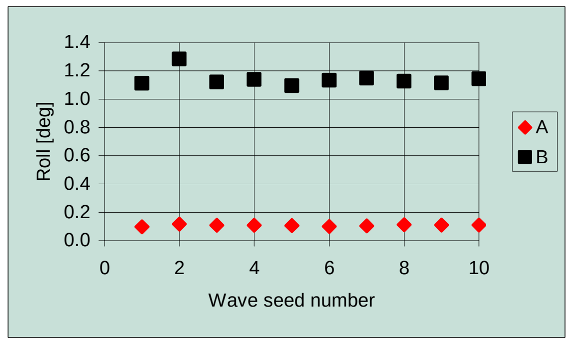

Figure 18 RMS heel for Hs=2m, damage D2

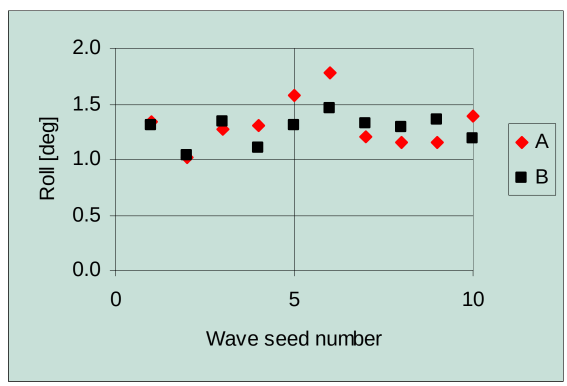

Figure 19 RMS heel for Hs=4m, damage D2

Figures 20 through 23 show the accumulated flood water mass, averaged over the last three minute time interval of the 1800 sec simulation duration. Code A generally shows less flood water accumulation than Code B. Despite the large differences in roll behaviour the differences in flood water mass appear to be relatively low, especially for damage case D2.

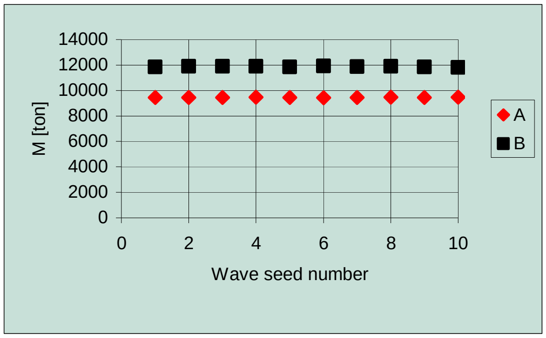

Figure 20 Floodwater mass for Hs=2m, D1

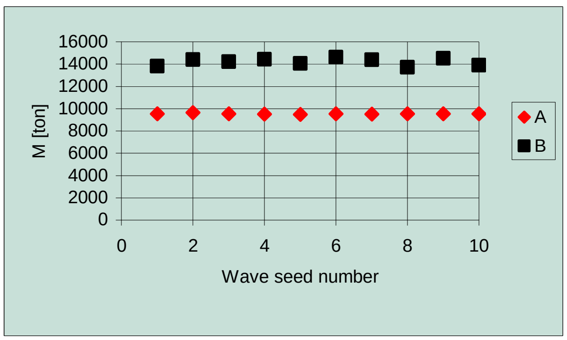

Figure 21 Floodwater mass for Hs=4m, D1

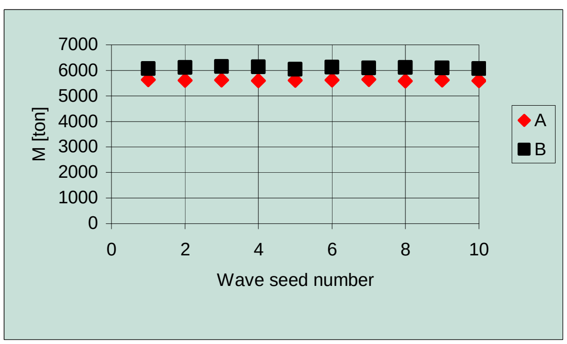

Figure 22 Floodwater mass for Hs=2m, D2

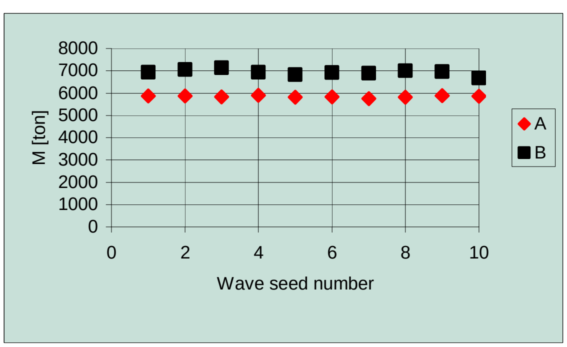

Figure 23 Floodwater mass for Hs=4m, D2

Time to flood

Following the ITTC recommended procedure for damage stability in waves, the survival limit of the ship is defined as:

- the roll angle exceeds 30 deg, or
- the 3 minute average roll angle exceeds 20 deg.

Code A three minute averaged values for roll and damage mass show constant values near the 1800 sec simulation duration. Code A simulations last no longer than 1800 sec, and in this time frame the criteria are never exceeded. For Code B, roll and damage mass are not always constant near the 1800 sec limit and the criteria can be exceeded during longer duration simulations, especially for aft damage case D1. For Code B, typical examples are shown in Figures 24 through 27. In each Figure, results are shown for five wave seeds. Figures 24 and 25 show the three minutes average heel angles versus time, while Figures 26 and 27 show the three minute average flood water mass versus time.

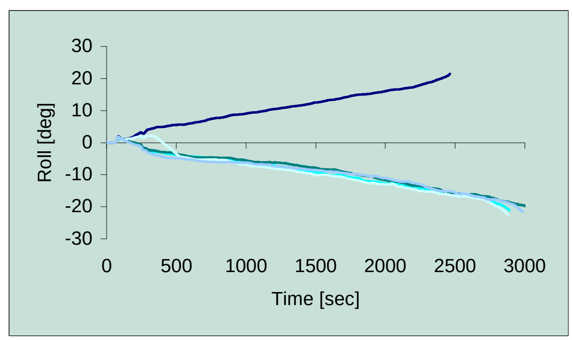

Figure 24 Roll versus time, Hs=4m, D1

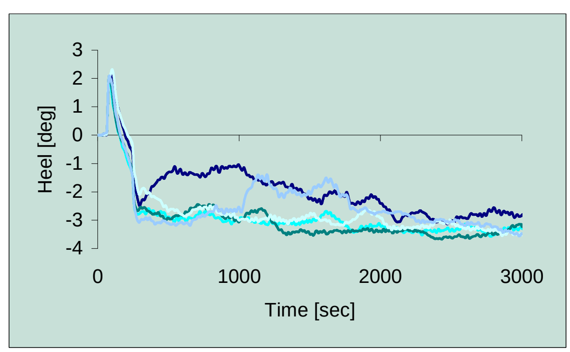

Figure 25 Roll versus time, Hs=4m, D2

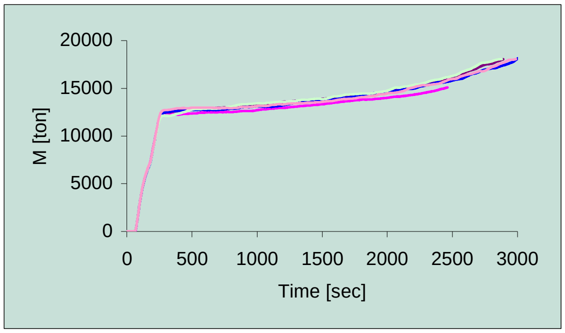

Figure 26 Mass versus time, Hs=4m, D1

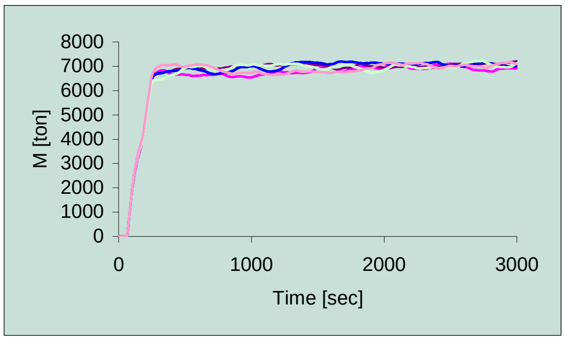

Figure 27 Mass versus time, Hs=4m, D2

It is seen that for damage case D1 (aft damage) and Hs = 4m significant wave height, the survival limit is reached in about 2500 to 3000 seconds. Damage case D2 (mid ship damage) is less critical in these conditions.

CONCLUSIONS

Based on an initial analysis of the results from Codes A and B it is concluded that:

- Code A viscous roll damping is much higher than that of Code B.
- Code A results show much lower roll motions for intact and damaged conditions than for Code B.
- As a result, Code A results do not exceed ITTC survivability criteria while Code B results do exceed these criteria in the most severe condition.
- The amount of accumulated damage mass seems to be relatively insensitive to the mean value and variation of the roll motion.

ACKNOWLEDGEMENT

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