Benchmark study of numerical codes for the prediction of time to flood of ships: Phase I

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ABSTRACT

This paper provides a summary of the progress of an ITTC benchmark study on numerical codes for the prediction of time-to-flood of damaged passenger ships. Simulation data for the flooding of a barge like ship has been provided by developers of several numerical codes and compared with relevant model experimental data. Overall it can be stated that the steady state flooding condition is reasonably well predicted by the codes. However, the prediction of the flooding rates and transient phenomena is less satisfactory and urges for increased research effort in this area in the future.

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. The development of a "structured approach" to benchmark testing is a key feature of the current effort. 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 cruiser ship. Unfortunately, the data for a realistic cruiser 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 box-shaped barge for which detailed model test data are available;

II. Benchmark based on a realistic passenger ship with complex internal geometry.

The present paper describes the benchmark work for the first phase.

OBJECTIVE

The objective of the herein reported benchmark study is to establish current capability and weaknesses in predicting, qualitatively and quantitatively, the time-to-flood for a simple configuration of compartments in a barge-like hull form. Besides time-to-flood, related quantities as motions and flooding volumes in compartments will be compared with experimental results.

BACKGROUND

The barge that is taken as the basis for the study has been tested recently at the Helsinki University of Technology (TKK, formerly HUT), see Ruponen [1]. The model is box shaped with tapered bow, stern and bilges, see Figure 1. The model scale was 1:10 while the model length was 4 m. The main particulars are shown in Table 1. The model was instrumented with water level sensors in the eight floodable compartments as to obtain detailed information on the flooding process. Two pressure sensors were located in the two lower double bottom compartments. The floodable compartments are located somewhat forward of midship as to introduce a trim angle and thereby progressive flooding, see Figures 2 and 3.

Length over all	4.000 m
Breadth	0.800 m
Height	0.800 m
Design draft	0.500 m
Block coefficient	0.906
Volume of buoyancy	1.450 m^3

Table 1 Main particulars barge

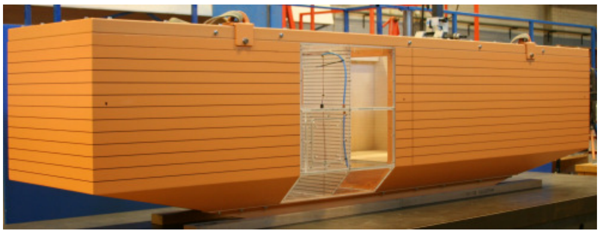

Figure 1 Barge model at TKK

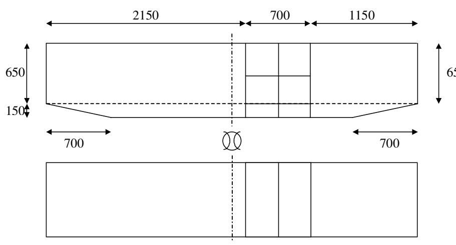

Figure 2 Compartment arrangement-1

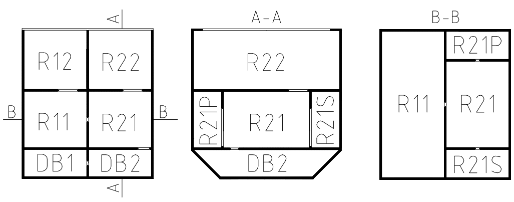

Figure 3 Compartment arrangement-2

Six damage cases have been tested of which four have been selected for benchmarking. Two cases are discussed herein as follows:

Test03 – Down Flooding

- Damage hole (25 mm x 25 mm) in the bottom of the forward double bottom compartment (DB2).
- The door on the upper deck is closed.
- The door, connecting R12 and R22, is open, allowing down-flooding from R12 to R11.

Test06 – Side Damage

- Damage hole (40 mm x 60 mm) is in the side of the forward compartment (R21S).
- The door on the upper deck is closed.
- The double bottom (DB1 and DB2) remains dry, i.e. the opening between R21 and DB2 is closed.

A comprehensive report about all benchmark tests may be found in Ref. [2].

PARTICIPATION

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

- Safety at Sea (S@S), United Kingdom.
- Helsinki University of Technology (TKK), Finland.
- Maritime Research Institute Netherlands (MARIN), The Netherlands
- Maritime and Ocean Engineering Research Institute (MOERI), Korea
- National Technical University of Athens (NTUA), Greece.

In the presentation of results the numerical simulation results from the participants are referenced to anonymously as C1 to C5.

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 although some have been applied also to (high speed) multi-hulls in the past.

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 corrected semi-empirically.

The employed flooding methods use relatively simple hydraulic models, although the implementation of more advanced CFD methods is currently investigated by some participants. 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.

More detailed:

S@S's code has also evolved from a manoeuvring model following the "modular" MMG philosophy, based on detailed models of hull, propeller and rudder plus their interactions. Wave effect is added by calculating the Froude-Krylov force up to the instantaneous free surface, use of strip theory for the radiating wave forces and slender body theory for wave diffraction. Appendage hydrodynamics are calculated from their geometry. A PD autopilot is used. Flooding is determined by means of Bernoulli type equations.

TKK's code is based on a two-stage approach where loading and responses are decomposed into a linear approximation and a nonlinear part. Linear responses are obtained from linear transfer functions while the loads are determined from strip theory. The nonlinear part is composed of cross coupling terms of body dynamics and the nonlinear part of the Froude-Krylov force. Wave radiation forces appear as convolution integrals. Flooding is determined by means of Bernoulli type equations in combination with a pressure correction method.

MARIN's code FREDYN can deal with large angles in roll and yaw. Wave pressure is calculated up to the instantaneous free surface. The memory effect is taken into account through convolution integrals accounting for the radiation forces. Wave orbital velocities are taken into account in the calculation of drag forces. Flooding is determined by means of Bernoulli type equations which are solved in the time domain in a quasi-steady manner.

MOERI's code also can deal with large motions. It considers gravity, buoyancy, propulsion, steering, wind, manoeuvring and viscous (roll damping) force components. Wave excitation (diffraction and Froude-Krylov) and radiation forces are accounted for. With respect to flooding, the method is much the same as described above in the general part.

NTUA's code CAPSIM is a non-linear time domain numerical method, which is based on linear potential theory with respect to the basic hydrodynamics of the problem and considers a variety of non-linear terms of ship's equations of motions, like the excitation by large amplitude regular or irregular waves, the exact body geometry below and above the still waterline and its impact on ship's restoring and semi-empirical nonlinear viscous damping. The flooding rate through the openings is governed by the Bernoulli equation modified with the discharge coefficient to account for the effects of the openings.

RESULTS

Graphs showing comparisons between the experimental (Test) and simulation results (C1 through C5) are shown in Figures 4 through 24. Water level heights in compartments are denoted by H-x where x stands for the compartment identification shown in Figure 2. The pressure in double bottom compartment DB1 is denoted by P-DB1. Sinkage, trim and heel are denoted by heave, pitch and roll respectively.

Water level results from Code C1 are only defined between the instants that the level starts to rise and that the compartment is filled. Otherwise a zero value is given.

In Code C2 a too low atmospheric pressure is present since this method can not be applied at model scale and the ambient air pressure is fixed in the code. Therefore, the effects of air compressibility are likely to be underestimated.

Codes C3 and C4 results do not include pressures as air compressibility is not taken into account, for the present case. The compartments are assumed to be fully ventilated.

In Code C5 individual compartments have been grouped into larger compartments as follows:

- Test 03: DB1+DB2 and R21+R21S+R21P
- Test 06: R21+R21P

Results for grouped compartments can not be compared directly to the results for the individual compartments.

In some of the codes it was possible to use the experimentally determined discharge coefficients, in other codes a fixed discharge coefficient has been used.

Test 03

This condition allows for progressive down flooding.

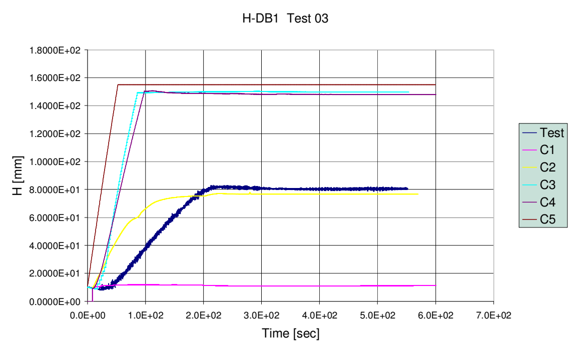

Figure 4 H-DB1 versus time

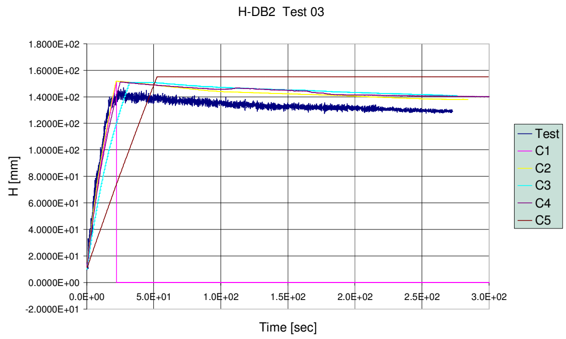

Figure 5 H-DB2 versus time

For the non-ventilated compartment DB1 the results are such that Code C1 overestimates the air pressure effect, C3 and C4 do not to account for air pressure while the Code C2 result is closest to the experimental flooding rate. For the ventilated compartment DB2 the agreement is better. Code C3 results lags behind a bit, but Code C4 results are reasonably good.

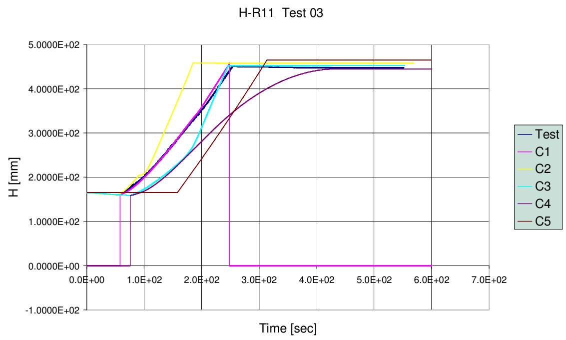

Figure 6 H-R11 versus time

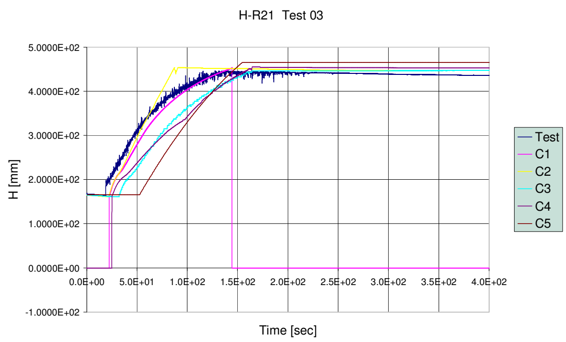

Figure 7 H-R21 versus time

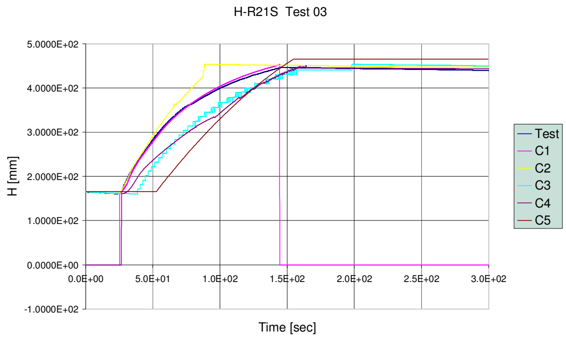

Figure 8 H-R21S versus time

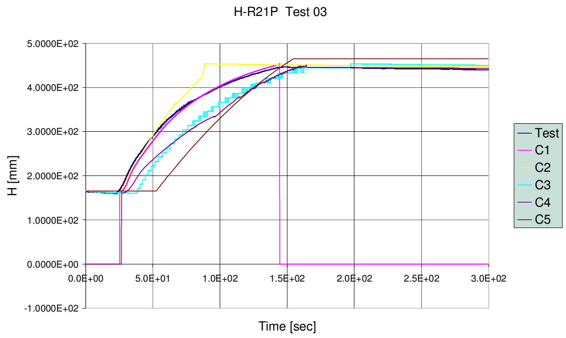

Figure 9 H-R21P versus time

For the R11, R21, R21S and R21P compartments located on top of the double bottom, the Code C1 result is about right, C2 shows a too high flooding rate while the flooding for C3, C4 and C5 lags behind in time.

For the top compartments R12 and R22, Code C2 results show a too early flooding, C1 and C3 results are close to the experimental values. Code C4 predicts no flooding in these compartments. C5 lags behind for R12 and R22.

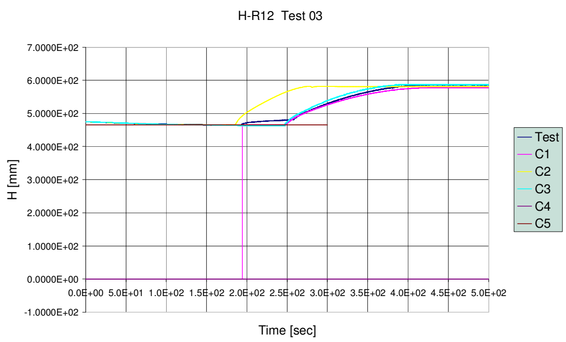

Figure 10 H-R12 versus time

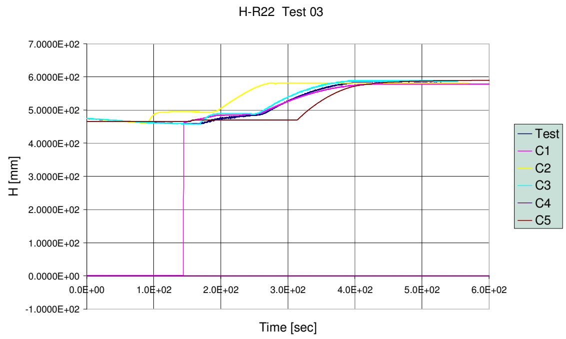

Figure 11 H-R22 versus time

The pressures in compartment DB1 are quite well predicted by Code C1, while C2 shows a too steep pressure rise. It seems strange that the pressure for compartment DB1 is well predicted by Code C1 while the water level is significantly off, see Figure 4. For compartment DB2, C1 does not provide the pressure while that of Code C2 is reasonable.

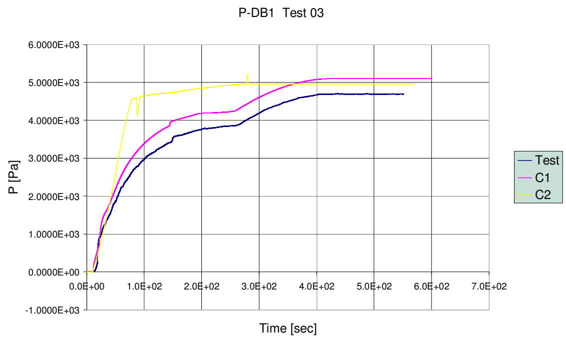

Figure 12 P-DB1 versus time

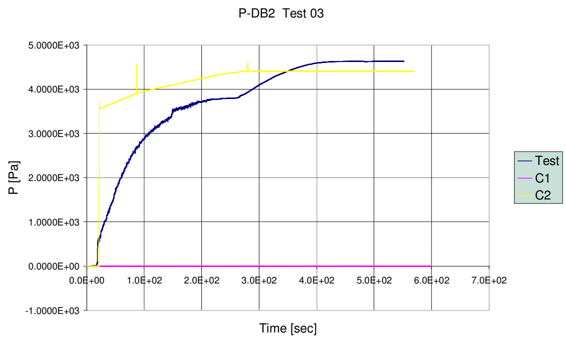

Figure 13 P-DB2 versus time

The results for the water level comparison are also reflected in the heave and pitch curves: the heave and pitch rates for C2 are too high but the steady values are well predicted. Code C1 results are close to the experimental values while C3 results also show too high heave and pitch rates and somewhat too high steady values. This is in contradiction with the general under prediction of flooding rates for C3. For Code C4 both heave and trim are under predicted which is in agreement with the general under prediction of flooding rates. Code C5 finally predicts the heave quite well while the pitch is somewhat underestimated.

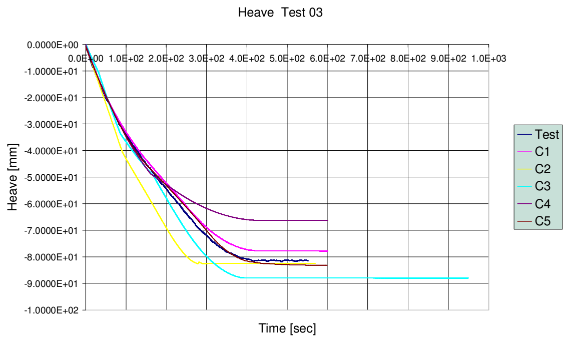

Figure 14 Sinkage versus time

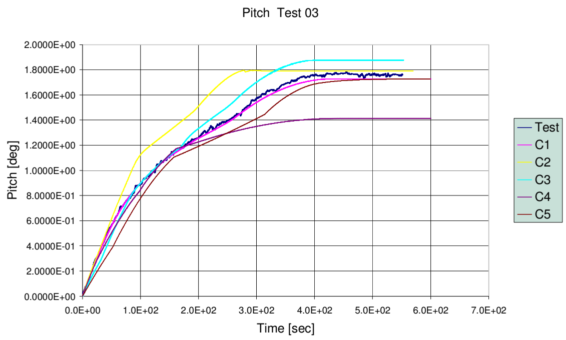

Figure 15 Trim versus time

Test 06

Test 06 shows a case with side damage in the starboard compartment R21S. The double bottom compartments DB1 and DB2 remain dry, therefore no results for these are included here.

Flow rates for compartment R11 are correctly predicted by Code C1 while C3, C4, C5 and especially C2 predict too low flow rates.

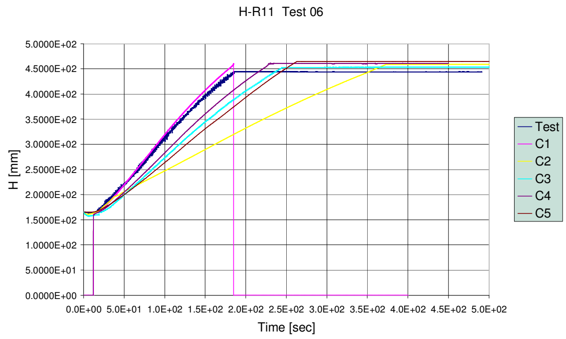

Figure 16 H-R11 versus time

For compartment R21, adjacent to the damaged compartment R21S, differences are smaller and most predictions are close to the experimental values. Code C5 predicts a too high flow rate. For the damaged compartment R21S itself, all codes over predict the initial inflow, furthermore code C5 does not predict well the reduction in flow rate at 50 seconds. This should have an effect on the roll angle shown later. For the port side compartment R21P, predictions are reasonably correct, but C5 again seriously over predicts the flow rate.

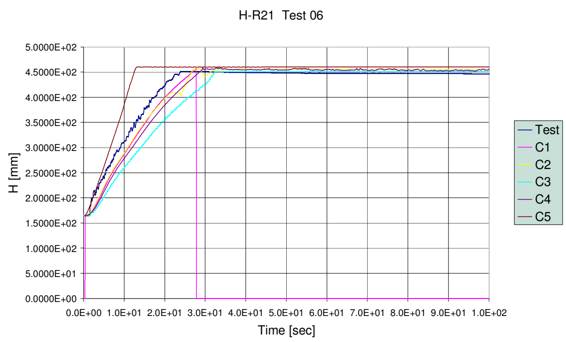

Figure 17 H-R21 versus time

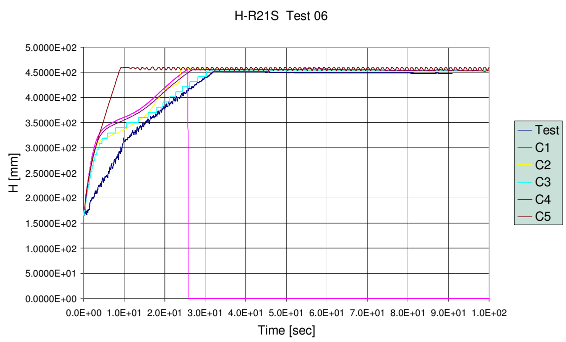

Figure 18 H-R21S versus time

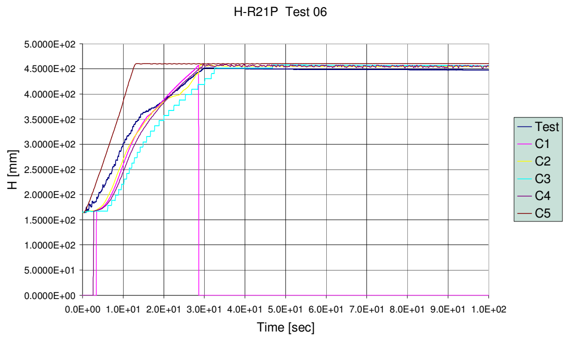

Figure 19 H-R21P versus time

For the top compartments R12 and R22, the predicted rise of the water level in time is generally acceptable, but Code C3 and especially C2, C4 and C5 lag behind for R12. Code C1 results are close to the experimental values.

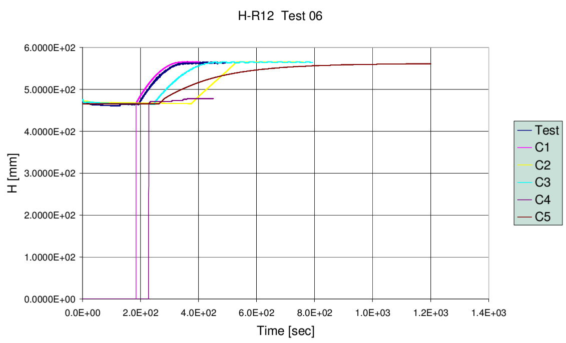

Figure 20 H-R12 versus time

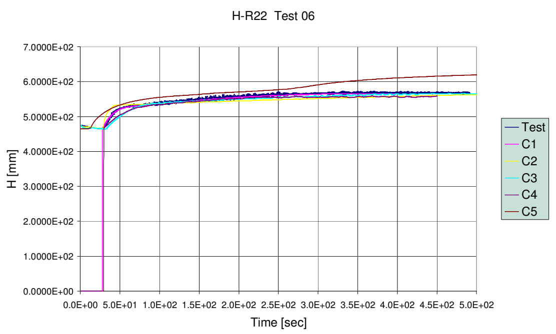

Figure 21 H-R22 versus time

Heave and pitch curves are well predicted by Code C1 while C2, C3 and C5 show deviating results. Code C4 shows again an underestimation of the equilibrium heave and pitch values.

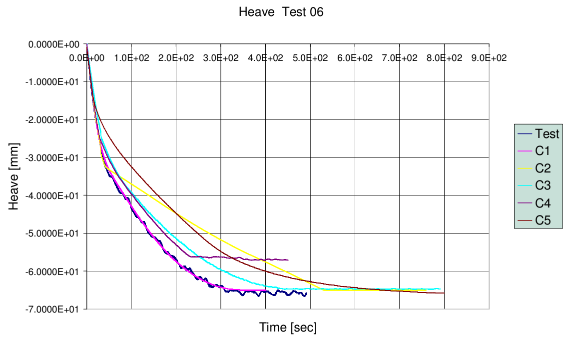

Figure 22 Sinkage versus time

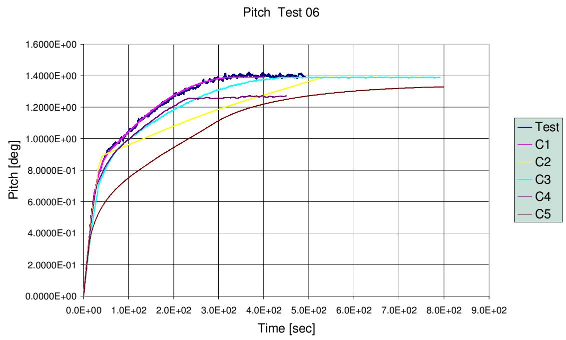

Figure 23 Trim versus time

All codes except C5 over predict the transient roll peak angle in a similar way, but also show upright conditions at approximately the same time instant as the experiments. The over prediction of the roll peak is probably due to neglecting the jet-like properties of the inflow and/or underestimating the roll damping. Interestingly, the roll time trace from Code C1, C4 and C5 are relatively smooth, while these from Codes C2 and C3 are irregular, similar to the experimental result.

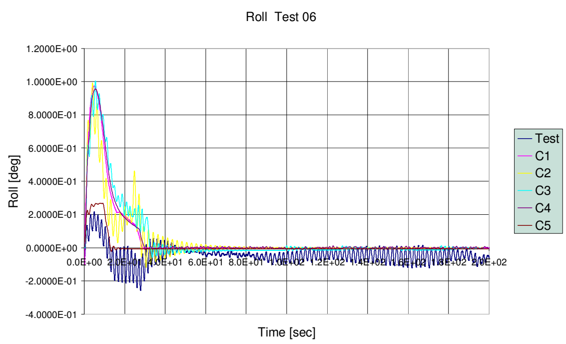

Figure 24 Heel versus time

CONCLUSIONS

On the basis of the above analysis, the following conclusions are drawn:
Code C1 produces results that are generally close to the experimental values. This code seems to have problems only with the non-ventilated double bottom compartment DB1 for Test 03.

Code C2 predicts generally the right trends but may show either too high flow rates for lightly ventilated compartments and/or irregularities in the water level and pressure signals. It is recommended to take into account the correct atmospheric pressure.

The over predictions in flow rates for Code C2 probably result in too steep heave and pitch rates. However, the steady state heave and pitch values are well predicted.

Code C3 and C4 predict generally the right trends but often predict too low flow rates while all compartments seem to be fully ventilated. This is inconsistent.

Heave and pitch predictions by Code C3 may either be somewhat under- or over-predicted. Code C4 generally under predicts the equilibrium sinkage and trim.

Results from Code C5 can be compared with the other data for a limited number of compartments only. Flow rates from Code C5 show the right trends, but are often too low or too high. Air pressure effects seem not to be taken in to account. Heave and trim predictions are reasonable to good.

The initial heel peak angle in the side damage case is over predicted by all codes, except for Code C5. This may be due to the simplifications made in the flooding method and an underestimation of roll damping. It should be noted that the experimental initial heel peak has a magnitude of 0.20 degree only. The steady state roll angle is correctly predicted by all codes.

Overall it can be stated that the steady state condition of all tests is reasonably well predicted by the codes. The prediction of the flooding rates and transient phenomena is less satisfactory. As such, reasonable time to sink predictions appear feasible by the present codes, at least for ships having a relatively simple internal geometry and interrelation between flooded compartments under calm water conditions. How this will work out for ships having a more complex geometry in calm water and for seaway conditions (including wave excited ship motions) remains to be seen in later stages of the present benchmarking work.

References

Ruponen, P., ‘Model Tests for the Progressive Flooding of a Box-Shaped Barge’, HUT Ship Laboratory Report M-292, 88 p., 2006.

Walree F. van, ’Benchmark Study of Numerical Codes for the Prediction of Time to Flood of Ships: Phase I’, ITTC-SiW report, July 2007.