On the Time Dependent Survivability of ROPAX Ships

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ABSTRACT

The time dependent survivability of ROPAX vessels is herein investigated by use of numerical simulations of ship motion and flooding in waves. Present studies further confirm that characteristically a ROPAX ship capsizes fast when sustaining damages leading to capsize. The time dependent survivability is estimated by applying Monte Carlo probability simulation, and was found to be limited within short times after the damage event. Finally, the survive wave height, unconditional to damage opening and loading condition, is approached.

KEYWORDS

Time to capsize; survivability; capsize; simulation; flooding; damage stability; ROPAX

GENERAL

The time a ship survives after a casualty of flooding has become an explicit design objective for passenger ships through the SOLAS amendments, *IMO* (2006), and the introduced concept of *safe return to port*. The purpose of the regulations is to establish design and operational criteria so that when a passenger ship is subject to flooding of any single watertight compartment then vital systems and services will remain operational for the safe return to port with its own propulsion and the ordered evacuation and abandonment of people on board. These regulations will be applicable to all passenger ships (of length 120 m and over) built on or after July 1, 2010 (one week after the date of the present workshop).

Implications on the ship design will be mainly related to the rearrangement of systems and services in order to provide the required redundancy for machinery and propulsion. New designs are expected to be, in principle, of improved safety with respect to flooding (and fire, which is regulated accordingly). However the watertight subdivision remains the basic approach to control the time to survive after a casualty.

The prime assumption of the safe return is that the ship is able to survive the flooding of one compartment for sufficient time, and then, safety concerns can be reduced to the loss of operability of the systems installed inside. The time dependent survivability of ships has been addressed both by setting a time threshold of 3 hours (IMO, MSC.78) for the development of the relevant regulations, as well as through the time requirements which are derived from the evacuation procedure and ordered abandonment for a passenger ship separately.

For ROPAX ships, and differently to other ship designs, to survive one compartment damage for sufficient time requires additional considerations, because ship’s survivability is strongly dependent on the possible flooding of the large vehicle space, which is located above the calm water free surface. For such arrangements, the damage openings are likely extended above the subdivision deck (car deck). Then, even if one compartment below the main deck is damaged, the vehicle space may also be flooded because of the action of waves, which may lead to ship capsize if the floodwater exceeds some critical amount. Hence, additionally to the transverse and longitudinal watertight subdivision, the horizontal subdivision is of importance for

ROPAX vessels and has to be thoughtfully considered in connection to the one compartment damage.

The amount of water on deck that a ROPAX vessel may sustain is characteristic to each ship loading condition and damage case. This critical amount has been extensively investigated over the last decades and was regulated with SOLAS'95 (Stockholm Agreement provisions). There, the damage stability is evaluated in the presence of a critical amount of water on deck that may potentially be accumulated. Nevertheless, it is still unknown how long a ship that complies with the provisions may survive after damage.

The flooding rate of the vehicle space eventually determines the time to flood the deck, up to the critical amount. Obviously if the rate happens to be slow, because of a small damage opening or low wave heights, then a long time is required for the water on deck to grow up to the critical amount and to approach critical stability. However, in earlier work of *Spanos* & *Papanikolaou* (2007), it was pointed out that the flooding of the vehicle deck is a relatively fast process, characterized by limited probability of ship loss in later times. These observations, which were related to the worst SOLAS damage, are herein further verified by analyzing another typical ROPAX, and by investigating the more general situation, where the parameters of the damage case are randomized too.

TIME TO CAPSIZE FOR DAMAGED ROPAX

Numerical simulation methods for the motion of the damaged ROPAX ships in waves may today provide excellent guidance in related studies and investigations. Herein the simulation method by *Spanos* (2002) is applied to analyze the time aspects of the complex flooding process and the dynamic stability in waves.

Figure 1 presents the time to capsize of a ROPAX vessel in beam waves versus the significant height of the incident waves. Numerical simulation results in comparison with experimental data from recent tank model tests by *Rask* (2010) are presented, referring to developed seas of *JONSWAP* spectrum and slope $Hs/\lambda = 0.04$.

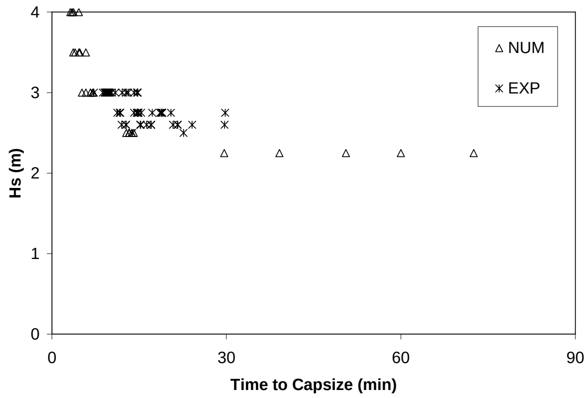

Figure 1 Numerical simulation and experimental data.

The time estimations regard a typical two compartments damage case as demonstrated in Figure 2. This is a ROPAX vessel of 137 m length, (geometrically similar to the ROPAX *Estonia*, lost on 1994) having damaged the two shaded compartments aft amidships plus the vehicle space. The fore compartment corresponds to the main engine room. Inside the aft compartment there is an intact side tank which causes an asymmetric damage case. The assumed damage opening, according to SOLAS'95 (B-II Reg.14), is located on the port side.

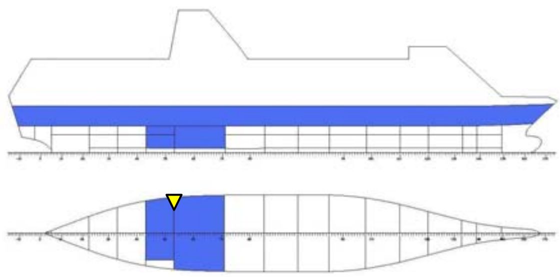

Figure 2 Typical damage case.

Figure 1 suggests a high correlation between the numerical results and the experimental data. The measurements in the tank are stopped after 30 min, hence there are no data for later times. A limit survive wave height at 2.25 m is identified from the numerical simulations as an asymptotic below which no capsize events may occur. The corresponding height for the tank tests is estimated at 2.50 m, thereof a difference within tolerance is observed.

For wave heights just below the survive limit, the flooding process reaches some average balance between the water inflow and outflow on the deck area, maintaining some average floodwater on deck, which is not enough to lead to any capsize and the vessel survives for long. For even smaller waves no floodwater could reach the deck, as a result of large damage freeboard compared to the incoming waves.

Some basic difference between the presented physical and numerical tests is that in numerical simulation the ship moves in 3 degrees of freedom (that of heave, roll and pitch) whereas in the tank the ship model freely moved in 6 degrees and drifted downstream in beam waves. This fact, together with the ideal test conditions with the computer simulation, may explain the different scatter of the times to capsize.

Figure 1 is characteristic for damaged ROPAX ships, according which, the ship survives infinite time for waves heights up to the survive limit and capsizes above that limit in a fast mode, in the particular case in less than 30 min. Half hour is considered a fast capsize in view of the required time for an ordered evacuation, in addition to the time needed to evaluate a damage and make any decision for evacuation.

SENSITIVITY OF THE SURVIVE TIME

Sensitivity studies based on numerical simulation have shown that the time to capsize keeps the characteristic behaviour of Figure 1 in the variance of the basic parameters of the damage cases. The ship loading condition, the sea state and the possible shape of damage opening may affect either the survive limit of wave heights or directly the time to capsize.

Regarding the incident waves, the time to capsize was found to be insensitive with respect to two different wave spectra, namely that of *JONSWAP* and *Pierson-Moskowitz* types of equal spectrum parameters. It was also insensitive to the wave heading for changes up to 20 degrees from beam waves. While a delay of capsize and simultaneously increase of survive limit could be observed for the longer waves, as shown in Figure 3. Another basic parameter, the *GM* also affects the time to capsize, also presented in Figure 3. By increasing the *GM* (by 0.5 m) an increase of both the survive limit (by 0.5 m) as well as a double time to capsize has resulted.

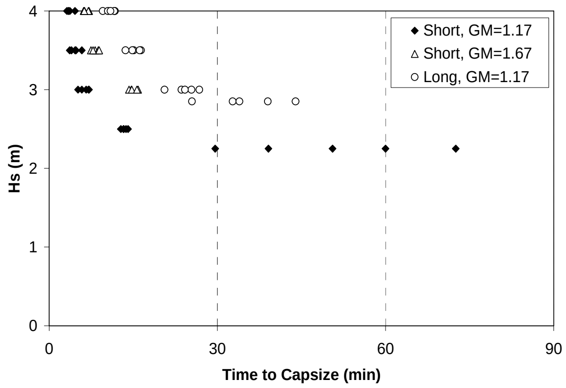

Figure 3 Effect of *GM* and wave periods on time to capsize.

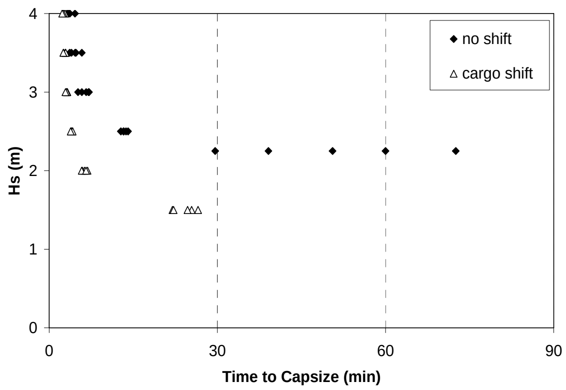

Figure 4 Shift of cargo strong effect on TTC.

Another notable effect could be observed for the transverse centre of gravity TCG of the ship, which may be due to some shift of cargo, Figure 4. Then a substantial decrease of the survive wave height and notably faster capsize observed. This change is actually an effect of ship loading condition and change of corresponding residual stability; however, the characteristic behaviour of the time to capsize remains still unchanged.

TIME DEPENDENT SURVIVABILITY

The parameters that practically affect the time to capsize, and discussed above, were the assumed sea state (significant wave height and period), the ship loading condition (as expressed through *GM*) and of course the size of the damage opening. For small sizes of the opening delayed capsizes or even not capsize at all is expected, while large openings may lead to fast capsizes.

To estimate the probability distribution of the time to capsize for the studied damage case in the most generic situation, a probability simulation has been applied by use of Monte Carlo method. The parameters that affect the time to capsize are assumed to be random variables of given probabilities. In particular, rough waves up to 4.0 m of significant wave height were assumed and of a probability distribution according to that of collision statistics. The waves were assumed of *JONSWAP* spectrum with slope Hs/λ uniformly distributed between 0.018 and 0.050. The metacentric height *GM* of the intact ship was assumed also uniformly distributed between 1.00 m and 2.75 m. And finally, the damage opening was of rectangular shape with dimensions that follow the statistical distributions of collision damages (see, Lutzen 2001).

The results of the probability simulation are summarized in Figure 5, which are the fit curves of the numerical statistics. The unimodal probability distribution has the peak at 10 min and thereafter it continuously decays. The probability to capsize within 30 min from the damage event equals 80% and it reaches almost 95% within 60 min.

Given the probability of the time to capsize then the time dependent survivability of the ship can be directly estimated, and it is presented in Figure 6 below. This is the probability to survive the damage case of Figure 2. The probability to survive *s* is a function of time, and asymptotically converges to 0.981. This limit is the survivability, unconditional to the time as well as to the damage opening, sea state and *GM*. If the survivability would be defined with respect to the 30 min limit, as used to be in SOLAS, then the it would slightly increase and reach a value of *s*=0.985. Apparently, the time dependence of survivability is limited to below 60 min, and remains practically independent of time for times longer than 1 hour.

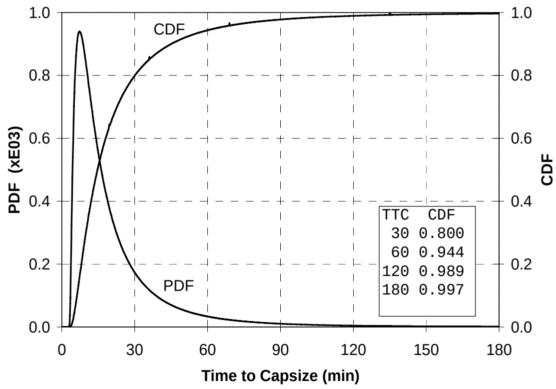

Figure 5 Probability of Time to Capsize in rough waves.

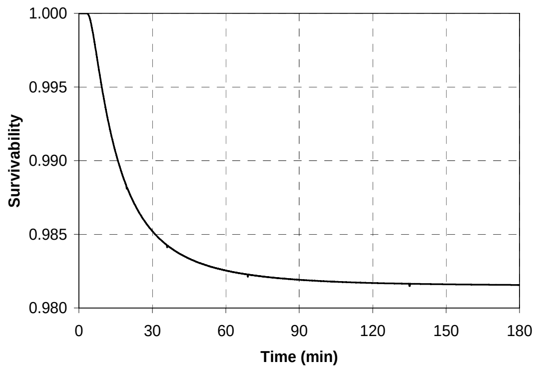

Figure 6 Time dependent survivability of the ship for the specific damage case.

According to SOLAS (2009, Part B1, reg.7.2) the survivability in waves for this particular damage case equals *s*=0.836 (with GZ_{max}=0.10 m and range 9.4 deg). This is notably different from the above *s*-factor, which was estimated by numerical simulation. This underestimation of survivability according to the SOLAS regulations confirms (at least in this case) the conservative nature of stability and safety regulations. However, the more than eight times higher value of the probability to capsize *c* (which is *c*=1-*s*) resulting from the two estimations, namely 16% against 2%, reinforces the necessity to sustain investigation on the survivability models.

CLOSING REMARKS

The survivability of a damaged ROPAX in waves has been analyzed in the most generic damage situation. It was confirmed that capsize may occur due to floodwater accumulated on the vehicle deck and that capsize is then fast.

Survive limits could be clearly identified for each particular investigated condition. Below that limits a ship capsize does not occur.

Taking into account the random nature of the main parameters, like the damage opening and loading condition, a generic survive limit could be still detected, below which no capsize events could occur and above which capsize was always a likely event.

It was also demonstrated that the survivability of a ROPAX ship is weakly dependent for times between 30 and 60 min, and practically time independent for times later than 1 hour. On the basis of the so far studies and evidences, the survivability of ROPAX ships may be regarded as time independent.

Finally, the survivability of the investigated ROPAX in collision damages is significantly underestimated by the present SOLAS 2009, which is an additional evidence for the necessity for further evaluation and possible improvement of these regulations.

ACKNOWLEDGEMENTS

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