Collision and Grounding of Passenger Ships – Risk Assessment and Emergency Evacuations

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ABSTRACT: This paper considers collision and grounding of passenger ships. Subsequent to a collision or grounding, there might be water ingress into the compartments and the risk of sinking exists. In such circumstances, timely and effective evacuation of all passengers and crew will be extremely important, and failure to evacuate in time may lead to catastrophic consequences. This paper presents probabilities of collision and grounding and investigates possible events subsequent to an incident, e.g. possibilities of flooding, sinking and capsizing, expected time to sink, etc. Evacuations in case of collision and grounding are also considered and the consequences are estimated in terms of expected loss of lives. The risk associated with collision and grounding is hence estimated and compared to other types of accidents such as onboard fire.

1. BACKGROUND AND INTRODUCTION

Any ship that experiences flooding of one or more of its compartments is exposed to the risk of losing its stability and thus the risk of sinking. Collision and grounding are considered to be the most relevant accident scenarios that may cause flooding of passenger ships, and will thus be the topic of this paper. Existing passenger ships will generally carry a large number of people when they are in normal operation and modern cruise ships can carry passengers in the order of several thousands. Although accidents involving such large passenger ships are very rare, if a serious accident should occur, its consequences could be disastrous.

Even though a lot of effort is constantly being made to keep passenger ships safe and measures are always taken to avoid serious accidents, one can never completely eliminate the probability of a serious accident to occur on board a ship. If an incident takes place, one can try to prevent it from evolving into a serious accident by for example intentionally beaching a ship that is taking in water and thus keep it from sinking. If such measures fail however, an evacuation provides a last opportunity to minimize the consequences of the accident by reducing the number of fatalities. In such situations, the evacuation performance will be very important and an orderly and timely evacuation can save the lives of many people on board.

Due to the conviction that an effective evacuation will be important in case of a maritime accident and realising that modern passenger ships will normally carry a large number of people, new requirements from IMO[1] states that an evacuation analysis shall be performed early in the design process for new ro-ro passenger ships [SOLAS (2001)]. The Maritime Safety Committee has produced guidelines for such evacuation analyses [MSC/Circ. 1033 (2002)].

2. THE FIRE EXIT PROJECT

One of the goals of FIRE EXIT[2] is to equip the marine industry with a Ship Evacuation Simulator that represents a quantum leap of present software regarding the level of reliability, realism and design utility [Galea et al. (2002), Galea et al. (2003)]. The simulator being developed within the FIRE EXIT project, the maritimeExodus, should be able to account for issues such as mustering, dynamic ship movement, static trim and heel, fire and smoke and abandonment. Data on passengers' behaviour in different conditions of movement and with or without the presence of smoke are collected and used in the simulations, and the evacuation simulator software is integrated with an interpretation and optimisation module. The propagation of fire and smoke are to be modelled through a link to the SMARTFIRE software [Taylor et al. (1996), Galea et al. (2003)]. An XML based interface is provided as a link to concept design software, enabling conceptual designs to be tested at an early stage. The outputs from the software simulations are to be validated against full-scale trials on board a real passenger ship in operation.

When performing evacuation simulations, it is important to have a basic understanding of what a typical evacuation scenario might be. In addition, the different probabilities associated with the scenarios will be useful. Because of this, an evacuation risk assessment has been carried out within the FIRE EXIT project [Vanem (2003)] that has investigated different accident scenarios. This study suggests that collision and grounding is among the most critical accidents involving passenger ships. The expected frequency of such accidents are comparable with that of fire [Vanem and Skjong (2004)], but the expected time available for evacuation is much less, and the expected consequences in terms of loss of lives are thus higher. Emergency evacuations are hence considered extremely crucial for collision and grounding of passenger ships.

3. EVACUATION ANALYSIS REQUIREMENTS FOR PASSENGER SHIPS

The evacuation analysis requirements do not state that advanced simulation software must be used for the analyses. There is an option to perform a simplified analysis using only pen and paper, considering evacuating crew and passenger as a flow of people through the escape routes in much the same way as water flowing through a pipe system. Performing a simplified evacuation analysis with no advanced tools is a very time consuming task however, and running advanced simulations can save several man-days of work for every evacuation analysis performed. It is thus expected that most evacuation analyses carried out in the future will utilize sophisticated tools such as the maritimeExodus to perform an advanced analysis. It should be noted, however, that regardless of whether the simplified or the advanced approach is taken, the objective is to assess the

[1] International Maritime Organization, http://www.imo.org
[2] FIRE EXIT – project website, http://www.bmtproject.net/fireexit

evacuation process through a set of well defined benchmark scenarios rather that to model the evacuation in a real emergency situation.

According to IMO guidelines, an evacuation analysis performed over a set of benchmark scenarios are required to demonstrate that possible emergency evacuations can be completed within 60 minutes for all new ro-ro passenger ships. The analysis should thus ensure that evacuation arrangements are appropriately adequate for swift evacuation of all passengers. This time limit corresponds to the requirements regarding confinement of fires within main fire zones of passenger ships. Passenger ships are required to be divided by thermal and structural boundaries into main vertical fire zones and horizontal zones, and these boundaries should be able to confine a fire for at least one hour within the fire zone where it originated. Historically, evacuations have primarily been considered in relation to fires and it has been assumed that evacuations would be successful if it is completed by the time the fire spreads from the zone of origin.

This paper indicates, however, that fire is not the only relevant scenario for evacuation of passenger ships and that collision and grounding are highly relevant accident scenarios that will impose even stricter requirements on the evacuation performance on passenger ships.

4. COLLISION OF PASSENGER SHIPS

Collision between two ships at sea is always a serious incident and depending on the extent of the impact, the ships involved in a collision may or may not sink. The striking ship will normally not be in any great danger of sinking, as it will receive the impact of the collision at the bow, and the bow in front of the collision bulkhead will normally receive all the collision energy. Damages restricted to this part of the ship will normally not affect the stability of the ship. The struck ship, however, if receiving a blow to its side, has a high risk of loosing its stability and will thus be in danger of sinking. If the struck ship is a passenger ship with many people on board, effective and orderly evacuation of these people will be crucial to the outcome of the incident.

The simplified model in Fig. 1 has been used to analyse collision of passenger ships. I.e. a ship may or may not take in water subsequent to a collision and in the case of water ingress, the ship may either survive or sink. The probabilities of collision and of flooding are obtained from investigation of historical data collected by the HARDER project, and from [Olufsen et al. (2003)], and the survivability is based on attained subdivision indices calculated by HARDER. Finally, the expected consequences given sinking are estimated in terms of expected time to sink and the corresponding expected number of fatalities.

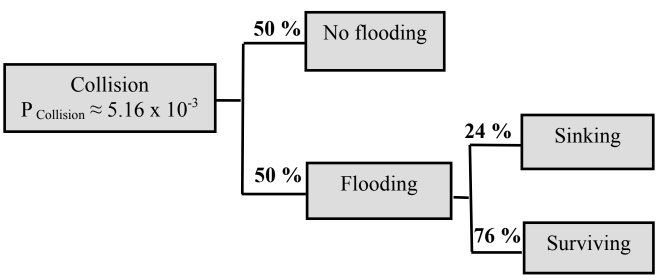

Fig. 1. Event tree for collision of passenger ships

4.1 Collision and Flooding frequencies

The frequency of collision was estimated by Olufsen et al. (2003) for passenger ships over 4000 GRT, based on data between 1990 and 2000. The frequency per ship year was estimated to be:

$$P_{collision} \approx 5.16 \times 10^{-3} \quad (1)$$

Furthermore, the probability of flooding given collision was estimated to be 0.38 although the statistical basis for this conclusion was rather weak. Only 16 collision accidents were involved in the study and the uncertainty associated with the estimate is hence considered to be high. An alternative way of estimating the frequency of flooding was therefore sought.

The HARDER project has collected a set of data on previous maritime accidents, primarily collision and grounding accidents, and studying these data will provide an alternative estimate of the probability of flooding conditioned on collision [Mains (2001)]. The database contains records of 2946 causalities including 1851 collisions involving different types of ships. The 1851 records of collision included ship-ship collisions as well as collisions between ships and other objects, and it included records regarding both the struck and the striking ship. Further examination of the data revealed 801 records of struck ships in ship to ship collisions. It was not obvious from all the records which ship experienced flooding subsequent to the collision, but after studying the data in more detailed it was assumed that 508 of the 801 records involved flooding of one or more compartments, i.e. a probability of flooding of 0.63. The uncertainty of this estimate is also considered to be rather high due to the somewhat incomplete information contained in the database.

The two estimates of the probability of flooding conditioned on collision must both be considered as uncertain. However, it might be appropriate to assume the actual value lies somewhere between these values. As an approximate value, it is thus assumed that the probability of flooding given collision is the mean value of these two estimates, i.e.

$$P_{Flooding \mid Collision} \approx 0.5 \quad (2)$$

4.2 *Survivability*

The survivability of passenger ships conditioned on flooding of one or more compartments is obtained from studying the attained subdivision index ***A***. This index has been calculated by the HARDER project for a number of different ship types, including ro-ro passenger ships and cruise liners and made public in HARDER (2003). The resulting attained subdivision indices are given as a function of the total ship length in Fig. 2 and Fig. 3 for ro-ro passenger ships and cruise liners respectively. In the figures, the circles represent the values of A as calculated by the HARDER project. The triangles in the figures are based on a different method of calculating it and will hence be ignored in this study.

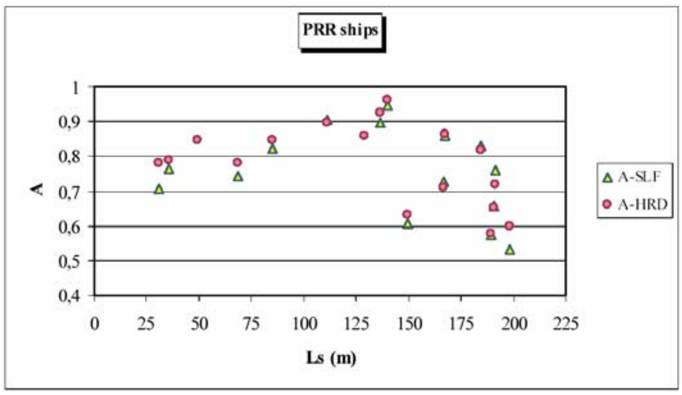

Fig. 2. Attained subdivision index ***A*** for passenger ro-ro ships as a function of the total ship length, as calculated by the HARDER project

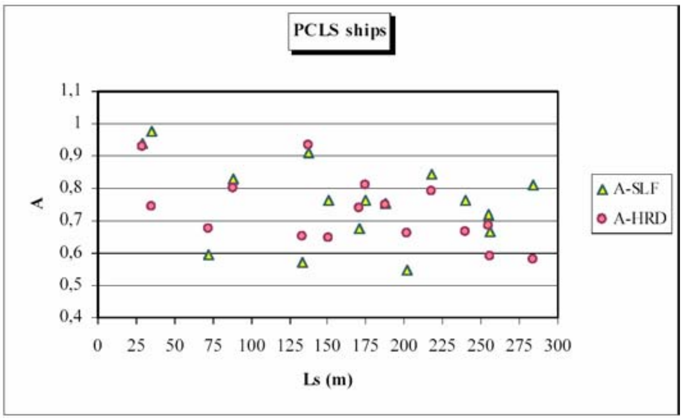

Fig. 3. Attained subdivision index ***A*** for passenger cruise liner ships as a function of the total ship length, as calculated by the HARDER project

The attained subdivision index corresponds to the probability of surviving given flooding, and thus:

$$P_{\text{Sinking | Flooding | Collision}} = 1 - \boldsymbol{A} \quad (3)$$

According to the graphs, large ships have the lowest survivability for both ship types, and cruise liners generally have lower survivability than ro-ro passenger ships. By averaging over all ships one finds the following approximate survivabilities for roPax and cruise liners receptively, $\boldsymbol{A}_{\text{PRR}} \approx 0.78$ and $\boldsymbol{A}_{\text{PCLS}} \approx 0.73$. As an average value for both ship types, $\boldsymbol{A}_{\text{average}} \approx 0.76$ can thus be used. I.e.:

$$P_{\text{Sinking | Flooding | Collision}} \approx 0.24 \quad (4)$$

$$P_{\text{Sinking due to collision}} \approx 6.19 \times 10^{-4} \quad (5)$$

These values, i.e. Eqs. (1), (2) and (4), are used to produce the numbers in the collision model illustrated in Fig. 1.

4.3 Expected consequences and time to sink

If a passenger ship sinks subsequent to a collision, the time to sink will be of crucial importance to the consequences, and it will determine whether or not the people on board will have time to abandon the ship before it sinks. How many people are able to successfully escape will be a function of the time to sink. Due to insufficient amount of historical data, estimates of time to sink were obtained using the Delphi method [Lindstone and Turoff (1975)]. A questionnaire was filled out in two iterations with a short discussion to clarify unclear issues in between.

A panel of experts provided estimates on expected time to sink based on expert judgement, given the condition that a collision has happed involving a large passenger ship and that the ship will sink within 24 hours. In addition, estimates on how many percent of the people on board would successfully be able to evacuate in time, i.e. by the time the ship sinks, capsizes or for other reasons makes the continuation of the evacuation impossible, were given. The average values of the estimates from the experts are given in Table 1. The estimates correspond to the time available for evacuation of a passenger ship in case it sinks following a collision.

The expert judgements on the expected consequences, together with the estimates of probabilities of collision, flooding and sinking presented above are used to produce the risk associated with collision for ro-ro passenger ships and cruise liners. This risk is presented in Table 2.

Table 1. Average of the experts' estimates of time to sink and survivors for collisions that result in sinking.

	Average estimate	
	P (sink)	% survive
5 min	0.23	4
10 min	0.47	12
15 min	0.63	20
30 min	0.80	37
60 min	0.88	60
90 min	0.94	80
24 h	1.00	93

Table 2. Risk of collisions for passenger ships

Consequence	**Probability (per ship year)**
> 5 % fatalities	6.19×10^{-4}
> 20 % fatalities	5.82×10^{-4}
> 40 % fatalities	5.45×10^{-4}
> 65 % fatalities	4.95×10^{-4}
> 80 % fatalities	3.90×10^{-4}
> 90 % fatalities	2.90×10^{-4}
> 95 % fatalities	1.42×10^{-4}

5. GROUNDING OF PASSENGER SHIPS

Another type of accident that may cause flooding of a ship and thus threaten the ships stability is grounding. Grounding is thus a relevant scenario that might involve evacuation and abandonment of the ship, and the subsequent development of the scenario will determine the outcome, e.g. how much time will be available for evacuation.

A grounding accident can cause flooding of the ship, and if the damage received by the ship is extensive, there is a possibility that the ship will sink. In order to describe grounding of passenger ships, the following model has been developed: 1) grounding, 2a) the damage received is too small for the ship to loose its stability 2b) the damage is sufficient to cause the ship to sink, 3a) the ship stays aground after the grounding, 3b) the ship is coming loose after the grounding, 4a) The ship is beached deliberately to prevent it from sinking, 4b) the ship is not beached and will thus sink. For ships that sinks due to grounding it is furthermore distinguished between two different ways of sinking, i.e. sinking in an upright position and capsizing before sinking. This model is illustrated in Fig. 4.

5.1 Probability of grounding

The probability of grounding for passenger ships above 4000 GRT was obtained from the LMIS database and presented in Olufsen et al. (2003). The frequency per ship years were found to be:

$$P_{\text{Grounding}} \approx 1.03 \times 10^{-2} \quad (6)$$

However, not all grounding accidents result in extensive damages that will cause sinking and the probability of receiving a damage that is sufficiently serious must be further investigated. This will be done in the following, utilizing the damage penetration statistics collected by the HARDER project.

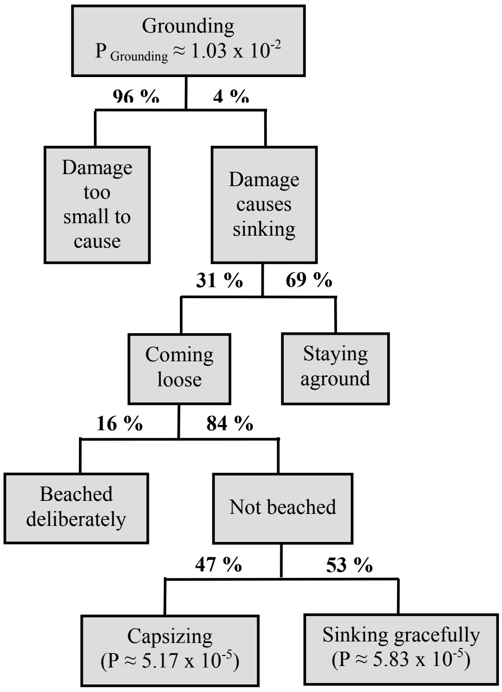

Fig. 4. Model for grounding of passenger ships

5.2 Grounding damages

A double bottom height of 2 meters is assumed for passenger ships in this general study. According to damage statistics in Mains (2001), 88% of all damages due to grounding are penetrating less than two meters from the bottom shelf[3]. This corresponds to a possibility of the damage to extend through the double bottom of 0.12.

Passenger ships comply with a two-compartment standard, and if a penetration should cause the ship to sink, it must therefore extend over more than two compartments. Assuming an average compartment length of 10 meters, a damage length of approximately 20 meters may be assumed to extend over three compartments. Damages beyond this length are henceforth assumed sufficient to cause the ship to sink.

Fig. 5 illustrates the distribution of non-dimensional damage length due to groundings from Mains (2001) (also published in Laubenstein et al. (2001) and Rusås (2003)) and it can be used to find the probability of damages extending more than 20 meters. However, it should be kept in mind that in these data, most of the damages (88%) only penetrate the bottom. If the damage were to penetrate also the double bottom, the same energy would be absorbed by half the length. A grounding energy causing damages that penetrates double bottom and extend beyond 20 meters thus corresponds to the energy causing a single bottom damage of 40 meters.

For passenger ships subject to this study, i.e. passenger ships above 4000 GRT, the length are assumed to vary from about 100 meters to more than 300 meters. For the purpose of this study, three different ship lengths are thus considered: small ships of 100 meters, medium size ships of 200 meters and large ships of 300 meters. Assuming these ship lengths, a damage of 40 meters corresponds to the non-dimensional damage lengths of 0.4, 0.2 and 0.13 for small, medium sized and large ships respectively. The probabilities of such damages can be read from the graph in Fig. 5, where the cumulative frequency of non-dimensional damage length of l/L_{pp} or less is indicated. The results are presented in Table 3.

[3] These results are derived for all ship types, but one can assume that they will be applicable in this study of passenger ships as well.

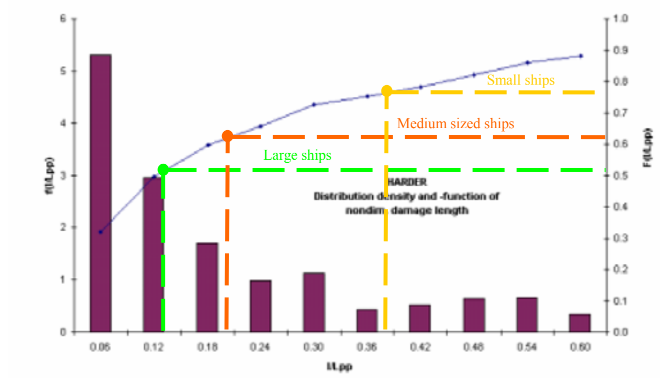

Fig. 5. Grounding damages distribution function from the HARDER project

Table 3. Probabilities of critical damage lengths for passenger ships

Ship size	Small	Medium	Large
Ship length (L_{pp})	100	200	300
$l_{critical}/L_{pp}$ ($l_{critical}$ = 40)	0.4	0.2	0.13
P ($l_{damage} > l_{critical}$)	0.23	0.38	0.49

The probability of receiving a critical damage length from grounding varies considerably for ships with different length, but one can assume the mean as an appropriate average value applicable for all ships, i.e. P ($D_L > l_{critical}$) ≈ 0.37. The probability of receiving sufficiently serious damage to cause sinking is thus (0.12 x 0.37):

$$P_{\text{Sufficient damage to cause sinking | Grounding}} \approx 0.044 \quad (7)$$

and thus (per ship year)

$$P_{\text{Sufficient damage to cause sinking due to grounding}} \approx 4.53 \times 10^{-4} \quad (8)$$

5.3 Grounding caused sinking

Not all ships experiencing damages that are sufficient to sink it actually sinks. One reason for this can be that the ship stays aground after the grounding incident. Even if the ship is not staying aground after grounding, there is a possibility to beach it deliberately in order to keep it from sinking. According to our simplified model, only ships that comes loose and that are not successfully beached subsequent to the grounding will actually sink. The probability of this will be estimated from investigation of historical accident data. Included in the survey are 61 records of ro-ro passenger ships above 5000 GRT and cruise liners above 4000 GRT between 1990 and 2002. Furthermore, it is assumed that the probability of staying aground or successfully beaching the vessel is independent of the type of ship and the damage of the ship. The following probabilities were found from the survey:

$$P_{\text{Coming loose | Grounding}} \approx 0.31 \quad (9)$$

$$P_{\text{Not beached | Coming loose | Grounding}} \approx 0.84 \quad (10)$$

and thus (per ship year)

$$P_{\text{Sinking due to grounding}} \approx 1.2 \times 10^{-4} \quad (11)$$

This estimate includes both ships that sink gracefully and ships that capsize. However, the way the ship sinks will have a big impact on the time available for evacuation, and thus on the outcome of the accident.

5.4 Expected consequences and time to sink

The expected time to sink subsequent to grounding is estimated using the Delphi method for both sinking scenarios, i.e. sinking gracefully or capsizing. If the ship sinks, the time to sink will determine the expected number of fatalities, and this is also estimated by the experts in the session. Similarly to the Delphi session for collision, a panel of experts filled out a questionnaire in two iterations based on their qualified judgement. Conditions given were that a grounding had occurred with a large cruise ship, that the ship had come loose, had not been beached and that it would sink. The average of the experts estimates are given in Table 4.

Table 4. Average of the experts' estimates on grounding consequences

	Average estimate	
P_c (Capsize)	**0.47**	
If capsizing:	P (sink)	% survive
Capsizing within 5 min	0.13	11.67
Capsizing within 10 min	0.27	18.33
Capsizing within 15 min	0.50	26.67
Capsizing within 30 min	0.70	36.67
Capsizing within 60 min	0.88	53.33
Capsizing within 90 min	0.95	85.00
Capsizing within 24 h	1.00	94.67
P_s = (1- P_c)	**0.53**	
If sinking upright:	P (sink)	% survive
Gracefully sinking within 5 min	0.02	15.00
Gracefully sinking within 10 min	0.10	21.67
Gracefully sinking within 15 min	0.25	38.33
Gracefully sinking within 30 min	0.47	56.67
Gracefully sinking within 60 min	0.63	76.67
Gracefully sinking within 90 min	0.93	95.00
Gracefully sinking within 24h	1.00	99.67

Based on the above discussion, the risks associated with grounding of passenger ships in Table 5 are estimated. The probabilities denote the probability of occurrence per ship year.

Table 5. Risk associated with grounding of passenger ships

Consequence	**Probability (capsizing)**	**Probability (graceful sinking)**	**Probability (Total)**
> 5 % fatalities	5.17×10^{-5}	5.42×10^{-5}	**1.06×10^{-4}**
> 20 % fatalities	4.91×10^{-5}	3.67×10^{-5}	**8.58×10^{-5}**
> 50 % fatalities	4.55×10^{-5}	2.74×10^{-5}	**7.29×10^{-5}**
> 65 % fatalities	3.62×10^{-5}	1.46×10^{-5}	**5.08×10^{-5}**
> 80 % fatalities	1.40×10^{-5}	5.83×10^{-6}	**1.98×10^{-5}**
> 90 % fatalities	6.72×10^{-6}	1.17×10^{-6}	**7.89×10^{-6}**

6. COMPARISON WITH OTHER RELEVANT ACCIDENT SCENARIOS

The current study has presented the risk associated with collision and grounding of passenger ships, in relation to emergency evacuations. When it comes to emergency evacuations from passenger ships, however, this has traditionally been considered in relation to ship fires. In a related study, the risk associated with emergency evacuations from passenger ships because of ship fires has been carried out (Vanem & Skjong (2004)), and the following will compare the risk levels of the different accident scenarios.

6.1 Accident frequencies

The frequency of fires is found to be significantly different for ro-ro passenger ships and cruise liners, and it is therefore deemed necessary to treat these ship types separately. The reason for this difference is not completely understood, but according to historical data, fires occur 6 – 7 times more frequently on board cruise liners. Possible explanations for this can be differences because of for example laundries and incinerators on board cruise liners. In Vanem & Skjong (2004), the probabilities of fire per ship year are found to be, for ro-ro passenger ships and cruise liners respectively:

$$P_{fire,\ roPax} \approx 1.9 \times 10^{-3} \qquad (12)$$

$$P_{fire,\ cruise} \approx 1.2 \times 10^{-2} \qquad (13)$$

It can thus be seen that the frequencies of fire on board passenger ships are comparable to the frequency of collision and grounding (Eqs. (1) and (6)). Other accident types occurring with comparable frequencies for passenger ships, according to Olufsen et al. (2003), are contact and hull/machinery, but these accident types are not considered relevant for evacuation scenarios and are not considered in the current study.

Foundering is another accident category with slightly lower frequency of occurrence according to Olufsen et al. (2003). In accidents categorized as foundered, evacuation might very well be important, but little information about these accidents is generally available. The foundering category will typically contain data on ships that have foundered for various different reasons, and it has not been deemed appropriate to consider these in the current study. These types of accidents are therefore not treated specifically in this paper, but it is assumed that a foundering scenario is somewhat similar to collision and grounding scenarios where the vessel is lost.

6.2 Risk associated with different accident types

Based on the risk associated with failure to evacuate in time in fire, collision and grounding scenarios achieved in Vanem & Skjong (2004) and in the present study, FN diagrams representing the risk can be produced for a sample ship. In Fig. 6 such a FN diagram for a sample ship with 3000 passengers is shown. It should be noted, however, that the FN curves do not represent the total risk of fire, collision and grounding. The risks that have been included are risks that are related to the evacuation performance, i.e. situations where evacuation were not successfully completed. This means that for example the risk of a few fatalities at the time and point of impact with another ship in a collision scenario are excluded. Likewise, the risk of fatalities in the initial outbreak of a fire, e.g. in an explosion, has been omitted for the fire scenarios. Neither is the risk of injuries nor the risk of loss and damage to property included. What is left is thus risk to life associated with poor evacuation performances. Nevertheless, the inclusion of such additional risks is not assumed to have affected the diagrams considerably, especially to the right end of the curves, corresponding to accidents with severe consequences.

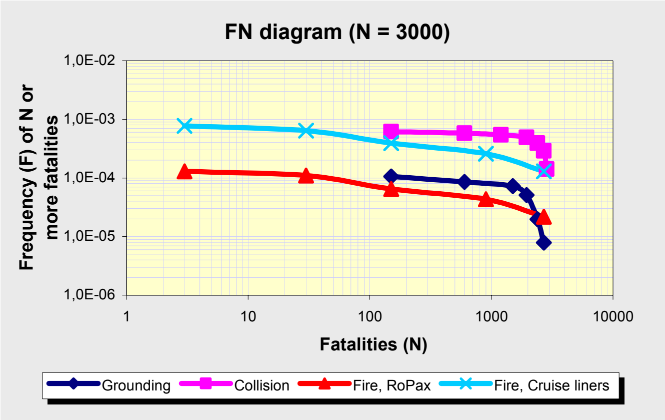

Fig. 6. FN diagram for ships with 3000 people on board.

From the FN-curves in Fig. 6 it can easily be seen that the risk associated with collision is considerable higher than the risk associated with grounding. This, in spite of the higher frequency of groundings, is a result of the generally faster time to sink in a collision scenario than in a grounding scenario. This leads to generally less time available for evacuation following a collision than a grounding accident. The risk associated with fires is significantly different for cruise liners and ro-ro passenger ships. For cruise liners, the risk associated with fires lies somewhere between the risk associated with collision and grounding, whereas for ro-ro passenger ships, the risk associated with fires is lower than both for collision and grounding.

6.3 Emergency evacuations due to different accident types

The probability of needing to perform an emergency evacuation at sea for the different types of accident scenarios can be summarized as presented in Table 6. However, the outcome of a situation requiring abandonment of the ship will also be greatly dependent of the time available for safe evacuation. Based on the current study, the expected available evacuation times for the different accident scenarios can be estimated.

Table 6 Probabilities of emergency evacuation

Type of scenario	**Probability of emergency evacuation (per ship year)**
Fire – ro-ro passenger ship	4.4×10^{-4}
Fire – cruise liner	2.6×10^{-3}
Grounding	1.1×10^{-4}
Collision	6.2×10^{-4}

6.4 Available evacuation times and IMO requirements

Fig. 7 illustrates the expected available evacuation times for different accident scenarios and compares it with the current IMO requirements of 60 minutes[4]. It can be seen that the time used for evacuation in case of collision or grounding is much more critical than during a fire, as less time is expected to be available. Furthermore, it can be seen that only about 10% of the emergency evacuations because of collision and grounding - capsizing will have as much time available as suggested by IMO. For collision and grounding scenarios, the graph indicates that an evacuation should be completed as quickly as within 10 – 15 minutes if significantly better results are to be achieved.

[4] Actually, the regulations allow for 80 minutes evacuation times for passenger ships other than ro-ro passenger ships if the ship has more than three main vertical fire zones.

Considering only fire scenarios on the other hand, 60 minutes seem to be a more reasonable time limit. In about 50% of the fires that require evacuation on board ro-ro passenger ships, there are expected to be 60 minutes or more available for evacuation. For cruise liners, this number is as high as 80%. The results from the current study thus suggests that collision and grounding scenarios implies much stricter demands on the evacuation performance, i.e. on the total evacuation time, and that it might be more appropriate to dimension the criteria on evacuation analyses based on such scenarios.

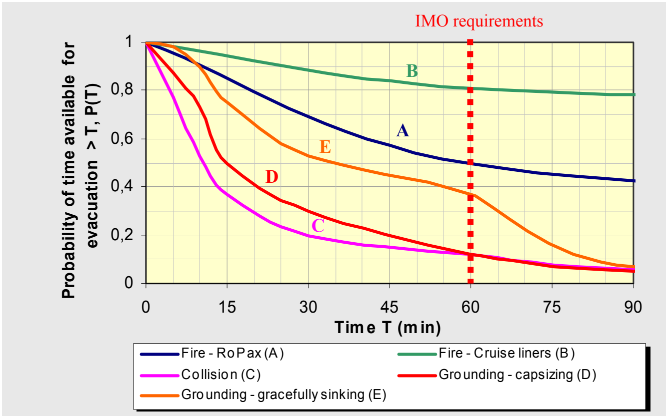

Fig. 7. Expected available evacuation times for different accident scenarios and IMO requirements

7. RISK CONTROL OPTIONS

Controlling the risk associated with evacuation from passenger ships due to any kind of accidents is mainly related to controlling and minimizing the evacuation time. According to MSC/Circ. 1033 (2002), the total evacuation time for each passenger can be split up into the time it takes to become aware of the need to evacuate, the egress time and the embarkation and launching time associated with the life saving appliances being use to evacuate the ship. This is illustrated in Fig. 8. The total evacuation times can thus be reduced by reducing any of these times. The response time will mainly be influenced by the signalling and alarm systems, the embarkation and launching time will be influenced by the LSA arrangements and the egress time will be influenced by several factors, of which the escape route layout and interior design of the ship and the evacuation procedures are important.

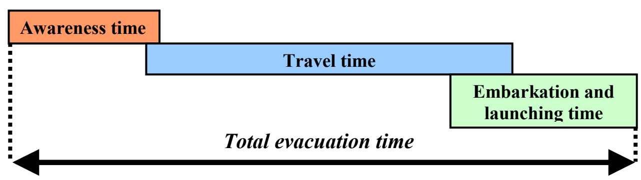

Fig. 8. Components of the total evacuation time

7.1 High level probabilistic risk control options

The current criteria regarding maximum permitted evacuation time is 60 minutes (or 80 minutes in some cases, see footnote 4). This is the upper limit of the calculated total evacuation time resulting from an evacuation analysis. One high level risk control option is thus to reduce this upper limit. By reducing the maximum allowed evacuation time to e.g. 40, 30, 20 or 15 minutes respectively, lives could be saved. Ship designers would have to demonstrate that such swift evacuation is possible before new ship designs would be approved. In order to establish an exact value for the optimum upper limit however, there would be need for extensive cost effectiveness calculations beyond the scope of this study. Nevertheless, it should be noted that posing stricter time constraints on the total calculated evacuation time in an evacuation analysis would be an important risk control option completely in line with the current trend of developing probabilistic criteria in maritime safety regulations.

An alternative probabilistic criterion can be derived from considering the risk level associated with situations involving evacuation from passenger ships as a whole. The risk associated with evacuation from passenger ships is the sum of the risk associated with all relevant scenarios, e.g. scenarios involving fire, collision, grounding etc. that leads to an evacuation. If a complete set of N scenarios exist that describe all possible evacuation scenarios, the total risk associated with evacuations can be expressed as follows:

$$RISK_{Evacuation} = RISK_{Sc\,1} + RISK_{Sc\,2} + \ldots \ldots + RISK_{Sc\,N} \qquad (14)$$

In Eq. (14), the risk of each scenario will be the product of the probability of that scenario and the corresponding expected consequence in terms of lives lost. An alternative risk control option to the upper limit criterion on the calculated total evacuation time can hence be to establish an upper limit of the total calculated risk according to an established set of well defined evacuation scenarios and the approach illustrated by Eq. (14). In order to establish an appropriate level of acceptable risk for this criterion, more extensive calculations and cost effectiveness considerations beyond the scope of the present study needs to be carried out.

Regardless of what risk control option is implemented, an effect of stricter probabilistic criteria regarding evacuation will be that the evacuation performance needs to be enhanced. This implies a reduction in either or all of the awareness time, travel time or embarkation and launching time. How this enhancement is to be achieved, however, will be left to the ship designers encouraging innovative design on new passenger ships.

7.2 Low level prescriptive risk control options

An alternative to such high level risk control options proposed in the previous section would be to develop more detailed prescriptive risk control options at a lower level. A number of risk control options could be implemented to reduce the awareness time, e.g. by improving alarm systems and accident detection. The embarkation and launching time will be greatly dependent on what kind of life saving equipment are used and what arrangements are use to install and operate these. More effective arrangements might reduce the embarkation and launching time and optimisations of life saving appliances can be a possible risk control option.

The travel time or egress time will normally be the longest of the three constituent times of the total evacuation time and thus the one with the most potential for time reduction. Such time reduction can be achieved by e.g. optimising the interior design of the ship, including layout of escape routes or by improving the actual evacuation handling procedures. It is considered out of scope to propose such detailed risk control options, but it should be noted that the effect of such modifications can be analysed with the aid of advanced evacuation simulation software. The results of iterative simulations can determine the optimal interior design and evacuation procedures for a given ship.

8. CONCLUSION

Collision and grounding represents a serious threat to maritime safety and for passenger ships carrying a large number of people on board, collision and grounding incidents have the potential to become particularly disastrous. This paper has analysed the risks associated with collision and grounding of passenger ships and the importance of swift evacuation in such accidents has been discussed. In order to study collision and grounding scenarios, generic models have been developed, and probabilities and consequences of the different components have been estimated based on a combination of different approaches. The risk associated with emergency evacuations due to collision and grounding accidents has been established and subsequently compared to that of fire accidents. Even though evacuation from passenger ships has traditionally been considered in connection with fires, it is suggested that collision and grounding are even more relevant when it comes to emergency evacuations as these scenarios impose stricter requirements on the evacuation performance. Finally, some risk control options are proposed that might reduce the risk of collision and grounding of passenger ships by enhancing the evacuation performance.

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