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Passenger Ferry Accidents in Bangladesh: Design and Socio-economic Aspects

Kho Shahriar Iqbal[1)], Kazuhiko Hasegawa[1)], Gabriele Bulian[1,2)], Md. Mashud Karim[3)], Zobair Ibn Awal[4)]

[1)]Department of Naval Architecture and Ocean Engineering,
Graduate School of Engineering, Osaka University, Osaka, Japan
[2)] Presently: Department of Naval Architecture, Ocean and Environmental Engineering (DINMA)
University of Trieste, Trieste, Italy
[3)] Department of Naval Architecture & Marine Engineering,
Bangladesh University of Engineering & Technology, Dhaka, Bangladesh
[4)]Accident Research Center,
Bangladesh University of Engineering & Technology, Dhaka, Bangladesh

Abstract

The safety of inland passenger vessels operating in Bangladesh has been investigated. By thorough analysis of the past accidents' data, the main cause behind structural failure has been found as collision. The main causes behind intact stability failures have been determined as adverse weather conditions and overloading, with consequent likely crowding to one side. Historical series of wind data were gathered, and their analysis suggests that an increase of the wind speed presently used in the Weather Criterion in force in Bangladesh could be advisable. A small passenger ship, of the type typically operated in Bangladesh, has been analyzed. A strongly jeopardizing effect of the overloading on intact ship condition has been detected when analyzing the hazard of crowding of passengers to one side.

In order to improve the ship safety, a proposal of modification of the original hull is considered where the ship is equipped with additional buoyancy above the waterplane to increase the restoring lever at large heeling angles. The proposed modification has been shown to be effective if no overloading is present. Ballasting the ship has also been briefly discussed showing that its effectiveness could be largely reduced due to the risk of progressive flooding.

Keywords

Inland transportation; Bangladesh water transport; Hazard identification; Weather criterion; Intact stability assessment; Ship safety; Passenger vessels.

Introduction

River transport plays a very significant role in the transportation of goods and passengers in Bangladesh. In terms of traffic intensity, the inland waterway network generates about 1.57 million passenger-kilometers per route-kilometer of waterway (Government of the People's Republic of Bangladesh, 2004). The density of the inland ports and terminals is much higher on the inland waterways with approximately 3.7 berthing facilities per 100 route-kilometers. But accidents, especially those involving passenger transports, have brought disrepute to this sector. A large number of people are killed every year in these accidents. Investigations showed that more than eight thousand people have died in the past two decades due to these accidents.

This paper is aimed towards analyzing the hazards involved in these inland water passenger transport accidents in Bangladesh, and then to propose possible remedies to such hazards with particular attention to the specific sample case of a ship very similar to one that has actually capsized in the past. Analysis of accidents' data of the last twenty-five years, collected from various sources, was carried out to find the main causes behind such accidents. To have a better understanding of the typical weather conditions in Bangladesh, a sample of wind data recorded in the last twenty years was collected and analyzed. A design of a small passenger ferry, similar to the most common types of vessels that are currently operated in Bangladesh, was considered as a sample for the hazard identification and mitigation procedure.

The analysis showed that collision was behind a significant number of structural failure occurred and the combined effect of crowding associated with overloading and storms were the severe causes behind a large number of intact stability failure cases occurred. For the analyzed ship, the addition of totally enclosed inflatable lifting bags under the rigid fender of the vessel has been shown to be a possible means to improve the design providing additional reserve of buoyancy above the waterline by increasing the ship restoring at large heeling angles.

Accident Data Analysis

Reliable data on water transport accidents occurred in Bangladesh in the past are not easily available. No relevant organization, indeed, maintains a database of all these accidents. So the data used in this analysis were collected from various resources like newspapers, journals, and personal communications to the relevant offices like Bangladesh Inland Water Transport Authority and Department of Shipping, Bangladesh. In such a way, information on accidents occurred in the twenty-five year period, 1981-2005, were collected. The collected data has therefore been analyzed in this study.

Data for a total of 359 passenger water transport accidents were collected in the period 1981-2005, in which passenger ferries (locally called as "launch") were involved in 219 occurrences, where small-sized country boats' and trawlers' involvement was found in 159 cases. The numbers add up to 378 (and not 359) because in some collision cases both launch and boats/trawlers were involved. Figure 1 shows the year-wise distribution of the number of accidents.

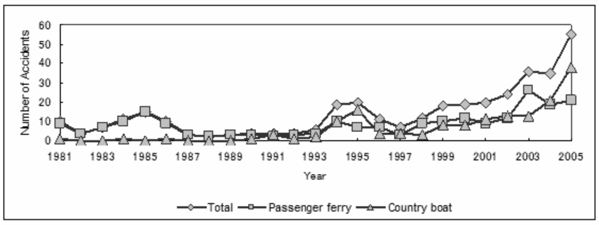

Figure 1: Number of accidents during 1981 to 2005.

Table 1 and Table 2 show the percentages of passenger ferry accidents related to structural failure and intact stability failure respectively. Collisions were found responsible behind 85% of the structural failures. About 48.4% of the total ferry accidents were due to intact stability failure, of which 35.9% cases were overloaded and loading condition in other 64% cases were not reported. In 4.1% of passenger ferry accidents, the loading conditions, weather conditions and the mode of failure were not reported. Since, according to most relevant news reports, overloading is very common in Bangladesh, it would be logical to believe that most of the cases where loading condition was not known were actually overloaded. Stormy weather conditions were reported for 65% of intact ship accidents. The weather conditions were not reported for 24.5% of cases involving an intact ship failure. These facts indicate that adverse weather condition and overloading were the main causes behind the accidents involving intact stability failure of passenger ferries.

Table 1: Conditions of structural failure occurred in passenger ferry accidents.

Structural Failure (47.5%)						
Overloaded		Not Overloaded	Loading condition not reported			
Fair weather	Foggy	Fair weather	Fair weather	Stormy	Foggy	Weather not rep.
0.9%	0.5%	1.8%	20.1%	0.00%	1.4%	22.8%

Table 2: Conditions of intact stability failure occurred in passenger ferry accidents.

Intact stability failure (48.4%)						
Overloaded				Loading condition not reported		
Fair weather	Stormy	Foggy	Weather not rep.	Fair weather	Stormy	Weather not rep.
1.8%	4.1%	0.5%	11.0%	2.7%	27.4%	0.9%

In the reported period, a total of 7811 death and 1244 missing were recorded in all reported passenger water transport accidents, where the total number of injured persons was 1923. The number of deaths, missing, and injured persons associated with passenger ferry accidents were 6237, 894 and 1209 respectively. Reasons are there to believe that these figures are under reported. Since there was no regular practice of collecting and keeping the records of accidents, many occurrences went unnoticed. In reality the number of injured persons is more than that of the deaths. Usually the injured people, mostly due to unawareness, do not report their injury to the relevant authority.

Socio-economical Aspects Related to the Accidents

There are some remote places in Bangladesh for which water transportation is the only possible commuting means. Moreover, passenger ferries in Bangladesh are the transport means with the cheapest fares. So, low income people and people living in far remote areas mostly use this mode of transportation for traveling in the country. The demand for these transports in long route is very high in the night time, because low salary passengers, traveling for business, prefer to save the money that would be required for spending one night in the expensive hotels located in the big cities.

Though still safer than the road transport, a significant number of lives are lost every year in ferry accidents. Even though many of the causes behind the accidents are known, it is very difficult to reduce the risk people are exposed to because of the passengers' unawareness and poverty, the inadequate number of transportation means compared to what would be actually required, the tendency of the owners towards a higher profit, etc. Some of the most common causes of accidents and their socio-economic involvement are discussed below.

Collision

Many vessels are operated by unskilled crews. There are about two thousand and five hundred registered passenger ferries operated in Bangladesh. The number of unregistered vessels is believed to be similar. But a sufficient number of certified crews is not available to operate such huge number of vessels. The owners often recruit unskilled crews to keep their vessels operating. Moreover, it is very common to see sort of speed competitions (intended to attract people by showing the performance of the vessels) among ferries sailing the middle channel. Many of the ferries are not equipped with navigational lights and signals specially required for safe operation in the night. The river banks and channels are also often out of markings and signals. All of these factors, combined or separately, are behind the collisions and grounding leading to structural failures.

Overloading

Overloading of ferries is a very common phenomenon in Bangladesh. Though it is known that the accidents due to overloading often cost the life of the passengers, many of the passengers do not have any other choice, as the number of ferries in the different routes is not sufficient to deal with the large demand. The owners also take illegal advantages of additional income through overloading.

Adverse Weather Conditions

Bangladesh is a highly tornado prone area. The coastal areas are often hit by cyclones formed in the Bay of Bengal. The inland areas also face locally formed tornadoes, which are difficult to forecast sufficiently in advance to provide any warning to the crews. These stormy weather conditions often cause capsizing of the ferries and consequent loss of lives, and should then be properly taken into account by the relevant national rules. Rules originally developed on the basis of geographical areas not characterized by such harsh and strongly localized phenomena cannot be considered suitable.

Analysis of Historical Series of Wind Data

To obtain reliable information on the wind conditions for the Bangladesh geographical area, a series of data concerning the monthly maximum wind speed for last 20 years has been collected and analyzed by Iqbal et al. (2006). Assuming 10^{-3} as an acceptable level for the probability of exceedance of the monthly maximum wind speed for intact stability assessment, we can estimate from the analysis a corresponding maximum wind speed of approximately 65 knots (33m/s). The corresponding approximated annual probability of exceedance, assuming independence among different months, is about 0.01 (i.e. $1-(1-10^{-3})^{12}$).

The obtained speed of 33m/s represents, however, the speed of the gust, and the corresponding average wind speed is, unfortunately, unknown from the available data. If we pragmatically decide to use the Weather Criterion assumption (IMO, 2002; IMO 2005) concerning the ratio between heeling levers due to gustiness and constant wind, to determine the average wind speed we obtain that the gustiness factor to be accounted for in the wind speed should be $\sqrt{1.5}$. From this assumption, an average wind speed to be used for intact stability assessment could be proposed as 27m/s (corresponding to about 52 knots). It is interesting that, incidentally, the obtained average wind speed is very close to the value of wind speed of 26m/s already implicitly considered by the IMO Weather Criterion (IMO, 2002), as explained in recent IMO documents (IMO, 2005; IMO 2006a). For this latter reason, with the aim of a harmonization with available rules, a value of 26m/s as average wind speed seems to be appropriate.

The Weather Criterion presently in force in Bangladesh (Zulfikar, 2005) is based on a reference pressure of 0.0322ton/m^2, that correspond to 316N/m^2. This latter pressure is identical to the minimum pressure reported by the IMO Intact Stability code (IMO, 2002) for fishing vessels (it is considered for ships having a distance between the center of the lateral projected area and the point at half draught less or equal than 1m). The corresponding wind speed can be calculated as 20.6m/s (the pressure in the Weather Criterion implicitly contains, indeed, a moment coefficient of 1.22 (IMO, 2005)). The reduction considered by the IMO Intact Stability Code (IMO, 2002) in the reference pressure for ships with not too high superstructures is likely to be related to the boundary layer effects, that reduces the wind speed close to the ground. On the other hand, typical ships sailing in Bangladesh and carrying passengers have higher distances between the center of the lateral projected area and half draft, and it is in addition not wise to relax on the reference pressure due to wind for ships carrying a large number of passengers as in the case of passenger ferries in Bangladesh. The difference between the heeling lever determined with the proposed average reference speed of 26m/s and that obtained by using the present rules in force in Bangladesh in the weather criterion is a factor of 1.6, i.e. quite significant.

On the basis of the analysis carried out, and bearing in mind the necessity of reducing the risk involved in the passengers' transportation, it seems to be appropriate to harmonize the reference average wind speed in the present Bangladesh stability rules to 26m/s in all the criteria, this leading to a reference pressure of 504N/m^2=0.0514ton/m^2 in the Weather Criterion for inland vessels.

Sample Inland Passenger Ship

Bearing in mind the outcomes of the accidents' data analysis, we have selected a sample ship to try to better understand which could be reasonable causes of capsize in intact condition. We started from the availability of a series of data for a passenger ship that actually capsized in Bangladesh. Because the available data were partial, and, in particular, the bodyplan was not available, we used the hull of a very similar ship, slightly scaled in order to fit the available hydrostatic data for the capsized ship. We have named the stretched ship "Small Launch" (we will indicate it as "SL" throughout this paper) and we have assumed the loading conditions of the capsized ship to be applicable to the ship SL.

Two loading conditions will be investigated:

- A "full load" condition;
- A condition with a 50% overloading;

Data for the two loading conditions and main particulars of the ship are reported in Table 3. In Table 3, two values are reported, for each loading condition, concerning the lateral projected area. The smaller value is the lateral projected area as reported for the basic ship, as found in the available documentation, and it corresponds to the actual lateral projected area considering the presence of the openings on the side. The larger value, delimited by parenthesis, is the estimated lateral projected area considering the presence of curtains (often put to protect passengers from rain and wind) closing the openings. In the following analyses, although otherwise specified, the loading conditions are such to give zero trim in upright position and all the calculations of the $\overline{GZ}$ curve are performed allowing the ship to freely trim when heeling. In the full load condition it is assumed 75kg/person in accordance with the IMO Intact stability Code (IMO, 2002).

Table 3: Reference loading conditions

			Full Load	50% Overloading
Length between perpendiculars	L_{BP}	[m]	28.2	
Breadth	B	[m]	6.15	
Depth	D	[m]	1.83	
Draught	T	[m]	0.900	0.971
Volume	∇	[m^3]	88.0	97.5
Vertical position of the metacenter	$\overline{KM}_T$	[m]	4.530	4.289
Transversal metacentric height	$\overline{GM}$	[m]	2.469	2.1
Mass of passengers and crews		[kg]	19050	28575
Lateral projected area exposed to wind	A_{lat}	[m^2]	71.6 (107.8)	69.6 (105.8)
Vertical distance between center A_{lat} and half draught	Z	[m]	2.711	2.740

The following analysis of hazards has the scope of identifying the possible presence of weak points in the design and/or operation of the sample ship. The following aspects will be addressed:

- Heeling moment due to passenger crowding to one side;
- Effect of engine room's hatch coamings and trim on the progressive flooding angle;
- Heeling moment due to wind;

Before proceeding, it is important to note that the draught for the "full load" condition does not correspond to the maximum allowed draught for the ship under analysis, that is about 1.2m, and that can be achieved only by means of a (quite unrealistic) ballast weight of about 35t. This discrepancy between the available data concerning the tested loading conditions and the actually operational draughts imposes to consider the outcomes based on the two tested draughts with care. A more thorough investigation should, therefore, be carried out with the availability of more precise data.

Analysis of Hazards

Heeling Moment Due to Passenger Crowding to One Side

The tested ship carries a payload that is a very considerable fraction of the total ship's displacement (especially when overloading is present), therefore a lateral crowding of passengers is a hazard that could seriously endanger the ship. Crowding to one side is a reasonable hazard in harsh weather (e.g. sudden storms that are quite typical in Bangladesh in some periods of the year). From an analysis of the number of passengers onboard, and assuming 4 persons per square meter during crowding, we have estimated a transversal position of the center of mass of the crowd equal to 70% of the half breadth.

The calculated heeling moment due to passengers crowding to one side is significant (see Figure 2). In particular the situation is critical in the overloaded condition, where the increased weight of the passengers onboard leads to an equilibrium angle of more than 18 degrees, and, more important, to a residual range of stability that is very small, with an also very small maximum residual $\overline{GZ}$. In the overloaded condition, the ship can be in extreme danger during crowding of passengers to one side if some additional heeling cause, like the expected presence of wind, is introduced. It is important to note that, due to the very large B/T ratio of the ship under analysis, the $\overline{GZ}$ curve shows, in both cases, a maximum at relatively small heeling angles despite the large metacentric height.

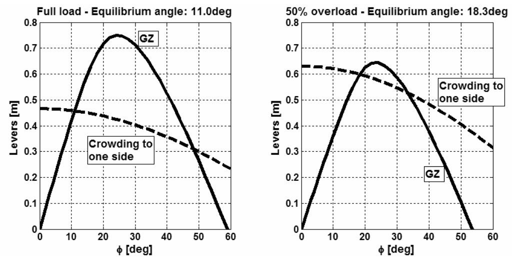

Figure 2: Heeling moment due to passenger crowding.

Possible Flooding of the Engine Room

In typical design of Bangladeshi small passenger ships, the engine room often shows a hatch at the main deck level, in the aft part of the ship, as depicted in Figure 3.

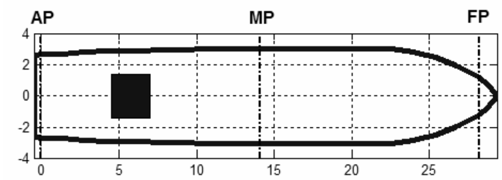

Figure 3: Position of the hatch of the engine room on the main deck.

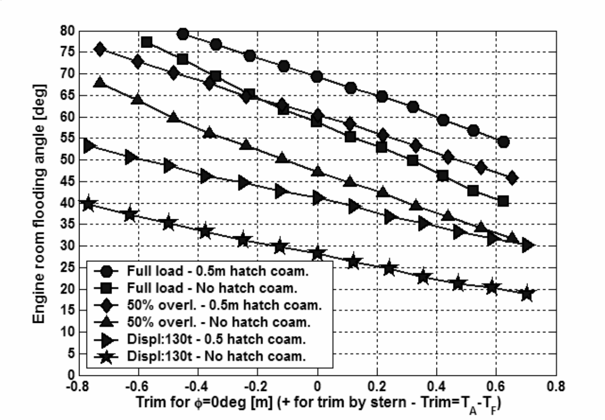

Figure 4: Angle of submergence of the hatch leading to flooding of engine room in case of absence of hatch cover.

Such hatch should be closed, however it has often found to be opened in operation, thus representing, in principle, a potential progressive flooding means. In some designs the hatch is provided with hatch coamings of having a significant height above the deck, whereas in other cases hatch coamings are, practically, not present. We have thus analyzed the angle at with the engine room starts flooding depending on whether a hatch cover is fitted or not. A representative height of 0.5m above the main deck has been considered for the hatch coaming and the effect of the initial trim has also been investigated. From the results shown in Figure 4 we can conclude that:

- Trim by stern should be carefully controlled;
- The fitting of sufficiently high hatch coamings as a significant positive effect;
- For the two basic loading conditions the downflooding angle is, in general, quite large. The same cannot be said for the ship sailing at the maximum draught.

As already reported, we have some concerns regarding the actual draught at which such ship could actually be operated, irrespective of the limits imposed by the rules. For this reason we have performed the additional calculation, shown in Figure 4, of the downflooding angle for the engine room, with and without hatch coamings, for a displacement of 130t (corresponding to the maximum allowed draught of 1.2m with zero trim) accounting for the effect of trim. Due to the reduced freeboard, now the angle of downflooding is significantly reduced, especially in the absence of hatch coamings and when there is a significant trim by stern. For the tested maximum displacement, the hazard related to the flooding of the engine room starts becoming significant.

Wind Effects

From the statistical analysis of wind speed data collected in Bangladesh, a reference mean wind speed of 26m/s has been proposed, also considering the present requirements of IMO Intact Stability rules (IMO, 2002). On the other hand, in the present stability rules in force in Bangladesh (Zulfikar, 2005) two values of wind speed are considered, depending on the particular requirement. Basically, in all the requirements, but the Weather Criterion, 10m/s are considered as the reference constant wind speed. In the Weather Criterion, a mean wind speed of 20.6m/s is (indirectly) considered. Here we want to assess the effect of constant beam wind considering the three mentioned reference wind speeds for the two reference loading conditions. In addition we want to assess the effect of the presence of curtains that potentially close the apertures on the superstructure. Although the wind heeling lever is depending on the heeling angle, we will, for practical purposes, simplify it as heeling independent.

The results of the analysis are reported in Figure 5: the effect of the wind is, despite the quite large exposed area, not very significant and the equilibrium angle in the worst considered case slightly exceeds 4deg. This is due to the large metacentric height in the considered loading conditions. The wind itself, for not too extreme speeds, seems thus not to be a very dangerous hazard able to capsize the ship without the concurring effect of other heeling causes. Nevertheless, it is important to pay attention to the large variation of the heeling moment due to wind depending on the assumptions used. Globally when we consider the best and the worst case, we find a ratio of about 10.2 between the corresponding heeling levers, thus, the corresponding heeling angles. In view of the analysis of the wind carried out in this research, and considering the quite common bad habit of fixing the curtains at the side openings, it would seem more reasonable to consider, in the stability assessment framework, the openings as obstructed and a wind speed of 26m/s.

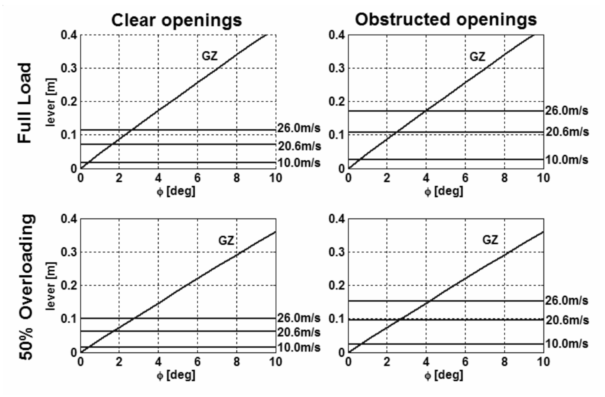

Figure 5: Analysis of the effect of beam steady wind.

A "Weather & Crowding" Criterion

From the analysis of hazards carried out, it seems that the large number of passengers onboard the considered ship renders the crowding to one side the most dangerous hazard. The effect of beam wind has been found to be a less demanding hazard in terms of steady equilibrium angle. However, the analysis of accidents has shown a significant number of capsizes in stormy condition with overloaded ships. It is thus important, at the design stage and during the approval process, to take into account the possibility of concurrence of the above effects.

The Weather Criterion presently in force in Bangladesh (Zulfikar, 2005) only considers the effect of beam wind. In the authors' opinion, a compliance with such a criterion does not necessarily lead to a sufficiently safe ship, due to the lack in acknowledging the possible detrimental effect of the crowding of passengers to one side. In addition, the pressure to be taken into account in the present criterion is about 1.6 times smaller than the pressure that should be accounted for if a mean wind speed of 26m/s would be considered. We would like to recall that very localized storms (tornadoes) are not uncommon in Bangladesh, and they can be associated to much higher wind speeds than 26m/s.

According to such reasoning, we would propose a criterion very similar to the present Weather Criterion concerning the application framework, but where the effect of mean wind and gust are combined with the effects of crowding of passengers to one side.

The idea is to substitute the mean heeling lever due to wind (usually called l_{w1}) with the sum of the heeling lever due to passenger crowding to one side and beam wind for the "steady state" analysis. The wind contribution to the total heeling lever under gust is considered as usual as $l_{w2} = 1.5 \cdot l_{w1}$, without modifying the contribution due to crowding. The requirement of dynamic survival (based on the relative magnitude of the so called "Area b" and "Area a") are considered to remain the same, i.e. "Area b">"Area a".

The last parameter to be accounted for is the rolling amplitude. The formula presently available in the IMO Weather Criterion (IMO, 2002) is likely unsuitable for the typical passenger ships presently operating in Bangladesh due to the historical background of such formula (see the recent IMO Document SLF48/4/5 (IMO, 2005)). The very large B/T values and the usually large value of the parameter $\left(\overline{KG}-T\right)/T$ put typical Bangladesh' passenger ships outside the range of parameters used in the original regressions (see MSC.1/Circ.1200 (IMO, 2006b)). In addition, and this is likely much more important, the "s" factor in the IMO Weather Criterion, that is basically a design wave steepness for a given rolling period, is based on the work of Sverdrup&Munk (1947). This latter work is based on observations of waves at sea, and thus the factor s represents, in some way, an open sea environment, therefore suitable for seagoing ship. The environmental conditions in inland rivers are completely different, and from some aspects, much more complicated. In river navigation, hazards like strong current, whirlpools, turbulent waters are present, that usually do not occurs at sea. The response of a ship to such excitations is, basically, unknown, and likely to be very difficult to predict. For these reasons, the application of the IMO formula for the rollback angle φ_1 when dealing with inland water transportation is likely inappropriate, and is lacking of physical bases. At the same time it is very difficult to provide a rational alternative, because of the difficulties in a sounding prediction of the rolling behavior in rivers. Therefore, in this paper, we assume that a constant, ship independent value for the angle of roll φ_1 could be an appropriate choice. The biggest problem is to rationally decide a suitable value, due to the almost complete lack of available data from ships in operation. What can be guessed is, however, that strong synchronous rolling for ships sailing in rivers is not a likely situation, due to the limited fetch leading to not very developed waves and due to the quite irregular flow. According to these, maybe questionable, ideas, it is the authors' opinion that the actual rolling motion to be accounted for should not be extremely large, and, therefore, a value of 10deg is used here that seems to be reasonable.

According to the discussions in previous sections, it was found that curtains are often present to protect people from wind and rain, significantly obstructing the available apertures on the ship side through which the wind could in principle flow. For this reason, in the criterion, openings on passenger decks should be considered closed or, at least, significantly obstructed. In the following calculation we will consider the openings as fully obstructed.

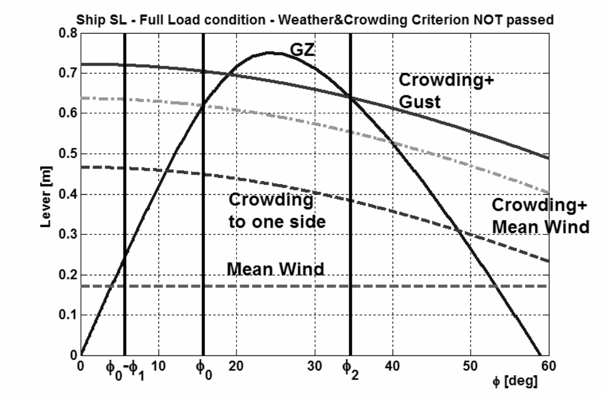

Figure 6: Application of Weather & Crowding Criterion in the full load condition.

Table 4: Application of Weather & Crowding Criterion in the full load condition: numerical data.

ϕ_{fl}	ϕ_{ds}	ϕ_0	ϕ_1	ϕ_2	Area "a"	Area "b"	Passed?
58.8	18.2	15.7	10.0	34.6	0.049	0.013	NO

ϕ_{fl} : flooding angle; ϕ_{ds} : deck submergence angle; ϕ_0 : equilibrium angle under the action of steady wind and crowding to one side; ϕ_1 : assumed rolling amplitude; ϕ_2 : minimum between 50deg, the angle of vanishing stability and the flooding angle;
Angles are measured in [deg] and areas in [m*rad].

For the crowding of passengers we have assumed, for this ship, a movement of 100% of the passengers onboard to a position equal to 70% of the half breadth of the ship. The application of the proposed criterion in the case of the "full load" condition is shown in Figure 6, with numerical data provided in Table 4: the ship cannot pass the criterion. In addition, due to the small angle of deck submergence (slightly above 18deg), the requirement of a steady equilibrium angle below 80% of the deck submergence angle or 16deg, whichever the less, cannot be fulfilled. In the overloaded condition, the situation is even worse, because the ship cannot even statically sustain the combined effect of crowding to one side and mean wind (as it is clear from the results given in Figure 2 and Figure 5). It can thus be said that, from the application of the proposed criterion, the analyzed design should be considered as not satisfactory and potentially dangerous.

Fitting Additional Buoyancy to Increase GZ

In order to improve the behavior of the sample ship in case of the hazards considered in the "Weather&Crowding" Criterion, we have investigated the possibility of modifying the ship design in order to improve the restoring capabilities of the vessel, bearing in mind the necessity of a relatively simple, and possibly cheap, modification.

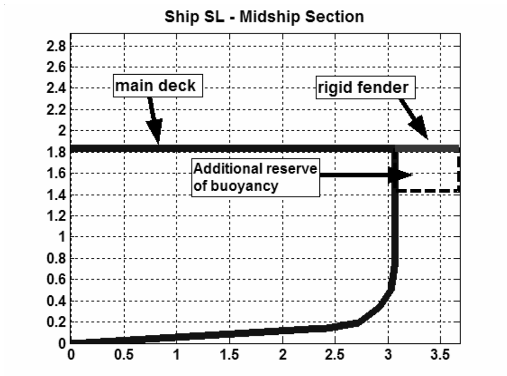

Figure 7: Rigid fender at the midship section.

The basic idea is to supplement the ship with an additional reserve of buoyancy above the waterline, in such a way to increase, especially, the maximum $\overline{GZ}$. Typical passenger ferries operating in Bangladesh are fitted with a rigid fender at height of the deck, extending transversally with a length depending on the particular ship. For the ship under analysis, the breadth of such fender is 0.6m, as shown for the midship section in Figure 7. Such rigid fender is used to protect the ship hull during berthing and during loading/unloading operation (and it is not uncommon, unfortunately, to see people standing on it).

The idea is thus to provide additional buoyancy to the ship by exploiting the clear area below the fender. The requirements for the ship modification are:

- The modification must be simple and not too expensive.
- The modification must not interfere with the normal ship operation.
- The additional buoyancy must be effective in increasing the maximum righting lever.
- The modification must not involve modification of the hull.
- The modification must not excessively reduce the payload.

We have thus considered the possibility of adding such buoyancy through totally enclosed inflatable lifting bags, to be fit in position under the rigid fender. Such buoyancy aids could be easily filled with air by means of an air pump connected to the main engine. In addition to providing additional buoyancy, they could be also considered effective as protections from collisions, thus increasing the inherent ship safety with respect to this latter hazard. Moreover, in case of breach of the hull, the presence of such bags, if not damaged, could provide a safe, though limited, additional reserve of buoyancy.

The selection of the dimensions of such buoyancy reserve is governed by the actual breadth of the fender and by the freeboard at the maximum allowed draught. The ship under analysis has a maximum allowed draught of 1.2m, with a depth of 1.83m. If we assume that 0.2m should be left clear between the waterplane and the bottom of the lifting bags, a maximum height of about 0.4m is obtained. It is to be said that such height could be increased by reducing the maximum allowed draught: the reduction in the maximum payload that the ship could carry would be compensated by the additional safety. The geometry and the position of the additional reserve of buoyancy are shown in Figure 7.

The longitudinal extension of the reserve of buoyancy has been assumed to cover 80% of the ship length, for a total of 22.6m. From a survey of commercially available lifting bags, we have estimated that, for the assumed dimensions, the weight of the bags for 1m of length is below 10kg comprising the necessary connections to the hull. This means that the total additional weight due to the modification is estimated to be below 0.5t. On the other hand, the total gained reserve of buoyancy is about 11t. Of course such estimations are, at this time, purely indicative.

Figure 8 reports the comparison of the $\overline{GZ}$ curves for the ship SL in the original and modified configuration, for the two tested loading conditions: the improvement in the $\overline{GZ}$ curve for the two tested loading conditions is evident. The maximum still occurs at quite low heeling angles; however the value of the maximum has been increased, on average, by about 22%.

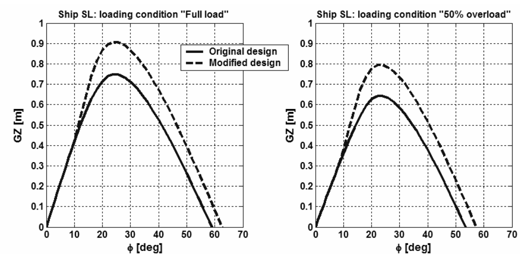

Figure 8: $\overline{GZ}$ curves for the ship SL in the two tested loading conditions for the original and the modified design.

In order to check the effectiveness of the proposed modification on a rational basis, we have again applied the proposed "Weather & Crowding" criterion to the modified ship at the full load condition. The results of the application are shown in Figure 9 and Table 5, where it can be seen that the modified ship is able to fulfill the requirements thanks to the additional restoring. For sake of comparison, in Figure 9, the $\overline{GZ}$ curve of the original design is also reported. Therefore, from the obtained result, it seems that the proposed modification is worthy attention, due to its potential of improving the safety of the considered ship with limited efforts.

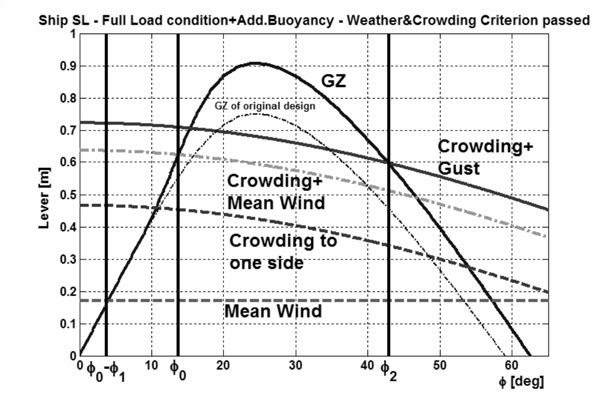

Figure 9: Application of Weather & Crowding Criterion to the modified SL at full load condition.

Table 5: Application of Weather & Crowding Criterion to the modified SL at full load condition: numerical data.

ϕ_{fl}	ϕ_{ds}	ϕ_0	ϕ_1	ϕ_2	Area "a"	Area "b"	Passed?
64.8	19.1	13.7	10.0	42.9	0.060	0.072	YES

It is however important to underline that the proposed modification, although providing an improvement with respect to the original design, is not able to solve the issue of concurrent crowding to one side and gust in the overloaded condition. In the overloaded condition, in fact, there is no intersection between the $\overline{GZ}$ curve and the lever of the moment due to crowding and gust, even after the fitting of the additional buoyancy reserve. A stable equilibrium angle of 18.7deg is found, on the other hand, if the gust effect is omitted: without the fitting of additional buoyancy, as already said, the ship would have statically capsized also in such situation.

Ballasting

As already mentioned at the beginning of the paper, about 35t seem to be missing to achieve the maximum allowed draught even assuming the maximum allowable payload (that comprises 7t of cargo). When the ship cannot achieve the design draught at full load, Bangladesh authorities usually recommended fixing solid ballast on the ship to compensate for the lack of weight. For the ship under analysis loaded at the maximum draught, a total ballast weight of 35t would be necessary assuming the mass of passengers unchanged and equal to that in the "full load" condition (i.e. without overloading).

At the maximum draught the flooding for the engine room is about 41deg with the presence of hatch coamings with 0.5m height, and about 28deg in absence of hatch coamings for a zero trim condition in calm water (see Figure 4). The deck submergence angle is significantly small, and equal to 11.8deg with zero trim. In the case of deck submergence, the change of trim has a limited effect.

The increase of displacement with respect to the two initially tested conditions leads to a significant reduction of the heeling levers of the moments due to wind and passenger crowding to one side, this having, in general, a significant positive effect. The $\overline{GZ}$ curve is, up to about 50deg, not extremely different from that in the "full load" condition. However, the increased draught leads to a loss of freeboard, with a consequent decrease of the deck submergence angle, this leading to more difficulties in fulfilling the Weather Criterion. It is important to note that, in absence of hatch coamings, the angle of flooding of the engine room is, as already said, quite small. This meaning that, in case of absence of hatch covers, the righting arm curve for heeling angles over 28deg should be considered as zero, or, at least calculated assuming the flooding of the engine room, and this would lead to a drastic decrease in the restoring capabilities of the ship. In addition, in the application of Weather Criterion, 28deg. should be considered as the maximum angle up to which the "Area b" should be calculated, this leading to a reduction of such area.

As a final comment it seems that the ballasting of the ship, although being a viable option for reducing the effect of wind and passenger crowding, is not free of drawbacks, basically because the increase of the displacement is paid by a significant decrease of the freeboard. In addition, the increase of displacement leads to an increase of the ship resistance, and, finally, of the fuel consumption. The fixing of fixed ballast seems, finally, to be a not very cost-effective measure to improve the ship safety.

Conclusions

The paper has investigated the issue of the safety of inland passenger vessels operating in Bangladesh from a rational point of view. Starting from an analysis of the accidents occurred in the period 1981-2005, the main cause behind structural failure has been found as collision. In case of intact stability failures (capsizing), the main causes have been determined as adverse weather conditions and overloading, with consequent likely crowding of passengers to one side. Bearing in mind the socio-economical environment of shipping transportation in Bangladesh, and because of the commonly occurring sudden change of weather in that region, with strong localized wind, it is difficult to provide, onboard the ships, effective means of advance warnings for bad weather. Therefore, the hazard of encountering an adverse weather cannot be efficiently mitigated. On the other hand much more can be done on the side of the overloading problem. Although this is only partially a design matter, because ships should simply not be operated in overloaded condition, it is a matter of fact that a not negligible number of ships in Bangladesh are overloaded during their operation, and this is causing a significant loss of lives. A sufficient safety factor related to this issue should therefore be implemented both from a design and a regulatory point of view.

The analysis of wind data suggests that an increase of the wind speed presently used in the Weather Criterion in force in Bangladesh could be advisable, and this would indirectly increase also the safety of the ships by increasing the required minimum metacentric height. In addition, a modification of the Weather Criterion by accounting for the concurrent effects of beam wind, rolling and crowding of people to one side could be an efficient and sufficiently easy criterion hopefully able to improve the safety of the future inland fleet by imposing additional reserve of stability with respect to the present criterion.

The ferry operation by unskilled crews and insufficient navigational equipments were found responsible for collision and grounding leading to structural failure. The strongly jeopardizing effect of the overloading has been detected when analyzing the hazard of crowding of people to one side. In addition, the risk of flooding of the engine room in case of absence of hatch covers has been assessed, showing the effectiveness of the hatch coamings in increasing the angle of progressive flooding. The detrimental effect of the presence of curtains on the openings of the superstructure has been assessed, due to the fact that passengers very often use to close the windows in order to shelter from wind and rain. The analysis has shown that it could be advisable, in a regulatory framework, to take into account the possible presence of the curtains by considering all the openings as closed.

The ship has been checked with respect to the hazard of concurrent beam wind, rolling and crowding of passengers to one side, showing that the limited reserve of stability in the assumed full load and in the overloaded conditions does not allow the ship to fulfill the assumed set of concurrent hazards. To improve the ship's safety, a possible modification of the design has been analyzed, where the original ship is equipped with an additional buoyancy reserve above the waterplane, so to increase the restoring lever at large heeling angles without influencing the resistance characteristics of the ship. The proposed modification has been shown to be effective in the full load condition (the ship can fulfill the proposed "Weather & Crowding" criterion), however in the overloaded condition the modification is not sufficient to allow the ship to withstand the effect of gusty wind combined with crowding to one side and rolling. Ballasting, as an alternative, has also been briefly discussed (being it a present recommendation/requirement in case the ship, at full load, could not reach the maximum draught) reporting that its effectiveness could be largely reduced due to the risk of flooding of the engine room in case of absence of the hatch covers.

The proposal put forward in this paper, i.e. providing the ship with an additional above-water reserve of buoyancy is worthy of additional investigations concerning its actual applicability, cost effectiveness and its impact on the safety of the small launches operating in Bangladesh.

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