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ORIGINAL ARTICLE

A rational analysis of intact stability hazards involving small inland passenger ferries in Bangladesh

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Abstract The safety of inland passenger vessels operating in Bangladesh has been investigated. By thorough analysis of past accident data, the main causes of intact stability failures have been determined: adverse weather conditions and overloading, likely resulting in crowding to one side. Historical series of wind data were gathered and their analysis suggests that an increase in the wind speed presently used in the Weather Criterion in force in Bangladesh could be advisable. A model of a small passenger ship typically operated in Bangladesh has been analyzed in order to identify the most relevant hazards under intact ship conditions. A strongly jeopardizing effect of overloading under intact ship conditions has been detected when analyzing the hazard from the crowding of people to one side.

Keywords Transport safety · Inland water transport · Passenger ferry · Intact stability · Hazard identification · Weather criterion

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1 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 [1]. The density of the inland ports and terminals is much higher on the inland waterways, with ~3.7 berthing facilities per 100 route-kilometers [1]. 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. Investigation have shown that more than 8,000 people have died in the past two decades due to these accidents.

This paper is aimed at analyzing the hazards involved in these inland water passenger transport accidents in Bangladesh. To find the causes of accidents there was no alternative but to analyze the data for past accidents. Therefore, the accident data from the last 25 years have been collected from various sources. The collected data were analyzed and the accidents were categorized according to their types, the types of vessels involved, the weather conditions at the time of accident, the loading conditions, and other human factors involved. To gain a better understanding of typical weather conditions in Bangladesh, a sample of the wind data recorded over the last 20 years was collected and analyzed.

The analysis of hazards shows that the combined effects of crowding associated with overloading and storms were the main causes of a large number of intact stability failure cases that have occurred, and should therefore be properly accounted for in the design and approval of ships similar to the one considered in this paper.

2 Accident data analysis

Reliable data on water transport accidents that occurred in Bangladesh in the past were not easy to obtain. No relevant organization maintains a database of all these accidents in Bangladesh. Therefore, the data used in this analysis were collected from various resources. The data were mainly gathered from the Accident Research Centre of Bangladesh University of Engineering and Technology, from different newspapers (The Daily Ittefaq, The Daily Prothom Alo, The Daily Jugantor, The Daily Star, The Daily Independent), journals (Journal of the National Oceanographic and Maritime Institute of Bangladesh) and personal communications with the relevant offices like Bangladesh Inland Water Transport Authority and the Department of Shipping, Bangladesh. Though the data were often associated with a lack of detailed information on the accidents, it is logical to believe that the information given in the news was based on the realistic causes and consequences of the accidents. The information on accidents covered a 25-year period, from 1981 to 2005. The collected data were therefore analyzed in this study.

A total of 359 passenger water transport accidents were reported in the period 1981–2005, in which passenger ferries (locally called "launches") were involved in 219 events, while small country boats and trawlers were involved in 159 cases. The numbers add up to 378 because in some collision cases both launch and boats/trawlers were involved. Figure 1 shows the year-wise distribution of the number of accidents. The lower number of accidents in the earlier years may be due to fewer vessels operating in the waterways and also due to the lack of information gathered on accidents during those years. A total of 7,811 deaths and 1,244 missing persons were recorded in these accidents, and the total number of injured persons was 1923. The proportions of the dead, missing and injured persons associated with passenger ferries were 80, 72 and 63%, respectively. The numbers of dead, missing and injured persons from passenger ferry accidents as a function of time are shown in Fig. 2.

The mode of failure, the loading conditions and the weather conditions during the intact stability failures of ferries are shown in Figs. 3 and 4, 5.

According to the figures, about 49% of all ferry accidents were due to intact stability failure, of which 36% cases were overloaded, and the loading conditions in the other 64% 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 the loading conditions were not known were actually overloaded too. Stormy weather conditions were behind 60% of intact ship accidents. The weather conditions were not reported for 14% of cases. These facts indicate that adverse weather conditions and overloading were the main causes of the intact stability failures of passenger ferries.

Even though many of the causes of the accidents were previously known, the scale of the influence of each cause was not clear. It was also very difficult to reduce the risk people were exposed to because of the passengers' lack of awareness and poverty, the inadequate number of transportation vessels compared to what would actually be required, the tendency of the owners to maximize their profits, etc. One possible cause of some water transport accidents in Bangladesh could also be the modification of

Fig. 1 Number of accidents during 1981 to 2005

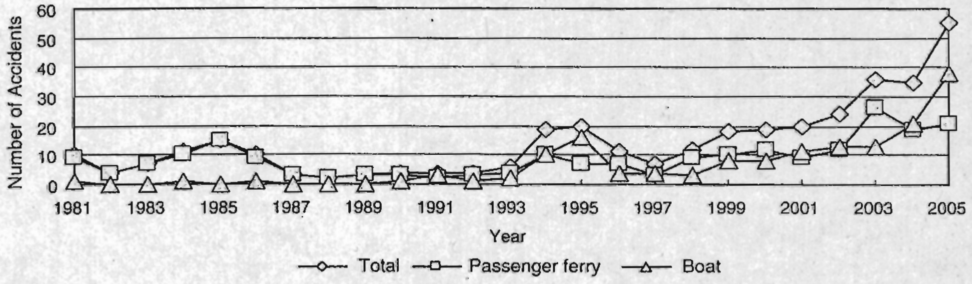
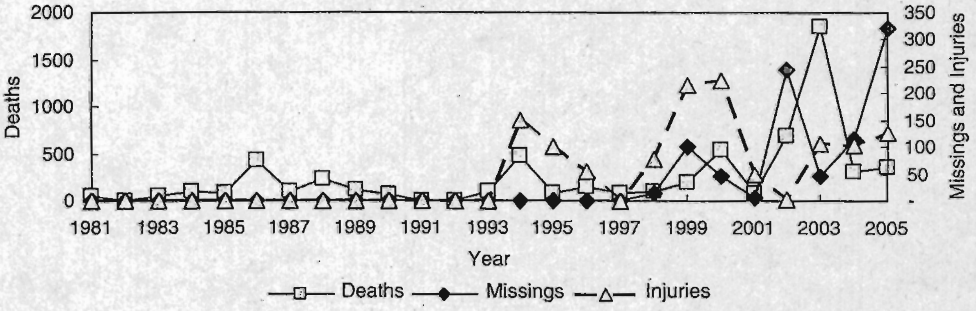


Fig. 2 Number of dead, missing and injured people involved in ferry accidents from 1981 to 2005



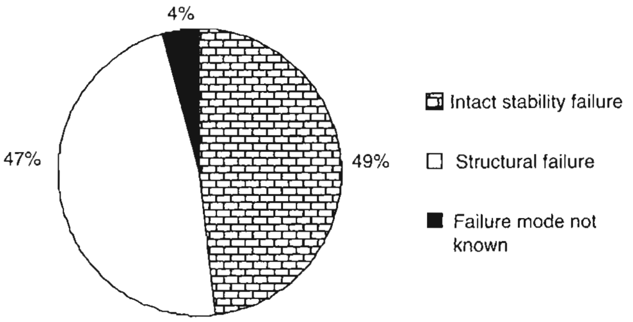


Fig. 3 Proportions of passenger ferry accidents caused by various failure modes

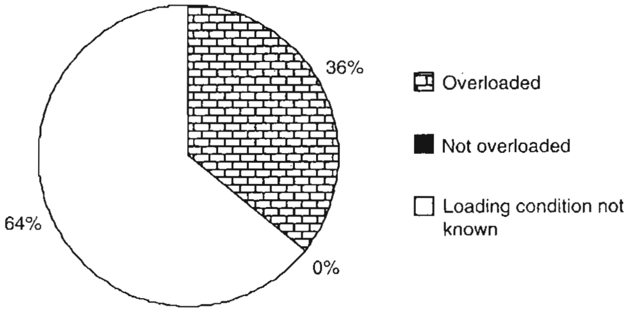


Fig. 4 Proportions of different loading conditions for ferries with intact stability failure

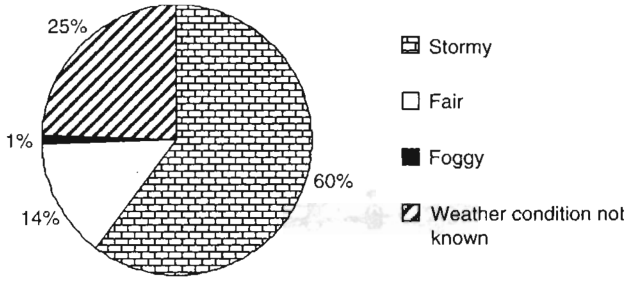


Fig. 5 Weather conditions during intact stability failures of ferries

vessels after approval. A small group of stakeholders might use the weakly regulated environment to earn more by modifying the vessels to carry more passengers.

3 Analysis of wind data

Wind data were gathered from the Climate Division of the Meteorological Department of the Government of Bangladesh for five different locations in Bangladesh. The wind data consist of the maximum monthly wind speed and direction recorded for each location in the years from 1986 to 2005 (a total of 20 years).

The list of locations is reported in Table 1, and a map showing the positions of the five locations in Bangladesh is reported in Fig. 6. Finally, sample data are reported in Table 2.

Table 1 List of the five locations for which wind data were available

Location no.	Location name	Latitude	Longitude
1	Dhaka	23°46′N	90°23′E
2	Chandpur	23°16′N	90°42′E
3	Barisal	22°45′N	90°20′E
4	Patuakhali	22°20′N	90°20′E
5	Chittagong	22°16′N	91°49′E

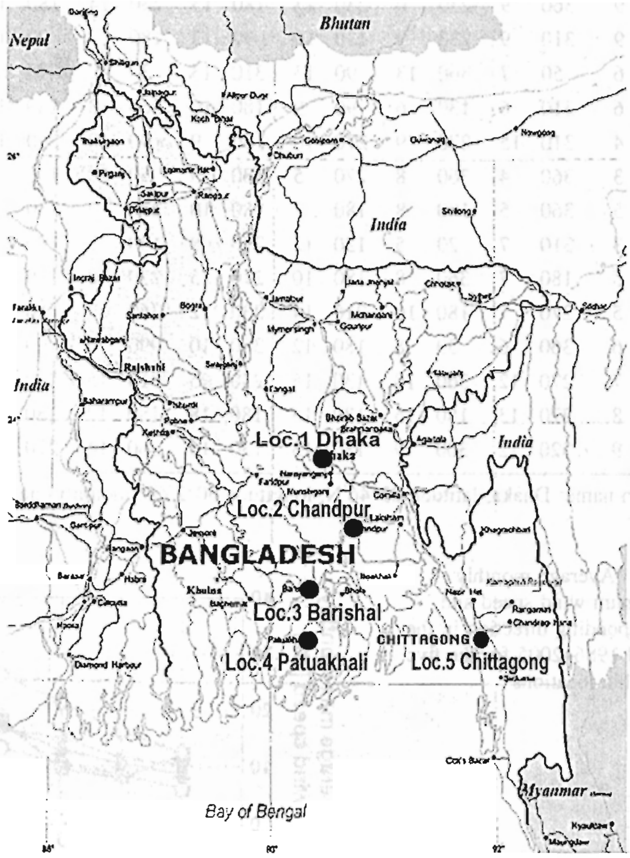


Fig. 6 Map showing the locations for which wind data were available

As a first analysis, we hunted for seasonal trends in the sample data. To do so, the average monthly maximum speeds and directions for the 20 years available were determined for each location, as shown in Fig. 7. From the reported analysis, the period between April and June appears to be the most critical period for all of the available locations, meaning that sailing during this period is expected to be more dangerous than sailing during the other months of the year, at least when only the wind is of concern. April to June is the period when a series of Nor'westers (the local name for typical, small localized

Table 2 Sample of the wind data (maximum speed and direction) available for the location Dhaka

Year	January		February		March		April		May		June		July		August		September		October		November		December	
	spd	dir	spd	dir	spd	dir	spd	dir	spd	dir	spd	dir	spd	dir	spd	dir	spd	dir	spd	dir	spd	dir	spd	dir
1986	5	310	5	310	13	180	18	90	9	90	18	270	13	180	9	230	18	130	5	270	13	90	5	310
1987	5	310	13	310	24	270	18	90	18	50	18	180	13	180	9	180	13	180	18	50	9	360	9	230
1988	5	90	9	360	9	230	13	50	18	180	13	90	13	230	13	90	9	230	18	360	37	50	5	90
1989	6	360	9	230	9	310	18	180	18	180	18	130	13	230	13	90	9	130	13	130	5	50	5	50
1990	7	230	5	50	18	130	15	180	21	310	13	130	13	90	9	130	9	130	18	130	7	90	13	90
1991	9	90	13	50	9	360	24	50	24	310	13	50	13	90	13	90	9	200	9	30	5	50	13	360
1992	9	360	9	230	9	230	13	180	13	230	14	180	17	90	11	90	12	130	9	230	8	270	7	90
1993	9	310	9	230	9	130	10	90	13	180	13	90	12	90	21	300	13	90	6	90	6	230	6	360
1994	6	50	7	360	13	90	13	310	13	30	9	90	31	180	13	130	7	90	7	270	9	270	3	310
1995	6	310	6	130	6	90	9	180	10	360	8	180	10	130	9	90	7	130	5	90	7	180	5	90
1996	4	310	15	270	9	270	10	180	9	90	10	50	12	130	5	90	21	30	9	270	3	360	3	270
1997	3	360	4	360	8	270	5	180	9	50	10	130	8	130	10	130	18	310	6	270	3	50	4	360
1998	5	360	5	180	8	180	7	180	10	270	9	180	6	180	5	180	9	180	8	180	13	50	4	50
1999	3	310	7	20	5	130	12	270	8	130	7	180	6	130	5	130	5	130	8	180	2	310	9	30
2000	5	180	7	360	8	180	10	270	15	270	8	180	9	180	9	210	10	210	15	50	5	230	5	360
2001	5	270	7	180	10	210	14	230	12	360	9	50	16	30	8	150	20	180	8	170	4	90	4	330
2002	6	360	6	30	8	180	12	360	10	990	9	90	10	180	8	180	10	130	6	180	15	40	6	360
2003	7	270	12	360	10	130	15	230	25	310	15	180	12	180	10	130	10	180	10	130	8	310	8	50
2004	8	220	13	180	15	180	15	180	18	180	12	180	18	130	13	130	15	90	10	130	8	320	9	270
2005	9	320	12	300	9	180	13	130	15	360	14	270	12	120	10	50	12	130	10	90	7	360	7	330

Station name: Dhaka, latitude 23°46′N, longitude 90°23′E; monthly maximum wind speeds (spd) in knots and directions (dir) in degrees

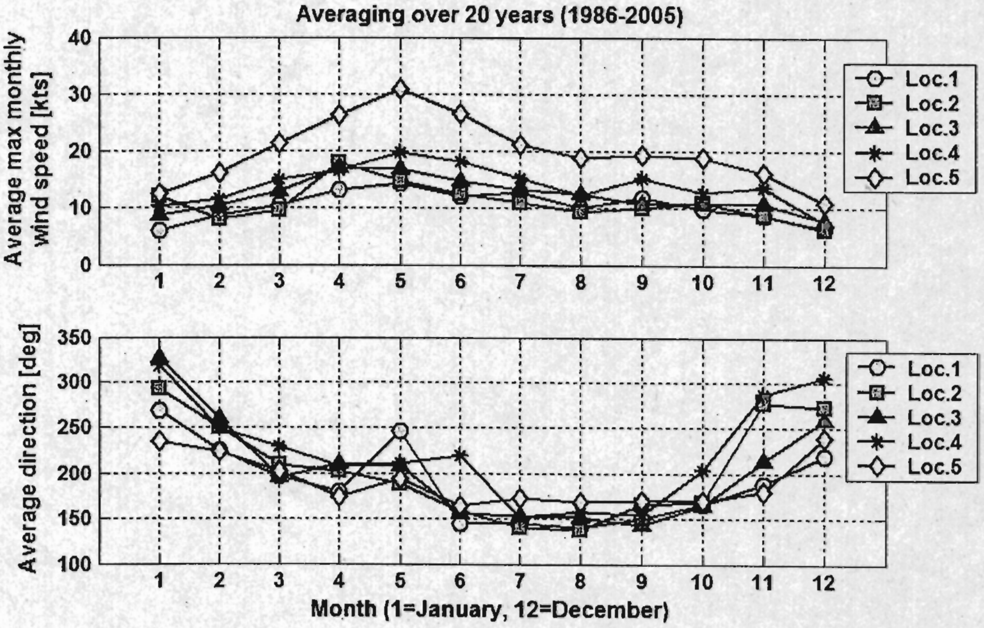


Fig. 7 Average monthly maximum wind speed and corresponding direction in the period 1986–2005 for the five available locations

tornadoes) pass over Bangladesh. The volume and current of the water flowing through the river during this period is not that high, because the usual monsoon period starts in the middle of June. The waves sometimes become severe for small vessels due to the influence of the Nor'westers, but they are usually of a negligible height due to the limited fetch.

From the trend analysis, the change in average wind direction is also evident. Such a change in the dominant direction could have an influence when a particular location is considered together with the possible sheltering effect of surrounding hills and mountains. It is also clear from the analysis that Location 5, Chittagong, shows an unusually high average maximum wind speed, while the other locations show comparable behavior with significantly lower average maximum monthly wind speeds. This is likely due to the fact that Chittagong is not an inland location, unlike all the other available locations, as can be seen from the map in Fig. 6. It is, instead, a city facing the Bay of Bengal, i.e., (almost) the open sea.

A thorough analysis of the details of the available wind data is beyond the scope of this paper; however, the interest in the available wind data was mainly driven by the intention to define a suitable magnitude for the wind speed to be used for regulatory purposes. Such a wind speed should, in principle, depend on the particular location where the ship is intended to be operated. In addition, the period of the year during which the ship is operated should also be taken into account. Unfortunately, the available data do not allow such a fine description of the reference environmental conditions to be defined, and thus we have to consider a series of simplifications. In addition, we have to bear in mind the socio-economic situation of the shipping industry in the developing country of Bangladesh, which leads to the need to define simple but effective rules.

First of all, we consider the ship to be operated throughout the year, and in addition we assume the ship to be operated in an unknown location in Bangladesh's National Waters. According to these assumptions, we can combine the observations of the monthly maximum wind speed for all the different locations and for all the available months and consider them as possible outcomes of the monthly maximum wind speed experienced by a ship operated in Bangladesh. By combining all of the data concerning the monthly maximum wind speed for all the locations, we obtain the probability density function and the corresponding cumulative distribution, as shown in Fig. 8. The variability of the CDF among different locations is shown in Fig. 9. In Fig. 8, the effect of neglecting the data coming from Location 5 is considered. The maximum measured wind speed over the 20 years among the five locations was 90 knots, and it occurred twice: at Location 2 in April 1998 and at Location 5 in May 1997. Due to the fact that the empirical CDF estimated for the maximum available from the sample is equal to one, this point does not appear in the logarithmic representations of Figs. 8 and 9. In all of the other cases, the maximum wind speed was below 64 knots (experienced once at Location 4 in November 1988). We can see that taking into account the data from the coastal Location 5 leads to a general increase in the probability that a given maximum wind speed will be exceeded, due to the more severe wind, as already pointed out when discussing Fig. 7. However, the differences in the range of speeds above 50 knots seem to be limited (even if, due to the limited amount of data in this region of the CDF, the confidence in the estimation is not very high).

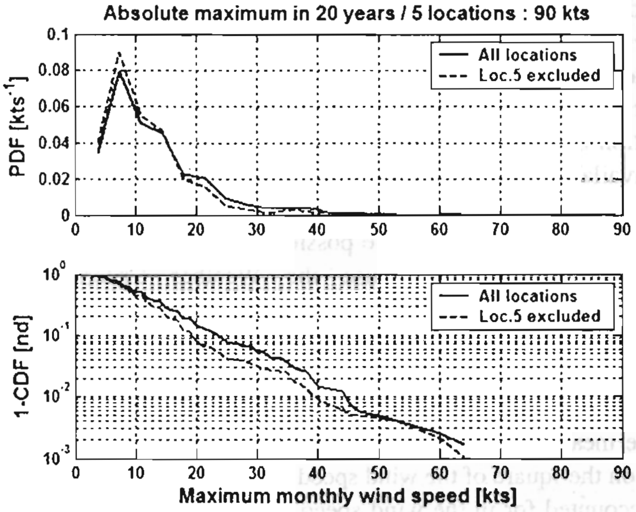


Fig. 8 Estimated PDF and probability (1-CDF) of exceeding the maximum monthly wind speed experienced. All months have been joined

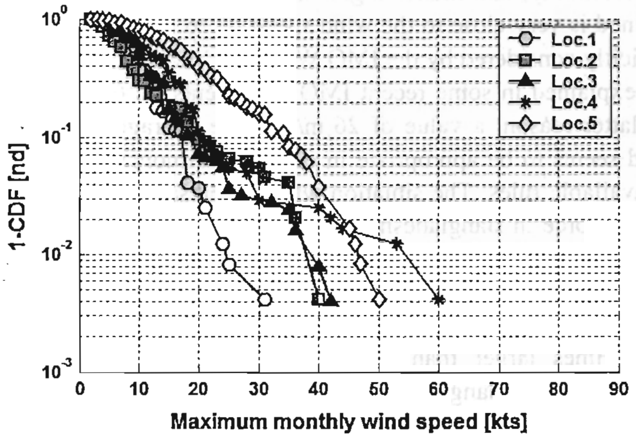


Fig. 9 Estimated probability that the maximum monthly wind speed experienced will be exceeded for the different available locations. All months have been joined

If we assume 10^{-3} to be an acceptable level for the probability of exceedance of the monthly maximum wind speed for intact stability assessment, we can estimate from Fig. 8 a corresponding maximum wind speed of ~65 knots, i.e., about 33 m/s. Such a level of probability can be translated into an approximated annual probability of exceedance, assuming independence among different months, of about 0.01 [i.e., $1 - (1 - 10^{-3})^{12}$]. It should be noted that such a probability could still be considered to be too high in a safety framework, and so a higher speed (corresponding to, e.g., a 10^{-4} probability level) may be more appropriate.

The obtained speed of 33 m/s represents, however, the speed of the gust, and the corresponding average wind speed is, unfortunately, not known from the available data. In order to rationally decide on a suitable corresponding average wind speed, additional information regarding the spectrum of the gustiness at the recording locations and the duration of the storms is required, which is unfortunately not available (with this information to hand, an analysis of the gustiness factor according to, e.g., Bulian and Francescutto [2], would indeed be possible). However, we can pragmatically decide to use the Weather Criterion assumption [3, 4] on the ratio between heeling levers due to gustiness and constant wind in order to determine the average wind speed. In the Weather Criterion, the heeling lever due to the gustiness is 1.5 times the heeling lever due to the mean wind. Because the moment is roughly dependent on the square of the wind speed, the gustiness factor to be accounted for in the wind speed would be $\sqrt{1.5}$. From this assumption, an average wind speed that can be used for intact stability assessment of 27 m/s (corresponding to about 52 knots) can be proposed.

Incidentally, and interestingly, the average wind speed obtained is very close to the wind speed of 26 m/s already implicitly considered by the IMO Weather Criterion [3], as also explained in some recent IMO documents [5, 6]. For this latter reason, a value of 26 m/s as the average wind speed seems to be appropriate in order to harmonize with the available rules. The situation with the present stability rules in force in Bangladesh is a little puzzling. Basically, a series of rules requiring the ship to be able to withstand the action of wind are based on a reference wind speed of 10 m/s. The proposed value for the average wind speed is 2.6 times larger than this reference speed, and the corresponding change in the wind heeling lever is approximately a factor of 7 (2.6^2). The value of the wind speed presently considered in the national rules in force in Bangladesh seems to be unreasonably low when compared with the available data. The probability of exceedance corresponding to a wind gustiness speed of $10 \cdot \sqrt{1.5} \approx 12\text{m/s} \approx 24$ knots is in the range $5 \cdot 10^{-2} \div 10^{-1}$ (depending on whether Location 5 is considered or not in Fig. 8), i.e., almost two orders of magnitude higher than the probability of exceedance corresponding to the proposed value of $26 \cdot \sqrt{1.5} \approx 32\text{m/s}$ for the gustiness speed.

On the other hand, the Weather Criterion presently in force in Bangladesh [4] is based on a reference pressure of 0.0322 t/m^2, which corresponds to 316 N/m^2. This latter pressure is identical to the minimum pressure reported by the IMO Intact Stability code [3] for fishing vessels (it is considered for ships where the distance between the center of the lateral projected area and the point at half draught is less or equal than 1 m). The corresponding wind speed can be calculated as 20.6 m/s (indeed, the pressure in the Weather Criterion implicitly contains a moment coefficient of 1.22 [5]). The reduction considered by the IMO Intact Stability Code [3] in the reference pressure for ships with superstructures that are not too high is likely to be related to boundary layer effects, which reduce the wind speed close to the ground. However, typical ships that sail in Bangladesh and carry passengers have higher distances between the center of the lateral projected area and the half draft, and it is also not wise to relax the reference pressure due to wind for ships that carry 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 26 m/s and that obtained using the present rules in force in Bangladesh for the weather criterion is a factor of 1.6, i.e., not negligible at all.

Based on the analysis carried out here, and bearing in mind the need to reduce the risk involved in passenger transportation, it seems to be opportune to harmonize the reference average wind speed in the present Bangladesh stability rules to 26 m/s in all criteria, which leads to a reference pressure of $504\ \text{N/m}^2 = 0.0514\ \text{t/m}^2$ in the Weather Criterion for inland vessels.

4 Description of the sample small inland passenger ship

Bearing in mind the results of the analysis of the accident data, we have selected a sample ship in order to try to better understand reasonable causes of capsizing in intact condition. We have started from the availability of a series of data for a passenger ship that actually capsized in Bangladesh. However, the available data were sketchy, and they mainly consisted of a series of reference loading conditions, hydrostatic tables, data concerning the windage area, the ship's main dimensions, etc. Unfortunately, the ship's bodyplan was missing. However, in order to exploit the available important information, a very similar ship (for which the bodyplan was available) was selected, and it was transformed by slightly scaling it in the longitudinal, transverse and vertical directions. The longitudinal scaling was used to obtain the length between the perpendiculars of the original ship. The vertical scaling factor was selected to match the original ship's depth. The final transverse scaling was decided by matching the hydrostatic tables available for the original ship with the hydrostatic tables computed for the stretched ship. Very good agreement was found between the hydrostatic computations and the available data (differences were a few percent points for the metacentric radius, the volume and the vertical position of the center of buoyancy), so we concluded that the generated hull form was likely to be very similar to the original ship. This idea was also supported by analyzing a series of available bodyplans for small/medium passenger ships operating in Bangladesh, where very similar hull forms were found among different ships. Based on these outcomes, we named the stretched ship "Small Launch" (we will abbreviate this to "SL" in this paper) and we consider the loading conditions of the capsized ship to be applicable to the ship SL.

Two loading conditions will be thoroughly investigated:

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

The 50% overloading condition is taken into account since the analysis of the data from accidents showed a significant number of cases for which overloading was actually present. From a merely technical point of view, overloading is not a pure naval architecture problem. On the other hand, though unfortunate, several cases of overloading have been reported in the media in many developing countries like Bangladesh. Keeping these socio-economical conditions in mind, it is important to address this aspect according to its effect on stability, and this is why the overloaded condition is addressed in this analysis. A proper consideration, at the design stage, of the possibility of overloading during the ship's operational lifetime would increase the inbuilt safety of the design, and this is a goal that designers, in order to make the best use of all the information available during the design stage, should always pursue, even when regulations are lacking.

The bodyplan of the ship SL is reported in Fig. 10. Data for the two loading conditions and the main particulars of the ship are reported in Table 3. In Table 3, two values are reported for each loading condition, for the lateral projected area. The smaller value is the lateral projected area 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 higher value given in parentheses is the estimated lateral projected area considering the presence of curtains (often installed to protect passengers from rain and wind) over the openings. The estimation was performed by considering the general plans of the similar ship. The wind lever Z was assumed to be the same whether curtains or clear openings were present.

In the following analyses, unless otherwise specified, the loading conditions are such that they give zero trim in the upright position, and all of the calculations of the righting

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 center of buoyancy above the baseline	$\overline{KB}$ (m)	0.528	0.568
Transverse metacentric radius	$\overline{BM}_T$ (m)	4.002	3.721
Vertical position of the center of gravity from the baseline	$\overline{KG}$ (m)	2.061	2.189
Transverse metacentric height	$\overline{GM}$ (m)	2.469	2.1
Mass of passengers and crew	(kg)	19050	28575
Lateral projected area exposed to wind	A_{lat} (m^2)	71.6 (107.8)	69.6 (105.8)
Vertical distance between the assumed center of application of the wind force and the center of application of the drift reaction	Z (m)	2.711	2.740

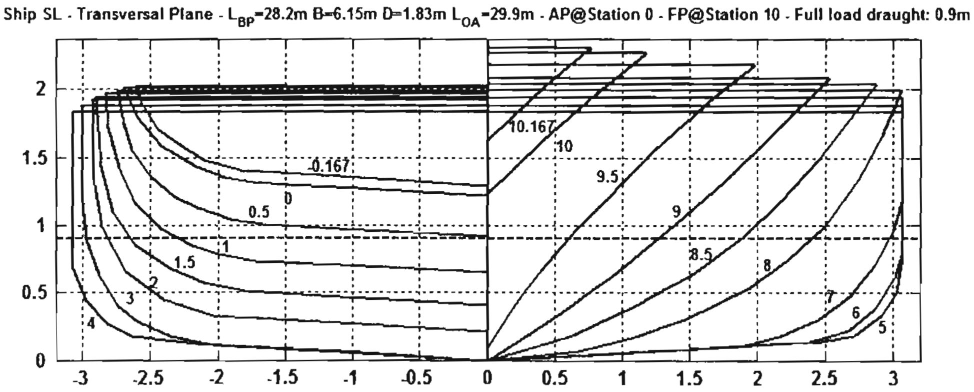


Fig. 10 Bodyplan of the ship SL

arm are performed allowing free trim. In the full load condition the mass of each person is assumed to be 75 kg.

The following analysis of hazards is performed in order to identify 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 passengers crowding to one side
- Effect of the engine room's hatch coamings and trim on the downflooding angle
- Heeling moment due to wind

It is important to report a series of comments, before proceeding, on the position of the draught in the loading condition referred as "full load." As is clear from the bodyplan in Fig. 10, such a draught is well below the draught corresponding to the position of the perpendiculars. Indeed, from the available drawings, the maximum allowed draught for the modified (scaled) ship would be 1.20 m, i.e., 0.3 m more than the considered "full load." Such a difference corresponds to a difference in displacement of about 42 t. The basic ship considered here is allowed to carry, in addition to passengers, a limited quantity of cargo (around 7 t). However, the absence of such a quantity of cargo cannot justify the difference in the draught. Unfortunately, this matter is not discussed in the report on the investigation into the capsizing of the ship from which we have gathered the information on the loading conditions, and thus it is not clear whether the loading conditions reported in Table 3 should actually be supplemented with some other loading condition in order to reach the maximum allowed draught. Also, it is difficult to imagine such a loading condition, due to the fact that the sum of the lightship weight, the maximum number of passengers allowed, the maximum cargo allowed, plus some other items (water, fuel, etc.) cannot reach the displacement at the maximum allowed draught, and a considerable amount of ballast (around 35 t) would be needed. Based on these considerations, the results obtained by considering only the two aforementioned loading conditions should be considered with care, and a more thorough investigation of the actual operation of the ship that capsized, and of similar ships, should be carried out.

5 Analysis of hazards

5.1 Heeling moment due to passengers crowding to one side

The tested ship carries, under the full loading condition, a total payload of 19.050 t that becomes 28.575 t when 50% overloading is considered. Such a payload is a considerable fraction of the total ship displacement (21.6% for the full load condition and 29% for the 50% overloaded condition), meaning that the shifting of the passengers to one side is a hazard that could endanger the ship. The shifting of passengers to one side could occur, e.g., if the ship is heeled to one side due to the presence of wind, or sometime passengers move to one side to protect themselves from the rain and the wind coming into the deck area through open windows. The openings in the lateral part of the superstructure are usually quite large, and thus rain and wind can easily prompt the passengers to move to the sheltered side. Often curtains are used to close such openings and to protect the passengers. However, such protection is not always effective, and it also increases the lateral projected area exposed to wind by blocking the transverse wind flow, leading to an increase in the moment due to wind which, in turn, increases the heeling angle under the action of the wind action. This could finally cause people to shift to the leeward side. For such reasons, crowding to one side is a reasonable hazard in harsh weather (e.g., sudden storms that are quite typical in Bangladesh during some periods of the year). From an analysis of the number of passengers onboard, and assuming four persons per square meter during crowding, we have estimated that the position of the center of gravity for the crowd occurs at about 70% of the half breadth.

A comparison between the assumed heeling lever due to crowding and the righting arm is reported in Fig. 11. The heeling moment due to passengers crowding to one side is significant, due, as already mentioned, to the large ratio between the passengers' weight and the ship displacement. Under the full load condition, however, the ship shows a quite large range of residual stability above the angle of equilibrium, suggesting that the crowding hazard under the full load condition, although important, is not extreme. The same cannot be said of the overloaded condition, where the increased weight of the passengers onboard leads to an equilibrium angle of more than 18°, and, more importantly, to a residual range of stability that is very small, as well as the maximum residual $\overline{GZ}$. This means that, under the overloaded condition, the ship is in extreme danger from the crowding of passengers to one side if some additional cause of heeling, like the expected presence of wind, is introduced. It should be noted 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 very large metacentric height.

5.2 Effect of engine room's hatch coamings and trim on the downflooding angle

In the typical design of a small passenger ship in Bangladesh, the engine room often shows an hatch at the main deck level, in the aft part of the ship, as depicted in Fig. 12.

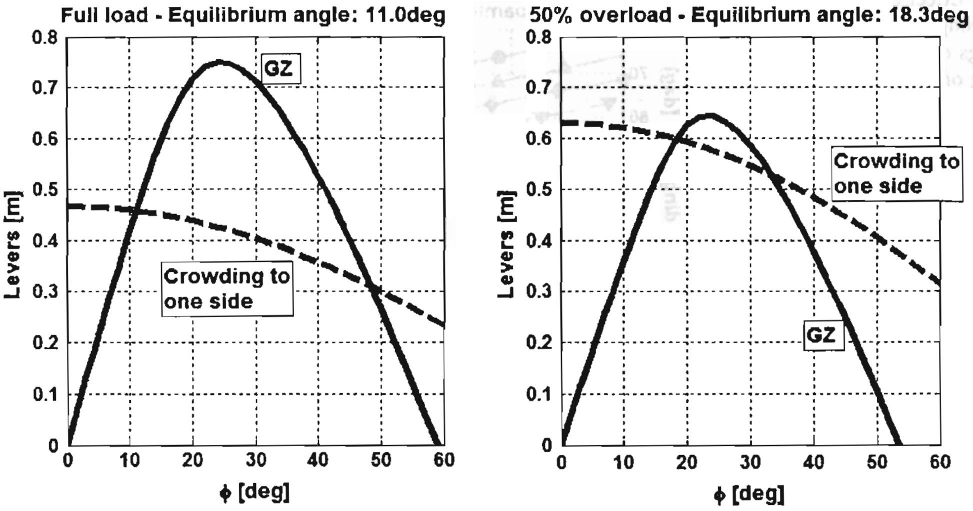


Fig. 11 Restoring and heeling moments due to passenger crowding

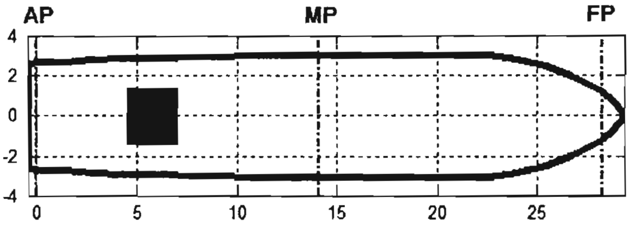


Fig. 12 Position of the hatch to the engine room on the main deck

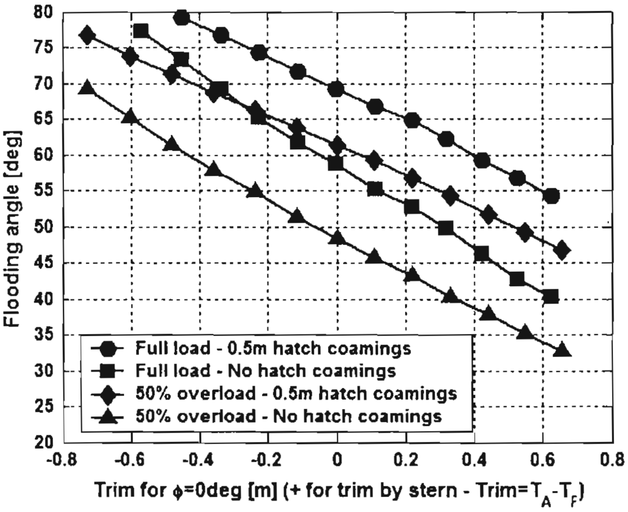


Fig. 13 Angle of submergence of the hatch leading to flooding of the engine room in case of the absence of the hatch cover

This hatch should be closed; however, it has found on several occasions to be open during operation, in principle representing a potential cause of flooding. In some designs the hatch is provided with hatch coamings of a not negligible height above the deck, whereas in other cases hatch coamings are, practically speaking, not present. We have thus analyzed the angle at which the engine room is flooded assuming the absence of the hatch cover. The analysis was carried out for the two loading conditions, considering the effect of the presence of hatch coamings with a representative height of 0.5 m above the main deck, and investigating the effect of the initial trim. From the results shown in Fig. 13, a series of comments can be made:

- As expected, trim by stern reduces the flooding angle and the effect of trim is significant.
- The fitting of sufficiently high hatch coamings can efficiently increase the angle of flooding of the engine room in the absence of a hatch cover. The increase in the flooding angle, for the tested height of 0.5 m, is around 10–12° on average.
- The angle of flooding under the full load condition is large enough to consider the flooding of the engine room to be an unlikely hazard with or without the presence of hatch coamings.
- The angle of flooding shows a significant decrease in the 50% overloaded condition. Under this condition, the fitting of hatch coamings is an effective means of increasing the downflooding angle.
- We can see that, for the zero trim condition, the flooding angle ranges from about 70° in the case of a fully loaded ship with hatch coamings 0.5 m in height, to about 48° in the case of the 50% overloaded condition without hatch coamings. This means that the tested ship, operated within the expected range of draughts, is unlikely to risk flooding the engine room even if the hatch cover is not present.
- For the tested cases the downflooding angle is always in the range of descending $\overline{GZ}$, and in many cases even in the range of negative $\overline{GZ}$, meaning that the flooding of the engine room under the effect of steady heeling moments can only occur if the ship has already reached an unstable condition, eventually leading to capsize.

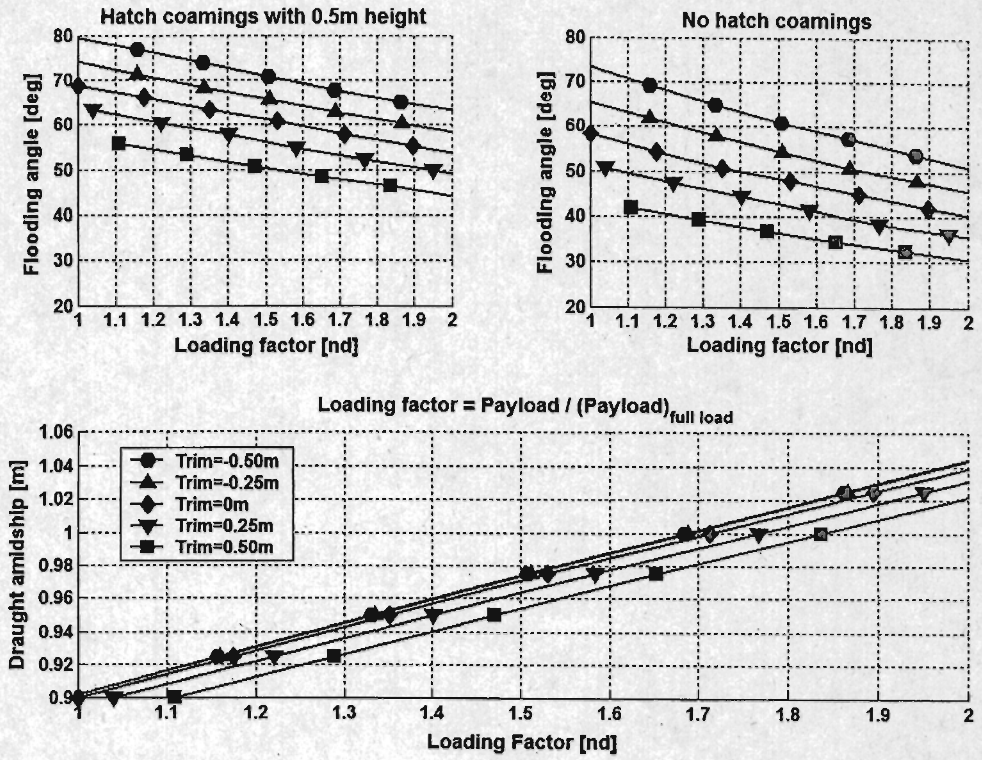


Fig. 14 Effect of the overloading, trim and hatch coamings on the angle of flooding of the engine room

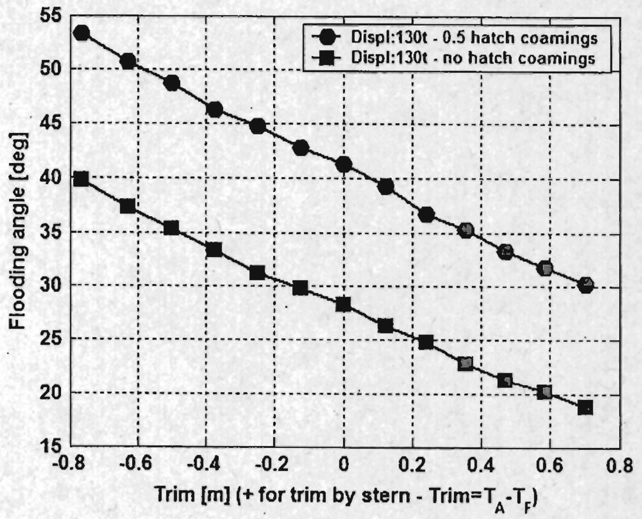


Fig. 15 Downflooding angle for the maximum allowed displacement of 130 t as a function of trim, with and without the presence of hatch coamings

In order to assess the effect of overloading on the risk of flooding the engine room, the downflooding angle has been calculated for a series of overloaded conditions up to 100% overloading (a condition unfortunately not uncommon in Bangladesh), and for a series of trims in the upright position, with and without the presence of hatch coamings. The results are reported in Fig. 14. In the worst cases characterized by large overloading, significant trim by stern and an absence of hatch coamings, the possibility of flooding the engine room in the case of large rolling angles increases. However, if the trim by stern is not excessive, the flooding of the engine room occurs at significantly large angles, even in the case of 100% overloading. It is interesting to note that the fitting of the hatch coamings reduces the loss in the downflooding limit given by the effect of trim.

As already reported, we have some concerns regarding the actual draught at which such a ship could actually be operated, irrespective of the limits imposed by the rules. For this reason we have performed an additional calculation of the downflooding angle for the engine room, with and without hatch coamings, for a displacement of 130 t (corresponding to the maximum allowed draught of 1.2 m with zero trim) accounting for the effect of trim. The results are shown in Fig. 15.

We can see that, due to the reduced freeboard, the angle of downflooding is now significantly reduced, especially in the absence of hatch coamings and when there is significant trim by stern. The hazard related to the flooding of the engine room starts to become significant for the displacement represented by Fig. 15.

5.3 Heeling moment due to wind

The action of beam wind is, of course, another hazard that must be analyzed. In this section, the effect of constant beam wind will be assessed considering the results from the analysis of historical wind speed data. Therefore, three steady wind speeds will be considered, namely 10, 20.6 and 26 m/s.

For each loading condition, we will consider two cases: one of a ship with clear openings on the side, and the other where the openings are closed due to the presence of curtains. Such curtains are often already present on the ship, and folded inside the top of the openings. When the wind or rain starts, people onboard usually unfold the curtains to protect themselves and fix them to prevent fluttering. In this way, they basically close or significantly obstruct the available openings. The presence of these curtains also increases the actual windage area exposed to the wind. For this reason, we will consider the wind heeling lever with both clear and obstructed openings.

Although the wind heeling lever depends on the heeling angle, we will simplify it and make it heeling-independent. This simplification is done due to the absence of sufficient information, and after noting that the same assumption is also done in the Weather Criterion calculation scheme presently in force in Bangladesh. We have considered the same position of the center of the lateral projected area in both cases (clear and obstructed openings). This basically means that we assume that the openings are almost uniformly distributed on the windage area. Of course, this is a simplification, and more detailed calculations would need to be performed in the case of real designs.

The results of the analysis are reported in Fig. 16. We see that the effect of the wind is, despite the relatively large exposed area, not very significant, and the equilibrium angle in the worst case considered slightly exceeds 4°. This is due to the large metacentric height in the loading conditions considered.

For not too extreme speeds, the wind itself does not seem to be a very dangerous hazard that is able to capsize the ship. Nevertheless, it is important to pay attention to the large variation in the heeling moment due to the wind, depending on the assumptions used. The ratio between the exposed area with obstructed openings and the area with clear openings is about 1.5, meaning that, if we consider the openings to be obstructed, the heeling lever due to wind is 50% more than in the case with clear openings. This results in a ~50% increase in the equilibrium angle, thanks to the linearity of $\overline{GZ}$ at small heeling angles. In addition, if we compare the case with a wind speed of 10 m/s with the case with a wind speed of 26 m/s, a factor of 6.8 is found in relation to the heeling levers and thus, approximately, the corresponding angles. If we compare the assumptions of 20.6 and 26 m/s, the ratio between the corresponding heeling levers is 1.6. Globally, if we consider the best and the worst case, we find a ratio of about 10.2 between the corresponding heeling levers, and thus, approximately, the corresponding heeling angles. In view of the analysis of the wind carried out in this research, and considering the relatively common bad habit of fixing the curtains at the side openings, it would seem more reasonable to consider the openings to be obstructed and thus a wind speed of 26 m/s within the framework of the stability assessment.

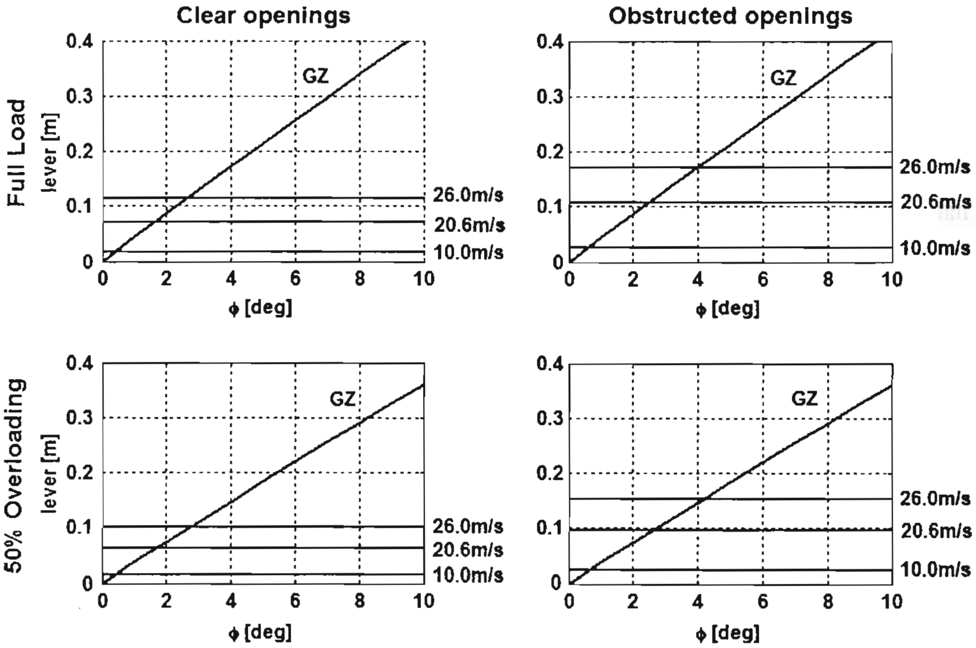


Fig. 16 Analysis of the effect of beam steady wind

6 Final remarks

This 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 that occurred in the period 1981–2005, the main causes of intact stability failures (capsizes) have been determined: adverse weather conditions and overloading, with consequent likely crowding to one side. Bearing in mind the socio-economic environment of shipping transportation in Bangladesh, and because of the common sudden changes in the weather in that region, with strong localized winds, it is difficult to provide an effective way of giving advance warning of bad weather onboard the ships. Therefore, the adverse weather hazard cannot be efficiently mitigated. On the other hand, much could be done in relation to the overloading problem. Although this is only partially a design matter, because ships should simply not be operated when overloaded, it is a matter of fact that a considerable number of ships are overloaded during their operation, and that this is causing a significant loss of life. A sufficient safety factor related to this issue should therefore be implemented from both a design and a regulatory point of view.

The analysis of wind data carried out in this paper suggests that an increase of the wind speed presently used in the Weather Criterion in force in Bangladesh could be advisable, and that this would indirectly also increase the safety of the ships by increasing the minimum metacentric height required. Crowding should also be taken into account.

A small passenger ship, representative of the typical small "launches" operating in Bangladesh, was analyzed from a rational point of view, by identifying hazards that can endanger the ship under intact conditions. A strongly jeopardizing effect of the overloading was detected when analyzing the hazard from people crowding to one side. In addition, the risk of flooding the engine room in the absence of hatch covers was assessed, and the effectiveness of the hatch coamings at increasing the angle of progressive flooding was shown. However, for the ship analyzed, the issue of the flooding of the engine room only seems to be relevant at the maximum draught (which does not correspond to the draught under the assumed fully loaded condition). The detrimental effect of the presence of curtains over the openings in the superstructure was assessed, due to the fact that passengers commonly close the windows in order to shelter themselves from wind and rain. The analysis has shown that it could be wise, in a regulatory framework, to take the possible presence of curtains into account by considering all of the openings to be closed.

The analysis of hazards carried out in this paper serves as a base for steps aimed at the determination of proper design/regulatory means for improving the safety of the analyzed typology of ships under intact conditions. Some of these remedial measures are proposed in Iqbal et al. [7].

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