Aspects of Passenger Movement to the Same Side in the Assessment of Intact Stability

INTRODUCTION

The main static stability rule governing the grouping of passengers on the same side is that the heel angle cannot exceed a certain value, in addition to various other stability criteria (minimum GM, minimum flooding angle, area under the stability curve, etc.), which are generally common to other types of vessels.

Internationally, this requirement is dictated by the International Maritime Organization's (IMO) Code of Intact Stability (ISC 2008) adopted by Resolution MSC.267(85), that requires a maximum of 10° of heeling angle when all passengers go to the same side.

In Brazil, the maritime authority (Brazilian Navy) applies this criterion through NORMAM-201 (for navigation in the open sea) and NORMAM-202 (for inland navigation). NORMAM-201 requires 10° (same as IMO), and NORMAM-202 requires 12° or 15° maximum, depending on if Area 1 or Area 2, among other differences that are not affected by the transverse movement of passengers.

In NORMAM-202, Areas 1 and 2 refer to the subdivision of Inland Navigation, which is carried out in sheltered or partially sheltered waters, such as rivers, lakes, lagoons, bays, and channels.

The fundamental distinction between them is based on the level of protection against environmental agents (winds, waves, and currents)

- Area 1 (Very sheltered waters): Covers lakes, lagoons, rivers, channels, and very sheltered sea areas (such as protected bays). These are places where there is no incidence of large waves or strong winds that pose risks to navigation.
- Area 2 (Partially sheltered waters): Refers to stretches where vessels are subject to larger waves and/or more adverse environmental conditions (wind and current) that make navigation more difficult. It generally requires more robust vessels and specific lifesaving equipment.

The Brazilian standard for inland navigation considers a maximum density of 4 standing passengers per square meter and requires evaluation of stability with maximum passenger capacity. Also, for ferries services lasting less than 1 hour, is allowed to have standing passengers.

Between the years 2013 and 2024, I was the naval architect responsible for the fleet of 19 vessels (some monohulls, some catamarans, some having a single deck, others tween decks, from 250 to 2000 passengers' maximum capacity), traveling in Guanabara and Ilha Grande Bays. Although I did not participate in these projects, I've always been concerned with the safety

aspect of this operation, the fourth largest in the world, transporting about 20 million passengers/year over more than 400,000 miles.

Calculations made with several vessels show that the moment of capsizing with passengers on a board can be greater with less capacity.

Several other aspects of stability and comfort in passenger transport are also discussed, comparing the rules of existing criteria and regulations.

HYPOTHESES

The calculation and the assumptions for the application of this technical criterion are structured as follows:

The Passenger Grouping Criterion

Crowds of passengers on one of the sides of the vessel are not difficult to occur, and can be divided into two types:

- External reasons, usually caused by the curiosity of passengers, who crowd on board in order to see dolphins, sharks, whales, corpses, external accidents, etc. Other causes such as running away from the sun, rain, splashing waves, etc., are also common.
- Reasons internal to the vessel, usually causing panic: gases, smoke, fire, poor stability, etc.

When all the people on board run to the same side of the ship. a capsizing moment (M_p) is generated. The standard requires that:

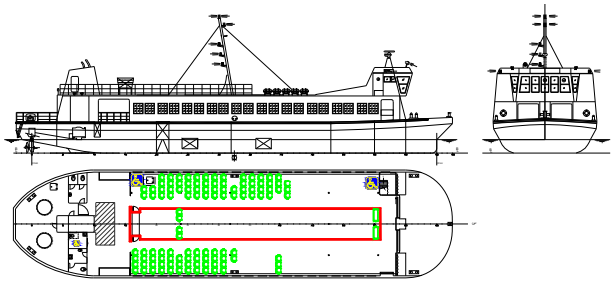
- Maximum angle: The static inclination resulting from the drive must not exceed 10°.
- Immersion: The main deck does not touch the water.

Human Mass Calculation Parameters

To simulate this condition in the official calculations of the ship's Stability Leaflet, the standards establish standardized weight and distribution values:

- Weight per passenger: An minimum weight of 75 kg per person is considered. Brazilian rules allow 25 kg per passenger as luggage, depending on the route.
- Space distribution: An extreme concentration of 4 people/m^2 is assumed in the available deck areas.
- Passengers center of gravity:
  - Standing: The individual center of gravity is calculated 1.0 meters above the deck.
  - Seated people: The individual center of gravity is calculated at 0.3 meters above the seat.
- Passengers should be distributed in such a way as to produce the most unfavorable combination that can be verified in practice for the capsizing moment due to the grouping of passengers on one side and/or vertical position of the center of gravity in the condition.

Sample Calculation



A simple observation of the arrangement of this vessel (2 seats/m^2 and 2 standing passengers/m^2 initial capacity) indicated that the grouping of passengers on one side resulted in a greater moment of capsizing when there were no standing passengers in the loading condition under analysis, freeing up space for passengers seated on one side to group on the opposite side.

The previous figure shows us a hypothetical example of capsized moments: in (a) the initial condition already presupposed trip with standing passengers, while in (b), with half capacity, all passengers were initially seated.

On the other hand, in Figure 3, on longer trips where only seated passengers are allowed, the capsizing moment at full capacity is greater than at half capacity.

We concluded that the capsizing moment with passengers on the same side depends on the internal arrangement of the deck, as well as the initial condition.

Whenever during the analysis of the accumulation of passengers on a board it is verified the possibility that an intermediate condition, with a number of people lower than the maximum expected passenger capacity, resulting in a more critical loading condition, an analysis verifying

These curves showed consistency in the six classes of different vessels, with the maximum loading moment lower than the maximum passenger capacity.

The question to be raised is whether there is empty space that can be fully filled by the passenger grouping. I think the answer is NO, if these empty spaces are already being occupied by standing passengers! But if there are only passengers seated in the initial loading condition?

VESSELS ANALYZED

The documentation available from the fleet of the concessionaire that operates the transport of passengers in Guanabara Bay and Ilha Grande were used as a reference, and the vessels with the capacity to simultaneously transport seated and standing passengers were selected.

Figure 7 – Class vessels analyzed

CLASS	Trad500	Inace500	Trad1000	HC18	Trad2000	US2000
PASSENGERS	500	800*	1000	1300	2000	2000
LPP (m)	39,00	52,00	40,64	48,42	53,00	77,40
B (m)	10,00	9,30	9,91	14,20	10,60	14,80
D(m)	3,00	3,20	3,25	4,00	3,70	4,00
T(m)	1,40	1,61	2,50	1,62	2,20	1,75
DECKS	1	1	2	2	2	2
HULL	MONO	MONO	MONO	CAT	MONO	CAT
Δ100% (t)	220	380	426	324	715	633

Table 1 - Characteristics of the vessels analyzed

CLASS	Trad500	Inace500	Trad1000	HC18	Trad2000	US2000
SEAT MAIN DECK	326	500	222	384	374	448
STAND MAIN DECK	174	300	300	230	695	552
PASS/m²	1,62	2,07	2,58	1,32	3.57	2,27
SEAT UPPER DECK	N/A	N/A	175	486	415	552
STAND UPPER DECK	N/A	N/A	303	200	516	448
PASS/m²	N/A	N/A	2,61	1,32	3,14	2,18

Table 2 - Passenger distribution

Although the Inace500 class was originally designed for crossings in Ilha Grande Bay, with a capacity of 500 seated passengers (draft of 1.45 m), in practice it is being used in Guanabara Bay. To this study, we are considering modifying its maximum draft and passenger capacity to include an additional 300 standing passengers.

We observed in Table 2 above that the density of standing passengers in the original condition varies between 1.6 and 3.6 passengers/m^2, indicating that in some extreme cases its increase to 4 passenger/m^2 due to their grouping on one side will not result in a very large moment of capsizing.

Just out of curiosity, using the minimum dimensions of chairs and distance between rows defined in NORMAM-202, the maximum density of seated passengers is 2.58 passengers/m^2.

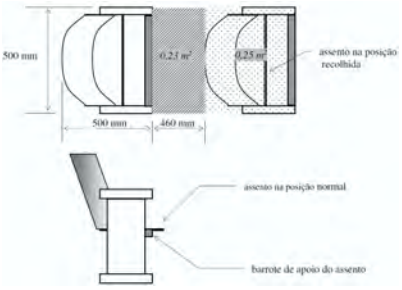


Figure 8 - Spacing between folded chairs

COMPARISON OF LOADING CONDITIONS

We made a comparative analysis of the stability conditions with 100% of passengers (seated plus standing) and with only passengers seated, on the six types of vessels. Their original hydrostatic data, centers of gravity, and cross curves were used.

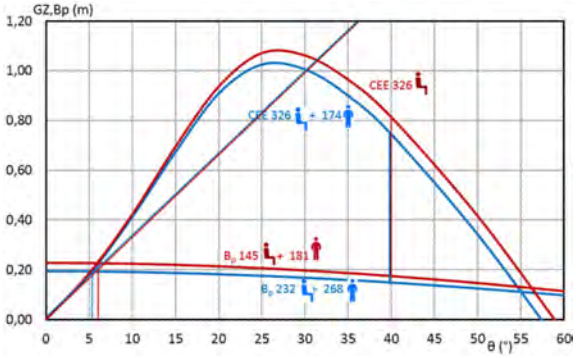


Figure 9 - Trad500 stability curves and capsizing arms

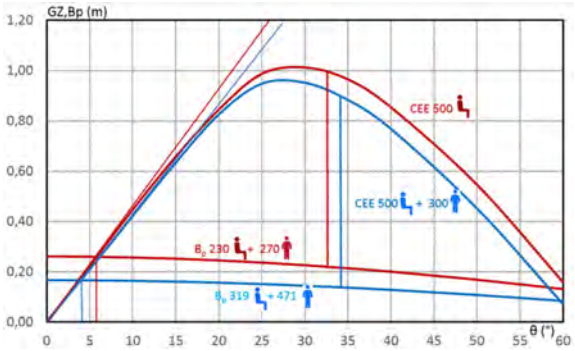


Figure 10 - Inace500 stability curves and capsizing arms

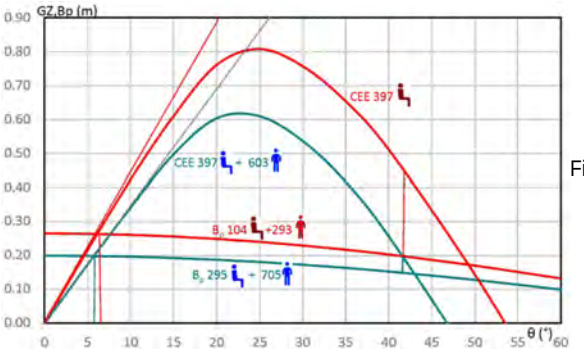


Figure 11 - Trad1000 stability curves and capsizing arms

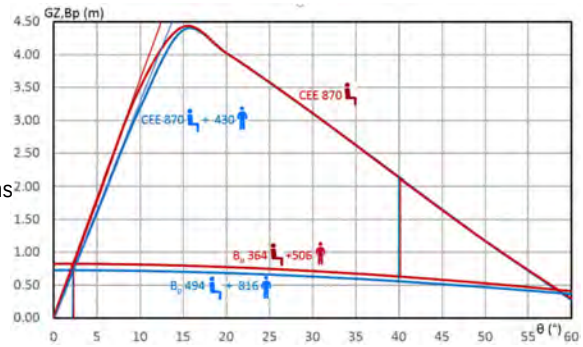


Figure 12 - HC18 stability curves and capsizing arms

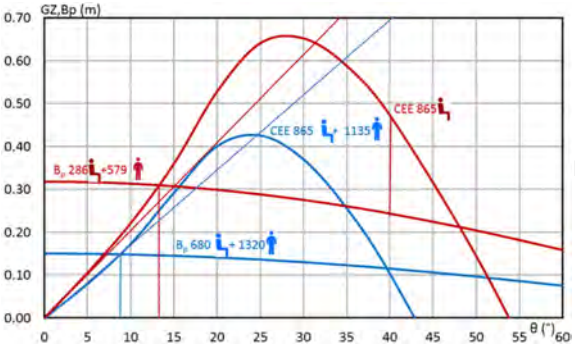


Figure 13 - Trad2000 stability curves and capsizing arms

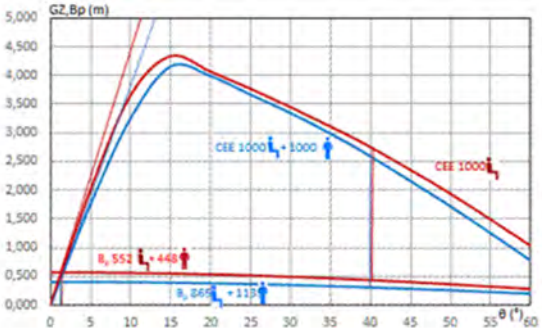


Figure 14 - Stability curves and capsizing arms US2000

Comparative Summary

Comparing the conditions of partial passenger loading (seated only) with that of 100% full loading (standing and seated passengers), we had the following results:

Table 3 - Comparison table (% from full capacity)

CLASS	Trad500	Inace500	Trad1000	HC18	Trad2000	US2000
PASSENGERS	65,2	62,5	39,7	66,9	39,5	50,0
Δ	95,6	92,1	89,4	90,5	84,5	85,1
VCG_{corr}	98,8	97,5	93,9	98,1	92,5	94,4
M_P	112,2	144,5	118,8	102,4	179,0	120,3
BP	121,1	162,5	135,0	113,7	213,3	140,0
GM_{corr}	100,0	107,2	122,2	115,4	155,4	110,3
GZ_{max}	104,9	106,2	130,0	101,1	153,5	102,9
θ_{gzmax}	101,1	107,3	110,7	98,7	120,4	95,7
θ_1	113,0	137,5	118,2	104,8	156,7	118,2
Θ_f	100,4	104,9	111,8	106,2	132,8	107,6
A2/A1	75,9	40,1	98,3	85,4	39,2	58,9

In conditions with only seated passengers (40 to 60% of the total passengers) there is a drop in displacement between 5% and 15%. Obviously, this smaller displacement, associated with a decrease in the height of the center of gravity (between 2% and 6%) leads to greater initial stability (higher GM_{corr}) as well as at large angles (GZ_{max}, $\theta_{GZMAX)}$. However, the greater capsizing moment (from 2 to 80%), associated with the smaller displacement, leads us to larger capsizing arms (from 13% to more than 100%), implying greater angles of static equilibrium θ_1 (5% to almost 60%), with a reduction of 2 to 60% between the A2/A1 area ratios.

BRIEF ANALYSIS OF PARAMETERS AND CRITERIA

Several items are not clarified or are not well defined in NORMAM-02 on stability in passenger vessels, leading to different interpretations by various designers.

In addition, a quick analysis shows us very different criteria from those used for inland navigation in most countries.

Navigation Area

NORMAM-202 classifies navigation areas into two, for the purpose of applying the rules:

- Area 1: Sheltered areas, such as lakes, lagoons, bays, rivers and canals, where waves with significant heights that do not present difficulties to vessel traffic are not normally verified.
- Area 2: Partially sheltered areas, where waves with significant heights and/or adverse combinations of environmental agents, such as wind, current or tide, are occasionally observed, which hinder the traffic of vessels. The areas of inland navigation considered as area 2, for the purpose of applying the standard, are described in the CP and CF Standards and Procedures (NPCP/NPCF)

Taking the example of the Port Authority of Rio de Janeiro, it establishes the areas in its jurisdiction based on more defined criteria:

- The traffic of vessels classified inland, with sail and/or engine propulsion, with a length greater than five meters and equipped with VHF, is allowed within the delimited area, only when favorable weather conditions and sea state limited to strength 1 on the Beaufort scale (1 to 3 knots of wind speed and sea aspect creased in small wrinkles, with the appearance of scales.).
- Traffic of passenger transport vessels, schooners and sloops approved for Area 2 is conditioned to conditions of limited sea state up to force 3 on the Beaufort scale (7 to 10 knots wind speed Slight swells of 30 cm (1 foot), with crests, but no surf.) and there is no forecast of deterioration of meteorological conditions.

Although the stability criteria are a little stricter in area 2, in both areas the wind speed considered is 80 km/h (43 knots or 22 m/s).

International laws provide that each State must classify its inland waterway waters in accordance with international law:

- The internal waters are those inside the coastline (the low tide line of the coast) and the State has full sovereignty over them (rivers, watercourses, lakes and even small bays).
- The territorial sea of the States extends up to 12 nautical miles from the coastline. The nation is free to establish laws and regulate their use, as in its own territory and its internal waters.

For the purposes of wave height, most of Europe, through the UNECE (2006) divides inland navigation into three zones: zone 1 with a significant maximum wave height of 2.0 m, zone 2 with 1.2 m and zone 3 with 0.60 m.

The United Kingdom defines three areas of operation similar to those of the UNECE, and adds a fourth for small rivers and canals with a depth of less than 1.5 m.

China establishes three categories of vessels for inland navigation: category A for significant wave height of up to 2.5 m, B for 1.5 m, and C for 0.5 m.

Russia has three similar categories but adds another for 3 m waves (Lakes Ladoga and Onega).

The way these heights are defined varies, ranging from 1 to 10% of the highest heights, depending on the country.

It is also interesting to note that the wind speed considered in the stability calculations also varies depending on the navigation zone.

Free Area for Passengers

How to treat the areas occupied by chairs?

- Consider that each seat continues to be occupied by 1 passenger, with no additional passenger between them?

- Consider that the passengers will be standing on the chairs and that there will be additional passengers between them?
- Consider that in the area of the seats the passengers will also crowd with a density of 4 passengers/m^2 ?
- Consider a grouping density in the seats specified in another standard (e.g. DNV) with 2.67 passengers/m^2)?
- Consider that the seats will have the seat retracted in their upright position and passengers will only use the area between them?
- Should the free area consider spaces outside the passenger lounge, which when traveling would be out of your reach? In the stability analysis of the US-2000 class, the area outside the passenger lounge is considered as a free area, capable of having passengers grouped together, although it is separated from the lounge by watertight doors of automatic closing that can be manually unlocked by an emergency button.

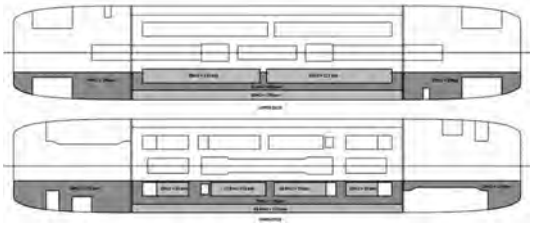


Figure 15 - Areas outside the passenger lounge considered in the calculation

Should the areas occupied by standing passengers in the condition of movement to the board include the areas reserved for cargo? It should be considered that these areas are usually separated from the passenger areas by tapes or markings on the floor.

Righting Arm Curve

The righting arm curve or static stability is usually calculated by considering the position of the center of gravity in the initial condition, when part of the passengers are seated. However, in the agglomeration of passengers on board, most of the passengers who were seated stand up, changing the vertical position of the center of gravity of the condition.

This change in the static stability curve is never considered, although it increases the equilibrium angle.

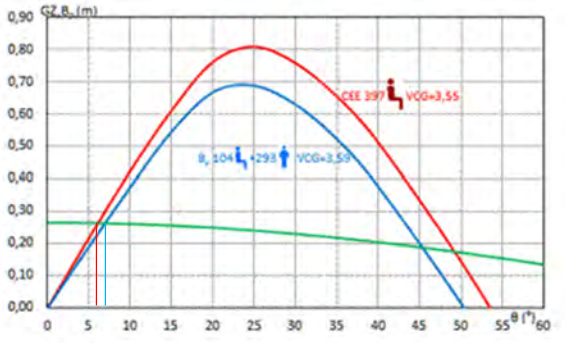


Figure 16 - Change in the static stability curve due to change in passenger VCG

Flooding Angle Not Available

Although NORMAM requires the presentation of cross curves or tables and that the static stability curve must be interrupted from the corresponding flooding angle, in practice this is never met. Even the most detailed specification does not indicate the presentation of these flooding angle curves. As a result, the KN curves and tables never indicate the progressive flooding curve, making it impossible to verify new stability condition without a new hull modeling.

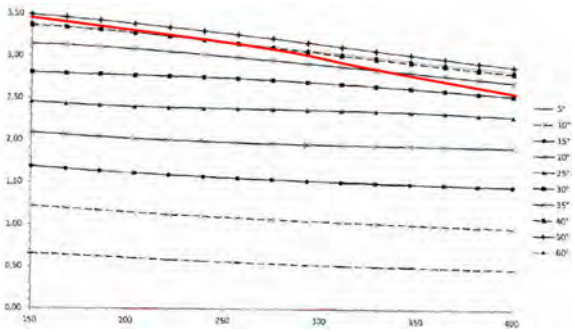


Figure 17 - Cross curves of stability (red curve of the flooding angle added by the author)

Δ [t]	5°	10°	15°	20°	25°	30°	35°	40°	50°	60°
150,0	0,655	1,22	1,689	2,091	2,457	2,807	3,143	3,359	3,489	3,38
167,9	0,637	1,192	1,66	2,064	2,432	2,792	3,129	3,338	3,456	3,343
185,7	0,619	1,166	1,634	2,04	2,414	2,781	3,108	3,31	3,42	3,306
203,6	0,602	1,142	1,611	2,021	2,4	2,771	3,081	3,275	3,381	3,268
221,4	0,585	1,12	1,59	2,004	2,39	2,762	3,051	3,235	3,34	3,23
239,3	0,57	1,101	1,571	1,99	2,383	2,751	3,02	3,191	3,298	3,192
257,1	0,555	1,082	1,554	1,978	2,378	2,736	2,986	3,147	3,255	3,153
275,0	0,542	1,065	1,539	1,967	2,372	2,718	2,952	3,103	3,21	3,114
292,9	0,53	1,049	1,524	1,959	2,367	2,697	2,918	3,059	3,164	3,075
310,7	0,519	1,034	1,511	1,952	2,362	2,675	2,882	3,015	3,116	3,036
328,6	0,51	1,02	1,5	1,947	2,355	2,65	2,847	2,972	3,068	2,996
346,4	0,502	1,007	1,489	1,943	2,344	2,625	2,811	2,93	3,021	2,955
364,3	0,495	0,994	1,479	1,938	2,331	2,598	2,775	2,888	2,975	2,914
382,1	0,489	0,983	1,471	1,934	2,316	2,57	2,739	2,847	2,93	2,873
400,0	0,483	0,973	1,463	1,929	2,298	2,542	2,703	2,807	2,887	2,833

Table 4 - Cross curve table (false red items - flooding has already occurred)

Deck Immersion Angle

Similar reasoning to that of flood angles can be applied to the deck immersion angle curve, which is also never presented.

Initial Passenger Density in Free Areas

Most rules allow a capacity of standing passengers at a density of up to 4 passengers/m^2, and simultaneously indicates this same value for the grouping of passengers on board, we can reach the extreme case in which this grouping will not cause any moment of capsizing.

The figure allows us to have a good visualization of what the density of people means.

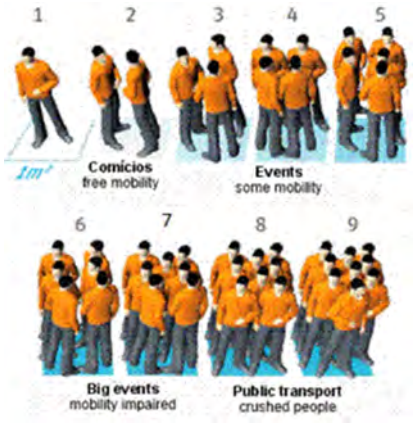


Figure 18 - Crowd density

The ideal density of passengers in public transport considers the accelerations of the means of transport, the duration of the journey and the degree of comfort that is intended to be given to the passenger.

The following graph was taken from Bovy (1974), but these values easily exceeded at peak times.

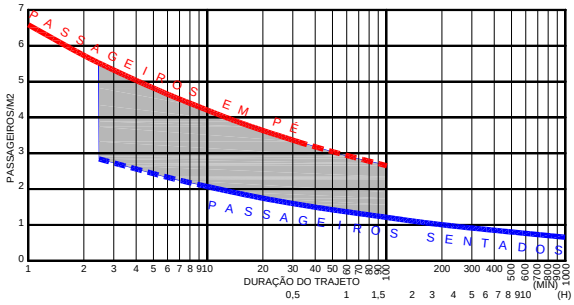


Figure 19 - Occupancy density of public transport

Reck (2010) refers to some European studies, where a comfortable surface of 0.30 to 0.40 m2 per person standing is ideal for displacements of about 20 minutes.

Fruin (1971) developed a study based on the relationships between anthropometric characteristics, circulation conditions and psychological factors of people in agglomerations, resulting in the table below.

COMFORT LEVEL	PERSONS/M²	PSYCHOLOGICAL FACTORS
A	Under 0.8	None
B	0.8 to 1.1	None
C	1.1 to 1.4	Comfort zone
D	1.4 to 3.3	Avoidable contact
E	3.3 to 5.0	Inevitable contact
F	Over 5.0	Discomfort

Table 5 - Comfort levels depending on the available area per individual

As a curiosity, the São Paulo Metro transports more than 8 passengers/m^2 during its peak hours (the bearable limit, according to experts, would be 6 passengers/m^2.)

Density of Grouping Passengers on a Side

Both DNV and Bureau Veritas and several other classification societies adopt a grouped passenger density of 3.75 passengers/m^2 for the free areas, but on the other hand they establish very different criteria for intact stability, in addition to requesting an analysis of the stability in damage.

CRITERIA	NORMAM AREA 1	NORMAM AREA 2	CFR	DNV / BV / IRCLASS / UNECE	MCA (UK)	RINA
θ1 (°)	≤ θi or 15	≤ θi or 12	*3	*1	≤ 10	≤ 12
Residual freeboard (m)	0,00			0,20		≥ 0.20
A2/A1	≥ 1	≥ 1.2		*2	*3	
GM_{corr} (m)	≥ 0.35		≥ 0.15			
θ_f (°)	≥ 25	≥ 30		≥ θ1+3		
GZ_{max} (m)	≥ 0.10	≥ 0.15	≥ 0.20			
θ_{GZMAX}(°)			≥ 25	≥ θf+3	≥ 30	≥ 25
INJURY CRITERIA	NO			YES		

Table 6 - Some stability criteria

*1 : Some standards establish the maximum angle of balance only according to the grouping of passengers on board, while others combine this moment with the one due to wind or yaw separately. Some others combine the effect of the three (passengers, wind and yaw) in the equilibrium angle criterion. It should be noted, however, that wind speed is not the same in all these standards.

*2 : The area under the curve of the righting arms must follow parameters that are quite different from those of NORMAM, and absolute values are defined for them:

*3 : By CFR, MCA and RINA the righting arm curve must not have an area less than 0.055 m.rad up to 30° and not less than 0.09 m.rad up to θf or 40°, whichever is smaller. In addition, between 30° and θf or up to 40° must be greater than 0.03 m.rad.

The MCA also establishes a criterion of severe wind and simultaneous swing (atmospheric criterion) where a constant wind and a gust of wind are combined, also taking into account the period of play of the vessel.

CONCLUDING REMARKS

Although NORMAM-202 provides that there may be a more critical intermediate loading condition than the one with 100% passengers, experience shows us, after analyzing dozens of Trim and Stability Leaflets, that this is never done by the naval architects.

It would be interesting if the rules requires, for vessels carrying passengers seated and standing simultaneously, at least the analysis of capsizing due to the grouping of passengers on board, considering a loading condition with passengers only initially seated, when possibly the moment of capsizing due to their movement to an edge will be maximum or very close to it, and the curve of righting arms takes into account the vertical position of the resulting center of gravity.

Several rules require that there be a residual freeboard when there is an accumulation of passengers on board, while Brazilian rule only requires that there is no submersion of the deck.

NORMAM-202 requires stability analysis for isolated action of passenger grouping on a side, wind, turning maneuver or towing. We verified, however, as usual for accidents, that most shipwrecks have occurred when there is simultaneity of the accumulation of passengers with the occurrence of waves/crosswind. Some of the rules add their effects to the calculation of the equilibrium angle, without the criterion of the A2/A1 ratio.

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