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REVISION OF THE INTACT STABILITY CODE

Intact stability equivalent criteria for small domestic passenger ships

Submitted by the United Kingdom

SUMMARY

Executive summary:	The United Kingdom submits the results of a research project* modelling three domestic passenger ships, investigating the influence of the still water GZ parameter angle of peak GZ, on the probability of exceeding a critical roll angle for the modelled ships. A critical roll angle is defined as 45 degrees, allowing the probability of its exceedence to be evaluated under a range of load conditions, speed, heading and sea states. The angle of peak GZ parameter is compared with other stability parameters currently in use or proposed.
Strategic direction:	5.2
High-level action:	5.2.1
Planned output:	5.2.1.2
Action to be taken:	Paragraph 7
Related documents:	SLF 49/5/2 and MSC 83/28, annex 13

1 Introduction

1.1 MSC 84 is expected to adopt a revised Intact Stability Code (IS Code) with a view to mandatory application under SOLAS and LL Conventions, to supersede or amend resolution A.749(18) [1]. This Code contains GZ based stability criteria as well as well as a severe wind and rolling criterion.

* Intact stability equivalent criteria for small domestic passenger ships. Project 572.

1.2 In the case of small United Kingdom domestic passenger ships, particularly those with open ro-ro decks and of a wide beam and shallow draft design, the various still water GZ curve criteria within resolution A.749(18) are sometimes unattainable. The criterion most frequently failed by wide beam, shallow draught designs is that requiring the GZ curve to peak at an angle of heel beyond 25 degrees. Such ships have in the past been permitted early peaking GZ curves, provided the energy criterion (area below the still water curve in m.rad) was suitably uplifted. Such 'equivalent' GZ curves had been allowed to have an angle of heel at the peak as low as 15 degrees in special cases.

2 Numerical simulations

2.1 The numerical simulation program FREDYN was developed by the Maritime Research Institute Netherlands (MARIN) for the Cooperative Research Navies working group, and continues to be applied extensively – both to intact and damaged ships. This time-domain program is able to take account of nonlinearities associated with drag forces, wave excitation forces, large-angle rigid-body dynamics and motion control devices. The FREDYN program permits investigations into the dynamics of intact and damaged vessels operating in realistic environments.

2.2 By using a conventional vessel that satisfactorily passes the current stability criteria, it allows the dynamic performance in realistic wind and waves to be evaluated and compared to that predicted for the more unconventional hull forms. This performance can also be related back to static stability criteria terms, which identifies the individual terms and the levels that will give the equivalent level of stability performance. It also indicates which criteria terms provide the best indication of the dynamic stability performance.

2.3 Three vessels were selected for this numerical study. The first was a more conventional vessel (CONTROL) which complies with all the stability requirements of the IS Code, with a maximum GZ occurring at a heel angle in excess of 30 degrees. The two other vessels that were selected were of similar size and pass the IS Code apart from maximum GZ occurring at heel angles just below 25 degrees. These vessels are VARIANTS 1 and 2. The main dimensions are given below in table 1.

Table 1 – Three test vessels

Ship Name		CONTROL	VARIANT 1	VARIANT 2
Length BP	[m]	79.45	91.2	75
Breadth moulded	[m]	16.3	15.8	15.8
Draught amidships	[m]	3.95	3.21	3.1
Cb	[-]	0.59	0.74	0.64
Displacement	[Te]	3100.9	3491.4	2398.3
Trim	[m]	0.04	0.16	0.05
LCG fwd AP	[m]	37.1	44.09	36.22

2.4 The loading conditions were chosen such that one condition matched the limiting condition according to the current IS Code, allowing an assessment of the current level of performance afforded by these regulations. Two alternative conditions were also tested with one having a higher GM, based on a typical loaded arrival operating condition, and one having a lower GM. Thus, one alternative condition failed the IS Code criteria and the other passed by some margin. The displacement and trim in each condition were identical and set to match that of the loaded arrival condition.

3 Probabilistic calculation of Critical Roll Index

3.1 FREDYN simulations were used to evaluate the critical roll (capsize) behaviour of the three vessels in a range of loading conditions from passing the IS Code through to failing. This Critical Roll Index Parameter allows the dynamic performance to be compared with the static stability criteria parameters.

3.2 It is understood that a capsize risk value produced by simulations has, in isolation, limited true meaning and should not be taken as an absolute level of capsize risk. The probability value produced by this method is therefore described as a Critical Roll Index rather than a pure capsize risk.

3.3 The methodology used to calculate the Critical Roll Index is similar to that used by QinetiQ within the CRNavies group to determine a Critical Roll Index for naval vessels. This procedure was developed by McTaggart [6] in 2002 and is described further in his paper [7]. A conventional vessel which passes current stability standards with acceptable performance is tested as a benchmark. This vessel's Critical Roll Index can then be compared to the more unconventional vessels which have lower peaking GZ max angles. The relationship between the static criteria terms and the affect on the dynamic performance on the vessels (i.e., Critical Roll Index) can be evaluated, which allows an equivalent level of dynamic stability and hence capsize safety to be identified.

3.4 The method used to determine the critical roll index combines predictions from FREDYN with probabilistic input data for wave conditions and ship speed and heading. The probability of capsize C_D in a random seaway of duration D is thus [4]:

$$P(C_D) = \sum_{i=1}^{N_{V_s}} \sum_{j=1}^{N_b} \sum_{k=1}^{N_{H_s}} \sum_{l=1}^{N_{T_p}} P_{v_s}(v_{s,i}) P_b(b_j) P_{H_s,T_p}(H_{s,k} T_{p,l}) P(C_D \mid V_s, b, H_s, T_p) \quad (1)$$

Where: V_s = ship speed, ß = wave heading relative to ship, H_s= wave significant height, T_p = wave modal period.

3.5 The last term is a conditional probability of capsize in a given wave condition and ship heading relative to the waves. For this study only two suitable speeds were selected to avoid unrealistic operator speed decisions, although an even probability of heading was assumed. In reality in very large seas, the operator may avoid the worst headings.

3.6 Using this method the motions of the vessels were simulated at every speed and heading combination at a wide range of significant wave heights and modal wave period combinations. Up to 30 simulations were conducted at each speed/heading/wave condition to generate data to calculate the probability of reaching the critical roll limit. A Bales wave climate statistics table [5] for the North Atlantic was used to provide the probability of the waves occurring.

3.7 Probability distribution curves were fitted to the peak roll angle data from each hour long simulation in each of the seaway conditions. The limited Gumbel distributions and the distribution free curves provide the best data fit [4] and better prediction at the higher roll angles which were of the most interest for critical roll (capsize) prediction [4]. The Gumbel distribution has the advantage that it can be used to extrapolate beyond the observed range of values. The distribution free predictions have less bias associated with them than using fitted distributions [4]. As the critical roll angle in this study was set to 45 degrees, the distribution free curve was used to fit to the roll data.

4 Model experiments

4.1 In consultation with the sponsor, the conventional vessel used for the numerical study (CONTROL) was selected for the physical experiments. The vessel's full scale and model properties are displayed in table 2 below:

Table 2 - Physical model properties

Scale ratio 1:30		Model		Ship equivalent	
		Operating	IS-Code Limit	Operating	IS-Code Limit
Length BP	[m]	2.648		79.45	
Beam	[m]	0.543		16.30	
Draught	[m]	0.132		3.95	
Displacement	[Te]	0.112		3101	
Trim	[m]	0.001		0.04	
LCG fwd AP	[m]	1.237		37.1	
KM	[m]	0.287	0.287	8.61	8.61
KG	[m]	0.242	0.261	7.26	7.83
GM	[m]	0.045	0.026	1.35	0.78
Roll Period	[s]	1.79	2.32	9.8	12.7
K_{zz}	[m]	0.636	0.636	19.08	19.08
K_{zz}/L_{PP}	[-]	0.240	0.240	0.24	0.24

4.2 The model tests were performed at zero speed in beam seas. Due to the time and cost which would be involved with a comprehensive set of free-manoeuvring model experiments, only a limited series were conducted to validate the FREDYN simulations. As the aim of the study was to predict and compare large roll angles the model tests were performed in a range of wave conditions.

4.3 Figure 2 shows a comparison of the normalised roll (roll amplitude divided by maximum wave slope) and phase responses in regular waves as predicted by FREDYN and calculated using the model test data.

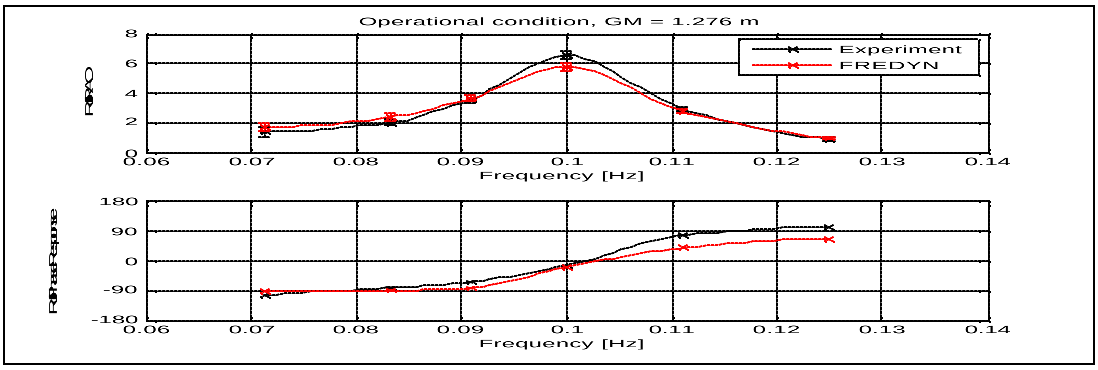

Figure 2 – CONTROL Vessel Operating Condition – Experiment and FREDYN roll response

Figure 2 shows a close comparison between the experiment results and the FREDYN simulations for CONTROL vessel in the operating condition.

5 Numerical results

5.1 Plotting the Critical Roll Index at a range of loading conditions against the corresponding static stability terms provides an indication of which current static stability terms give the best indication and relationship with the predicted dynamic stability performance. This allows the current criteria to be ranked, according to which give the best indication of dynamic stability performance. By comparing the whole set of criteria it was possible to get an indication of the relative level of dynamic stability performance associated with complying with each of the stability criteria terms. An example of one of the plots is given in figure 3, which shows the area to GZmax against the Critical Roll Index for the three vessels at the three loading conditions.

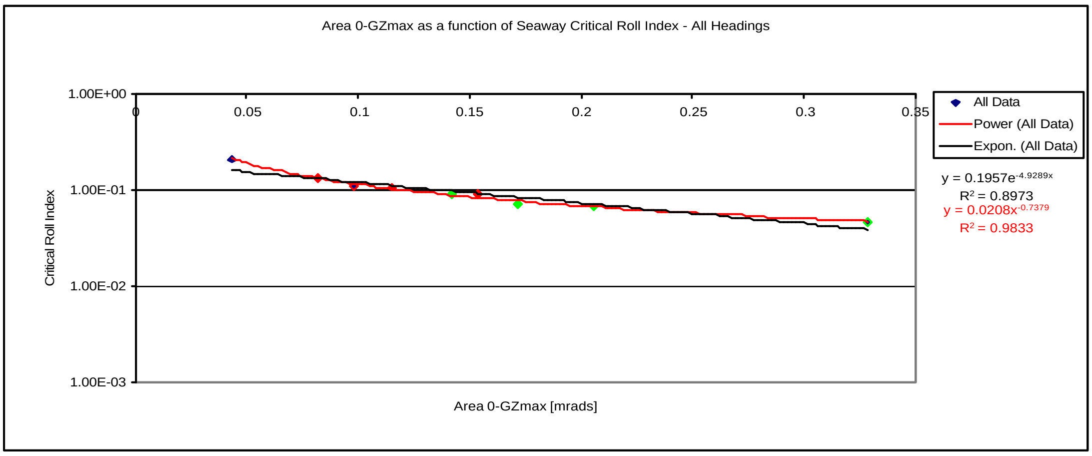

Figure 3 – Area to GZmax Vs Critical Roll Index

5.2 Table 3 shows the data ranked for four subsets of data using a power curve data fit. The top ranking four criteria were colour coded to highlight the criteria with the best data fit. The data set includes the results for all of the vessels in all of the waves tested. There are three further subsets, the second is with all the vessels but with the waves limited to a mid sea state 7. The final two data sets are for the two high B/T vessels in all waves and also restricted to a maximum of a mid sea state 7.

5.3 The power trend line data and criteria ranking is shown in table 3 below.

POWER	Value				Rank			
Parameter	All Data All Waves	v1 & v2 All Waves	All Data Upto Mid SS7	v1 & v2 Upto Mid SS7	All Data All Waves	v1 & v2 All Waves	All Data Upto Mid SS7	v1 & v2 Upto Mid SS7
GM_F(m) not less than 0.3	0.591	0.8952	0.5794	0.868	12	10	12	10
$AREA_{0-30}$ not less than 0.08	0.6524	0.9342	0.651	0.9154	9	7	9	7
$AREA_{0-40}$ not less than 0.133	0.7944	0.9176	0.7883	0.8969	6	9	6	9
$AREA_{30-40}$ not less than 0.048	0.7486	0.8358	0.7274	0.807	7	14	8	14
Area to GZ max	**0.9833**	0.9713	0.9819	0.9296	1	1	1	3
Angle of GZ_{max} not less than 30	0.3646	0.8452	0.3654	0.8515	14	13	14	12
GZ_{max} not less than 0.3	0.7389	0.8493	0.7426	0.8389	8	12	7	13
Total Dynamic Stability	0.9629	0.9487	0.9586	0.9336	3	4	3	2
RPS	0.4085	0.8773	0.3975	0.8527	13	11	13	11
DS/Cvp	0.9715	0.9632	0.9647	0.9467	2	2	2	1
Total Dynamic Stability +30	0.8372	0.9325	0.8232	0.9123	4	8	4	8
DS+30/Cvp	0.8143	0.9414	0.7995	0.9206	5	6	5	6
Total Dynamic Stability +40	0	0	0	0	15	16	15	16
DS+40/Cvp	0	0	0	0	15	16	15	16
Wind A1/A2	0	0.796	0	0.7884	15	15	15	15
$AREA_{0-15}$ not less than 0.07	0.6341	0.9504	0.627	0.9264	10	3	10	4
$AREA_{0-20}$ not less than 0.065	0.6069	0.9479	0.603	0.925	11	5	11	5

Table 3 - Power fit R^2 values and ranking

5.4 The current GZ area criteria do not produce the best data fit compared to some alternative stability measures with the power curve trend line using all of the vessels in the data set. For the vessels tested, the area under the GZ curve, area under the GZ curve over the vertical prismatic coefficient (Cvp) and the area up to GZmax were shown to be the best fitting criteria with the complete data set for the three test vessels.

6 Equivalent levels of Critical Roll Index

6.1 Taking the Critical Roll Index for all the cases tested allowed the levels of the current criteria limits to be compared in a relative manner. By using the current criteria limit lines and the data trend lines from the figures, the current level of risk of reaching the critical roll angle could be evaluated at each of the current intact stability criteria limit levels. It was found that many of the existing current IS Code criteria limits were reached at similar values of critical roll risk, at around the 2×10^{-1} level. The exception to this was the a/b wind criteria, where the criteria level is reached at 9×10^{-2}. This was using approximated data with a fixed 25 degree roll back angle (roll angle to windward due to the wave action) which could account for this. This measure does however still show a good fit of 0.94 and was one of the better current measures.

6.2 The Area 0-15 criterion was found to provide an equivalent Critical Roll Index at 0.055 and so the current proposed 0.07 m.rads is greater. However, the vessels tested do not have a GZ curve that peaks that low. The Area 0-20 criteria requires an area of 0.065 m.rads in the proposed IS Code. To obtain an equivalent Critical Roll index an area of 0.085 is required based on the high B/T vessel data where their GZmax values are above 20 degrees (23 to 25 degrees). Considering the area to the GZ max for the two larger B/T vessels at the three conditions, it can be seen that they will currently pass the new proposed IS area criteria code (based on offshore supply vessel criteria), which is dependant on the actual GZmax angle when it is between 20 and 30 degrees. To achieve an equivalent Critical Roll Index then an area to GZmax of 0.14 is required for these vessels with the angle of GZmax between 20 and 25 degrees.

6.3 There are currently no stability criteria for the total area under the GZ curve (dynamic stability) or the area under the GZ over vertical prismatic coefficient in the current IS Code. The trend lines on the complete data set give a data fit of 0.96, which is better than most of the standard criteria measures tested. To achieve an equivalent level of critical roll index to the IS Code limiting case for the conventional vessel, then a total area under the GZ curve of greater than 0.2 m.rads is required or a GZ area / Cvp of 0.34.

7 Action requested of the Sub-Committee

7.1 The Sub-Committee is invited to note the above discussion in the context of the long term review of Intact Stability requirements. The full report can be downloaded from the website below, as Research Project 572:

http://www.mcga.gov.uk/c4mca/mcga07-home/aboutus/mcga-aboutus-whatwedo/mcga-aboutus research2.htm

8 References/bibliography

[1] IMO. Draft Revised Intact Stability Code, MSC 83/28, annex 13.

[2] IMO-SLF. *Proposal of a probabilistic intact stability criterion.* Agenda item 5, submitted by Germany. SLF 49/5/2. April 2006.

[3] Lloyd, ARJM. *Seakeeping: Ship Behaviour in Rough Weather*. Revised Edition. Published by the author. Available from Royal Institution of Naval Architects, 10 Upper Belgrave Street, London. 1998.

[4] McTaggart, KA. *Improved Modelling of Capsize Risk in Random Seas*. Defence Research Establishment Atlantic. July 2000.

[5] Bales S.L, Lee, WT and Voelker J.M (1981) Standardised Wave and Wind Environments for NATO Operational Areas.

[6] McTaggert K.A, DeKat J.O 'Capsize Risk of Intact Frigates in Irregular Seas', SNAME Transactions 2000.

[7] McTaggert K.A, DeKat J.O 'Capsize Risk of Intact Frigates in Irregular Seas' SNAME Transactions 2000.

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