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REPORT TO THE MARITIME SAFETY COMMITTEE

Attached is annex 4 (part 6 of 6) to the report to the Maritime Safety Committee (SDC 8/18).

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APPENDIX 6

APPLICATION EXAMPLES OF TREATMENT OF LOADING CONDITIONS

Introduction

1 The application of vulnerability criteria should cover all loading conditions intended for the ship's operation. In this respect, *GM*, draught and trim should be appropriately considered. However, for the sake of simplicity, the application examples here cover only combinations of *GM* and draught. Specifically, matrix calculations have been carried out, where vulnerability criteria have been applied for each combination of *GM* and draught; and the roll period has been estimated in accordance with paragraph 2.7.1.2.

2 Paragraphs 2.2.1.3, 2.3.1.3, 2.4.1.3, 2.5.1.2 and 2.6.1.2 allow the use of direct stability assessment or operational measures as alternatives to the vulnerability criteria specified for each particular failure mode. Nevertheless, for demonstration purposes, the application examples stipulated here show only the results of probabilistic direct stability assessment and probabilistic operational measures for the parametric rolling and pure loss of stability failure modes. It is also noted that the verification of failure modes, according to section 3.5.2, has not been carried out for the reported example applications. Therefore, reported direct stability assessment results are conservative compared to those that would be obtained by applying section 3.5.2. Furthermore, for each example ship, results of the direct stability assessment are shown only for a typical draught. Examples of direct stability assessment for other loading conditions can be found in section 4.2 of appendix 4.

3 Since direct stability assessment requires significant computational efforts, the user may be guided by a sequential logic of application of the Interim Guidelines (section 1.1.3 therein). In this regard, direct stability assessment may be applied to the loading conditions that are indicated to be potentially vulnerable according to the vulnerability criteria for the relevant failure mode.

4 The numerical model used in the direct stability assessment should be validated based on paragraph 3.4.1.2 and the identified failure mode in the direct stability assessment should be the same as that used in the validation (see paragraph 3.5.2.1).

5 In these application examples, whenever the Weather Criterion is mentioned, the use of MSC.1/Circ.1200 is not taken into account. Thus, for the actual application, the possibility of its use could be considered in accordance with the provisions of part A, paragraphs 2.3.3 and 2.3.5 of the 2008 IS Code.

6 When comparing specific loading conditions with results from the assessment, *GM* values corrected for free surface effects should be used for the dead ship condition, pure loss of stability and parametric rolling failure modes (see paragraphs 2.2.1.7, 2.4.1.7 and 2.5.1.6, respectively); whereas *GM* values not corrected for free surface effects should be used for excessive acceleration failure mode (see paragraph 2.3.1.7).

7 In the matrix calculation shown in this appendix, red and blue colours indicate that the ship is "possibly vulnerable" and "acceptable" to the failure modes, respectively.

1 Examples of the treatment of loading conditions

1.1 Cruise ship

1.1.1 An existing cruise vessel with the length between perpendiculars 230.9 m and waterline breadth 32.2 m was used as an example.

1.1.2 The criteria from part A of the 2008 IS Code and the deterministic damage stability requirements in the SOLAS (as amended by resolutions in effect as on 1 July 2004) result in minimum GM dependencies on the draft shown in figure 1.1.1.

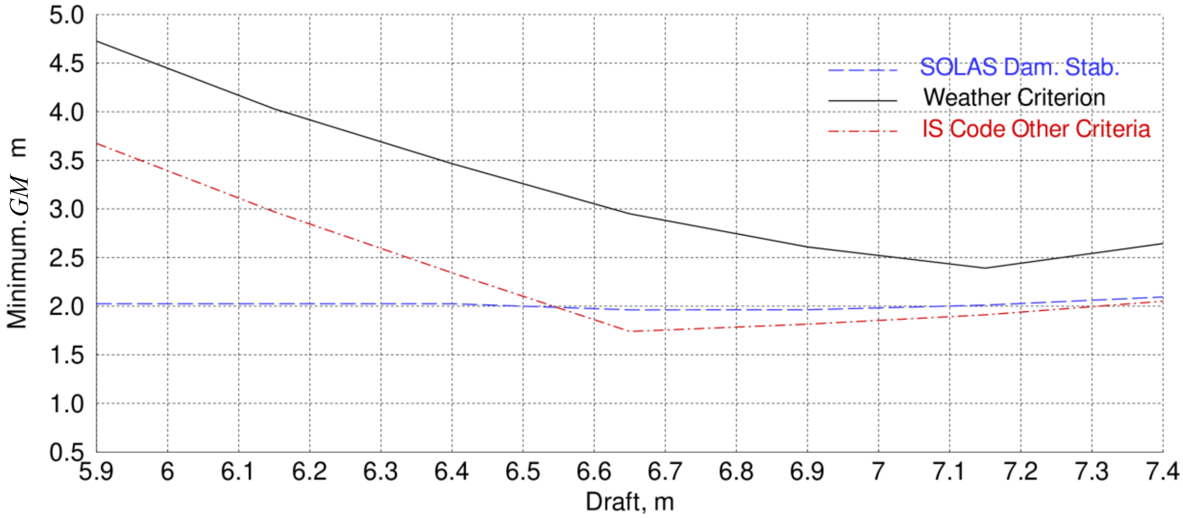


Figure 1.1.1. Minimum GM curves vs. draft according to the 2008 IS Code part A criteria and SOLAS damage stability requirements for cruise vessel

1.1.3 Figure 1.1.2 shows results of assessment with respect to level 1 and level 2 vulnerability criteria for parametric roll stability failure mode. Since it is sufficient to satisfy one of these three assessment options, these criteria do not suggest additional recommendations on the minimum GM for this vessel compared to the criteria from part A of the 2008 IS Code and SOLAS damage stability requirements because the mandatory criteria shown in figure 1.1.1 supersede those recommended in figure 1.1.2.

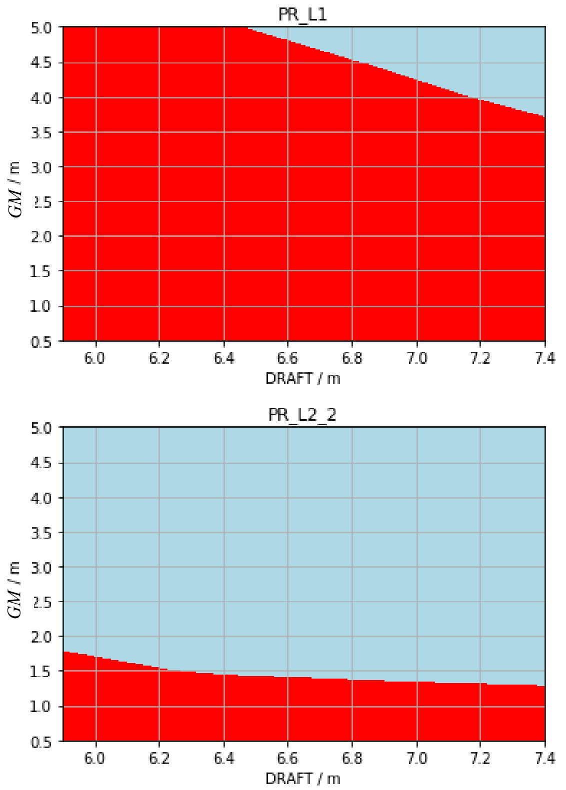


Figure 1.1.2 Result of level 1 (top left – PR_L1), level 2 check 1 (top right – PR_L2_1) and level 2 check 2 (bottom left – PR_L2_1) assessment for the parametric roll stability failure mode for cruise vessel

1.1.4 Assessment with respect to level 1 and level 2 vulnerability criteria for the pure loss of stability failure mode, figure 1.1.3, shows that the ship is vulnerable with respect to level 1 criterion in all combinations of draught and *GM* shown in figure 1.1.3. This failure mode does not suggest additional recommendations on the minimum *GM* for this vessel compared to the criteria from part A of the 2008 IS Code and SOLAS damage stability requirements.

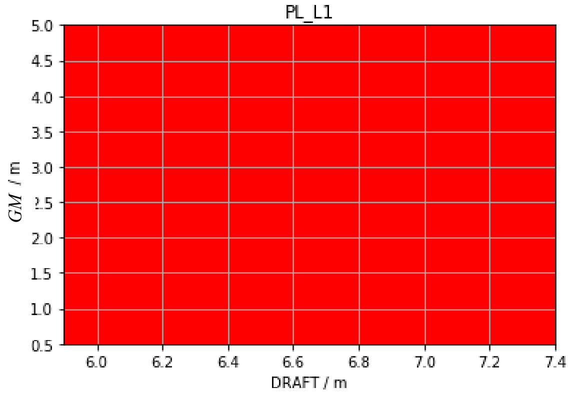


Figure 1.1.3 Results of level 1 and level 2 assessment for pure loss of stability failure mode for cruise vessel

1.1.5 Because the length of the vessel is greater than 200 m, an assessment with respect to the level 1 criterion for surf-riding/broaching indicates that the ship is not vulnerable to this stability failure mode in all loading conditions.

1.1.6 Since the natural roll period of the ship in the considered loading conditions is below (or only marginally above) 20 s, there is no difference between the Weather Criterion from part A of the 2008 IS Code and level 1 criterion for dead ship condition stability failure mode, figure 1.1.4. Application of level 2 criterion for dead ship condition stability failure mode does not suggest additional recommendations on the minimum *GM* value.

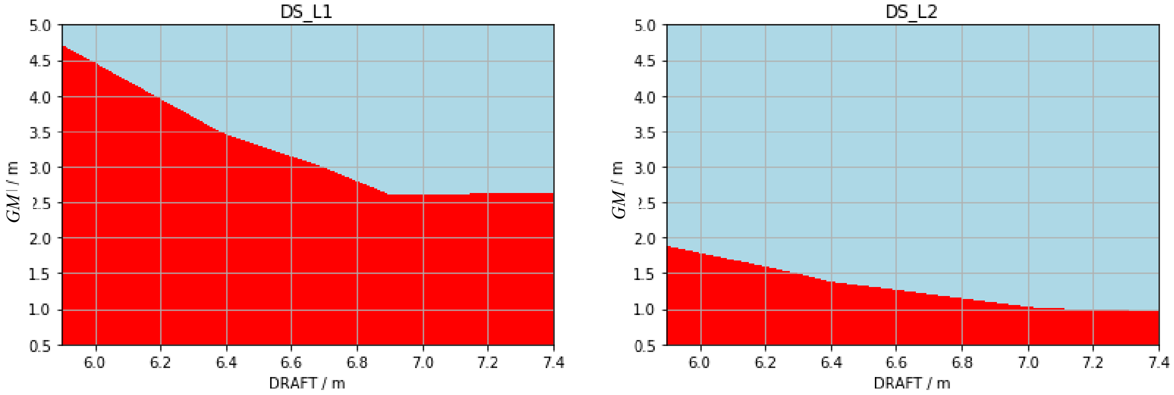


Figure 1.1.4. Results of level 1 and level 2 assessment for dead ship condition stability failure mode for cruise vessel, DS_L1 and DS_L2, respectively

1.1.7 The application of vulnerability criteria for the excessive acceleration stability failure mode leads to recommendations on the upper limit of *GM*. Figure 1.1.5 shows that level 2 allows significantly greater maximum *GM* values than level 1, which are also well above the *GM* range relevant in practice for this vessel. Users should note that the *GM* values associated with results of excessive acceleration criteria represent metacentric heights without correction for free surface.

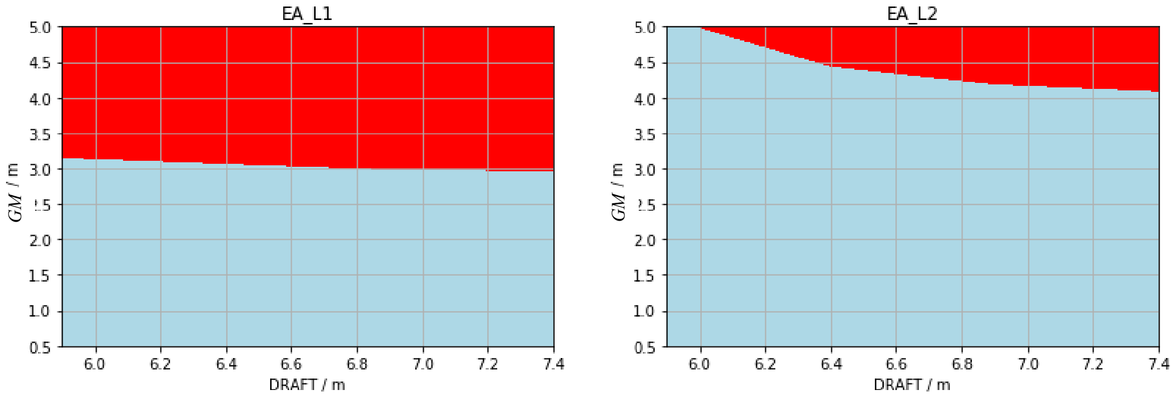


Figure 1.1.5. Results of level 1 and level 2 assessment for excessive acceleration stability failure mode for cruise vessel

1.1.8 For the considered cruise vessel, the second-generation intact stability criteria do not result in any additional recommendations relative to part A of the 2008 IS Code and the damage stability requirements of SOLAS on the minimum *GM* values (for the considered, practically relevant, range of draughts). Since the limiting criterion for the minimum *GM* values is the Weather Criterion, figure 1.1.6, and that the assessment for the level 2 criterion for the dead ship failure mode indicates lower minimum *GM* values, then the application of MSC.1/Circ.1200 may be utilized to evaluate revised minimum *GM* values. The vulnerability criteria for excessive accelerations impose additional limitations on the maximum *GM* values (however, these limitations are above the *GM* values relevant in practice).

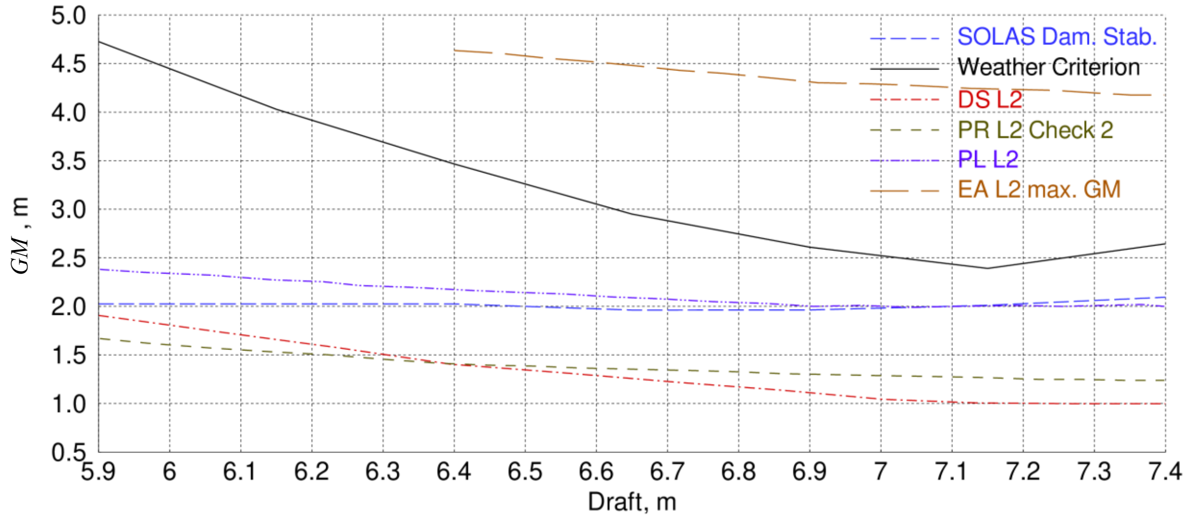


Figure 1.1.6. *GM* limits according to the 2008 IS Code part A, SOLAS damage stability requirements and second-generation intact stability criteria (including maximum *GM* according to excessive accelerations criterion) for cruise vessel

1.1.9 Six loading conditions at the practically most relevant draught 6.9 m and *GM* values 1.5, 2.0, 2.5, 3.25 and 3.75 m, table 4.1.1 of chapter 4 of appendix 4, were assessed using full probabilistic direct stability assessment. Figure 1.1.7 plots the conservative estimate of the upper boundary $\bar{r}_U$ of the 95%-confidence interval of the average "long-term" stability failure rate, calculated as the weighted average of the upper boundaries of the 95%-confidence intervals of the "short-term" stability failure rate (see explanatory note to paragraph 3.5.3.2.1 of the Interim Guidelines). The standard $2.6 \cdot 10^{-8}$ 1/s for $\bar{r}_U$ is satisfied for *GM* values above 2.158 m. This is greater than the minimum required *GM* from chapter 2 of MSC.1/Circ.1627 – vulnerability requirements (which indicates inconsistency between the vulnerability assessment and direct stability assessment for the considered ship and draught). However, the weather criterion requires greater minimum *GM* and, therefore, this consistency does not suggest any additional recommendations for the minimum *GM* value.

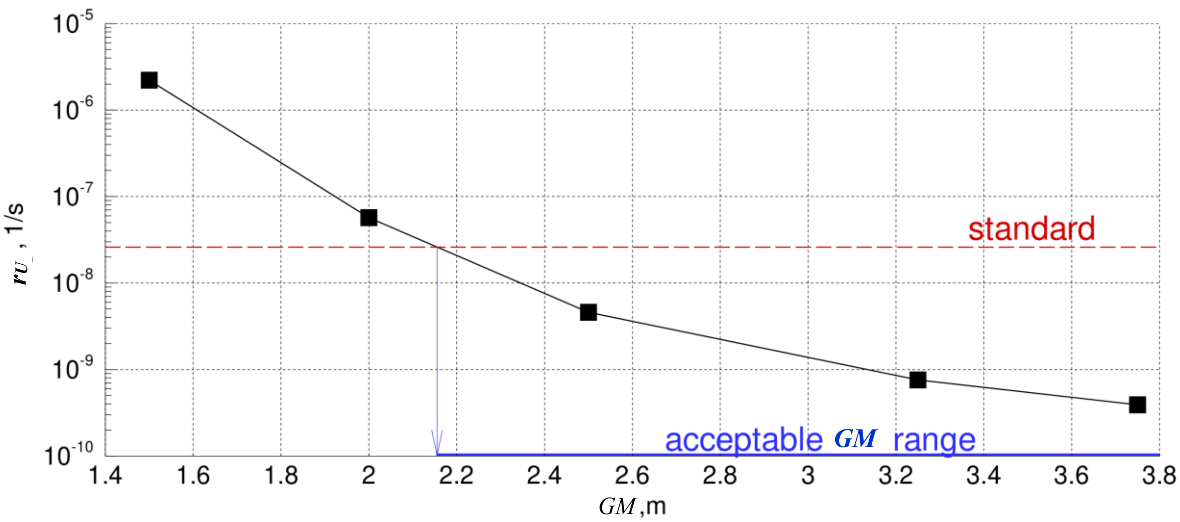


Figure 1.1.7. Conservative estimate of upper boundary $\bar{r}_U$ of 95%-confidence interval of average "long-term" stability failure rate vs. *GM* at draught 6.9 m for cruise vessel in comparison with acceptance standard $2.6 \cdot 10^{-8}$ 1/s and resulting acceptable *GM* range

1.1.10 Probabilistic operational guidance was prepared for the same loading conditions by identifying unacceptable sailing conditions (v_0,μ), i.e. sailing conditions for which the upper boundary of 95%-confidence interval of "short-term" stability failure rate exceeds acceptance standard 10^{-6} s^{-1}, for each sea state (H_s,T_z) in the North Atlantic wave scatter table. Figure 1.1.8 shows "long-term" weighted average $\bar{r}_U$ of upper boundaries of the 95%-confidence intervals of the "short-term" stability failure rate with and without using operational guidance together with the operability due to the use of operational guidance vs. GM. Since operability exceeds 0.8, operational guidance is an acceptable option for all considered loading conditions.

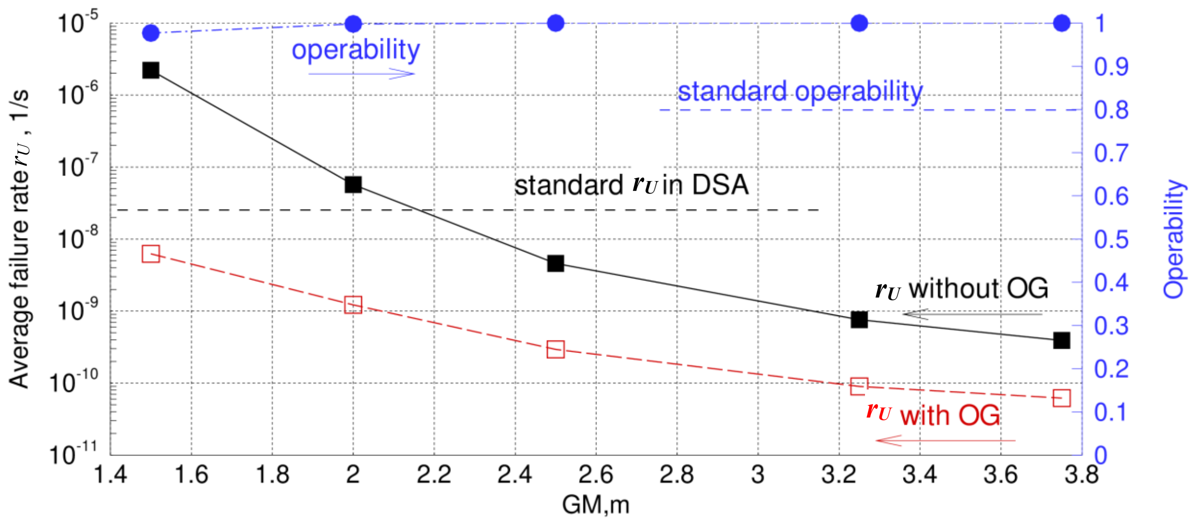


Figure 1.1.8. "Long-term" weighted average of upper boundaries of 95%-confidence intervals of "short-term" stability failure rate with and without OG and operability vs. GM at draught 6.9 m for cruise vessel

1.1.11 Examples of operational limitations related to areas or routes and season concern the same loading conditions for sample operational routes and seasons from table 2.2.1, chapter 2 of appendix 5. Table 1.1.1 shows the upper boundary $\bar{r}_U$ of the 95%-confidence interval of average "long-term" stability failure rate for unrestricted operation (area 1) and specific routes and seasons (areas 2 to 6); red colour indicates unacceptable loading conditions. The stability failure rate generally decreases for considered sample routes and seasons compared to unrestricted service but the reduction is insufficient to render the loading conditions that are unacceptable for unrestricted operation acceptable for considered specific routes and seasons.

Table 1.1.1. "Long-term" weighted average $\bar{r}_U$ of upper boundaries of 95%-confidence intervals of "short-term" stability failure rate for areas or routes and seasons specified in table 2.2.1, chapter 2 of appendix 5

LC	Areas or routes and seasons					
	1	2	3	4	5	6
01	2.214e-6	1.549e-6	5.125e-7	6.940e-7	5.154e-7	4.243e-7
02	5.706e-8	1.114e-7	4.859e-8	6.461e-8	4.800e-8	2.702e-8
03	4.587e-9	1.025e-8	4.066e-9	5.798e-9	4.051e-9	1.911e-9
04	7.582e-10	1.781e-9	5.266e-10	8.253e-10	5.456e-10	2.592e-10
05	3.911e-10	1.085e-9	3.276e-10	5.103e-10	3.388e-10	1.611e-10

1.1.12 Operational limitations related to maximum significant wave height were developed for loading conditions LC01, LC02 and LC03 for the North Atlantic wave scatter table, limited by a systematically varied maximum significant wave height with a step 1.0 m. Figure 1.1.9 shows the "long-term" weighted average $\bar{r}_U$ of the upper boundaries of the 95%-confidence intervals of the "short-term" stability failure rate and operability vs. maximum significant wave height. Table 1.1.2 shows the significant wave height at which $\bar{r}_U$ is equal to the standard $2.6 \cdot 10^{-8}$ 1/s, together with operability corresponding to this wave height. Note that since operability exceeds 0.8, operational limitations related to maximum significant wave height is an acceptable option for all considered loading conditions, and that in the same wave climate, a probabilistic operational guidance allows achieving significantly greater operability than operational limitations related to maximum significant wave height, i.e. operational limitations related to maximum significant wave height are less efficient than operational guidance.

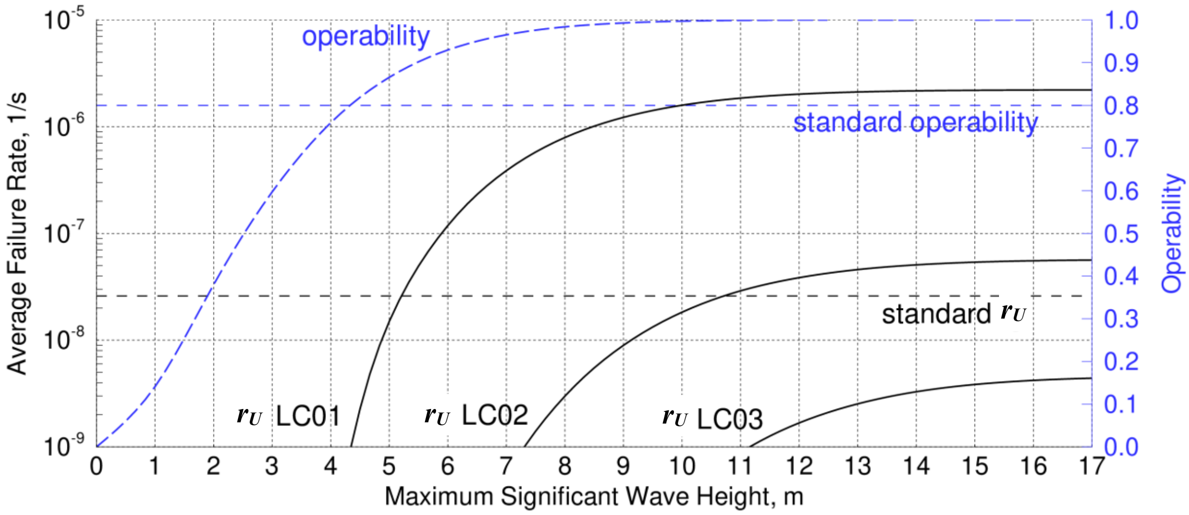


Figure 1.1.9. "Long-term" weighted average $\bar{r}_U$ of upper boundaries of 95%- confidence intervals of "short-term" stability failure rate (left y-axis, black solid line) and operability (right y-axis, blue dashed line) vs. maximum significant wave height (x-axis) in North Atlantic wave climate for cruise vessel

Table 1.1.2. Maximum significant wave height at which "long-term" weighted average $\bar{r}_U$ of upper boundaries of 95%-confidence intervals of "short-term" stability failure rate does not exceed standard $2.6 \cdot 10^{-8}$ 1/s and corresponding operability in North Atlantic wave climate for cruise vessel

Loading condition	LC01	LC02	LC03
GM, m	1.5	2.0	2.5
Maximum significant wave height, m	5.266	10.763	unlimited
Corresponding operability	0.883	0.999	1.000

1.2 1700 TEU container ship

1.2.1 This example concerns a container ship with the length between perpendiculars 159.6 m and waterline breadth 28.1 m.

1.2.2 Figure 1.2.1 shows minimum *GM* values vs. draught according to the criteria from part A of the 2008 IS Code and damage stability requirements in the SOLAS (as amended by resolution MSC.216(82)).

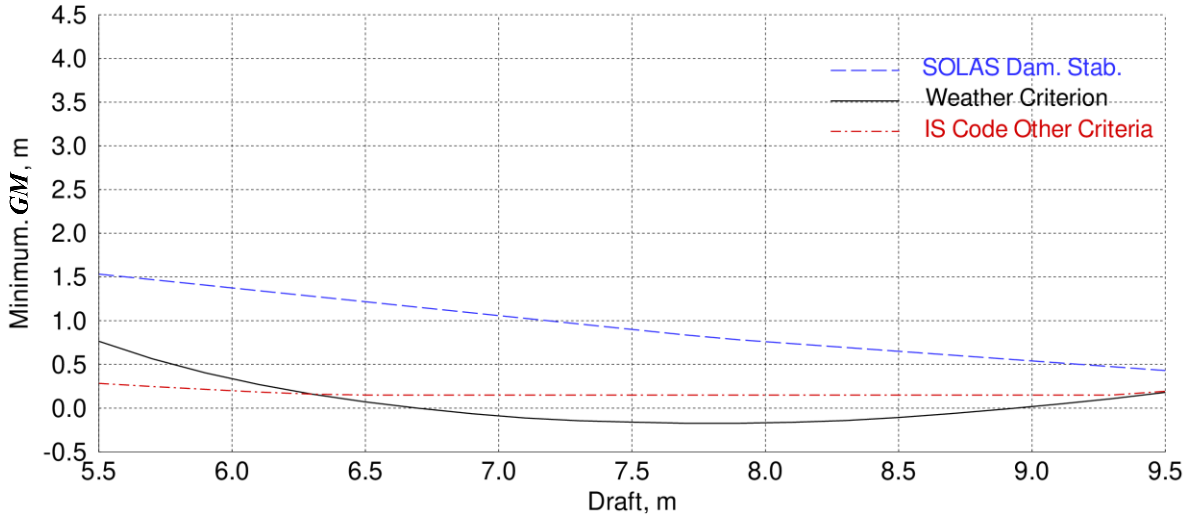
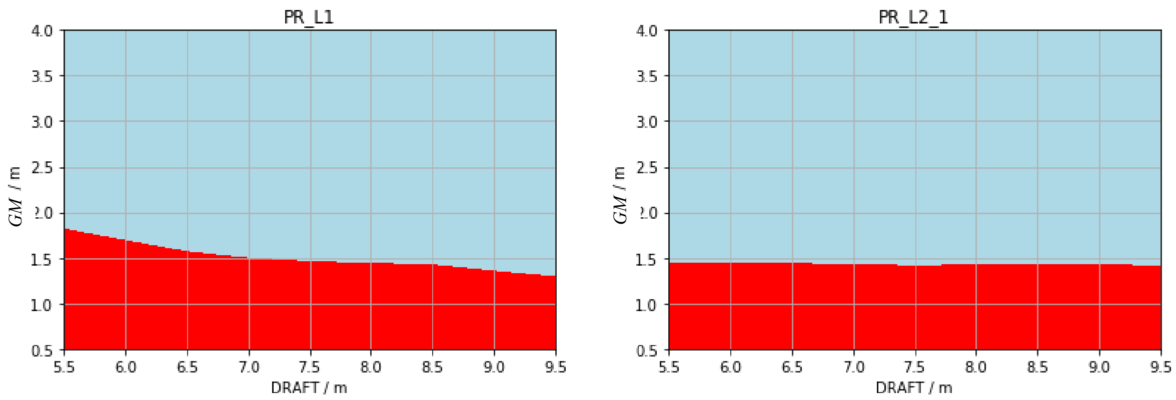


Figure 1.2.1. Minimum *GM* curves according to the 2008 IS Code part A criteria and SOLAS damage stability requirements for 1700 TEU container ship

1.2.3 Figure 1.2.2 shows results of vulnerability assessment for parametric roll stability failure mode. Since it is sufficient to satisfy one of these three assessment options, they do not impose additional limitations on the minimum *GM* value compared to the criteria from part A of the 2008 IS Code and SOLAS damage stability requirements. Figure 1.2.3 shows assessment results with respect to vulnerability criteria for pure loss of stability failure mode. Assessment with respect to level 1 criterion for surf-riding/broaching indicates that since the operational Froude number of the vessel is less than 0.3, the vessel is not vulnerable to this stability failure mode in any of the considered loading conditions, therefore level 2 assessment was not performed. The assessment with respect to vulnerability criteria for dead ship condition, figure 1.2.4, shows that the ship is not vulnerable to this stability failure mode in all considered combinations of draught and *GM*.



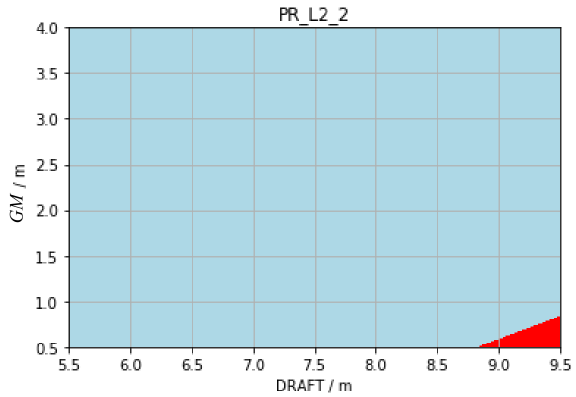


Figure 1.2.2 Results of level 1 (top left), level 2 check 1 (top right) and level 2 check 2 (bottom left) vulnerability assessment for parametric roll stability failure mode for 1700 TEU container ship

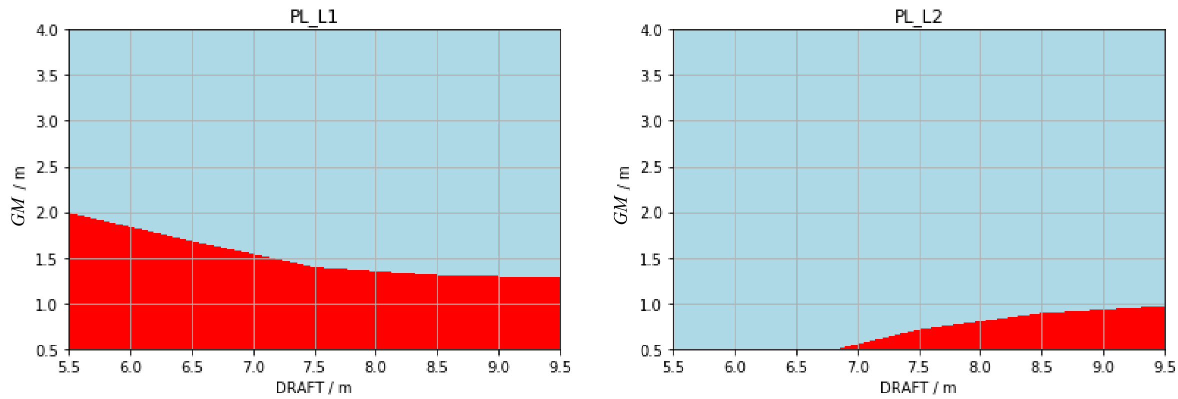


Figure 1.2.3. Results of assessment with respect to level 1 (left) and level 2 (right) vulnerability criteria for pure loss of stability failure mode for 1700 TEU container ship

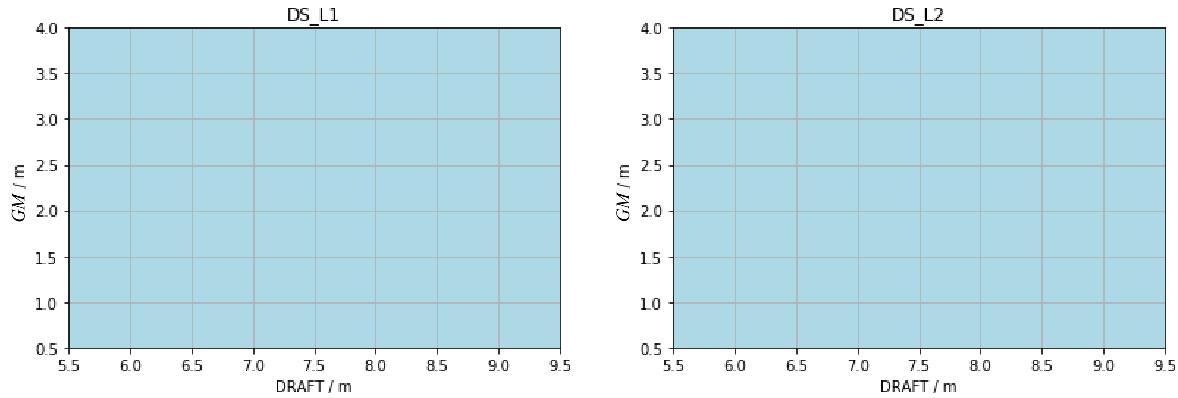


Figure 1.2.4 Results of application of level 1 (left) and level 2 (right) vulnerability criteria for dead ship condition stability failure mode for 1700 TEU container ship

1.2.4 Application of vulnerability criteria for excessive acceleration stability failure mode leads to recommendations on the upper limit of *GM*, shown in figure 1.2.5. Level 1 leads to a very restrictive maximum *GM* limit, which is slightly lifted by applying level 2 assessment. Note that the *GM* values associated with results of excessive acceleration criteria represent metacentric heights without correction for free surface.

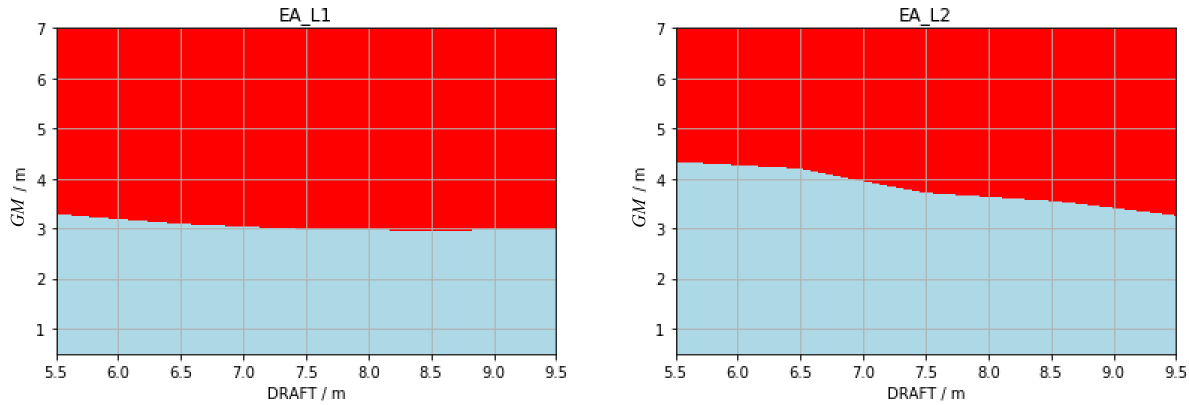


Figure 1.2.5. Results of level 1 and level 2 assessment for excessive acceleration stability failure mode for 1700 TEU container ship

1.2.5 The vulnerability assessment according to the second-generation intact stability criteria indicates for this ship additional limitations compared to the present requirements of part A of the 2008 IS Code and damage stability requirements of SOLAS on minimum acceptable *GM* values, as well as requirements on maximum acceptable *GM* values, figure 1.2.6. For draughts greater than 7.9 m, level 2 of pure loss of stability vulnerability assessment suggests increasing the minimum *GM* values compared to the damage stability requirements, whereas the maximum *GM* values are suggested to be limited by the vulnerability assessment for excessive acceleration stability failure mode. It is important to note that the *GM* values associated with results of excessive acceleration criteria represent metacentric heights without correction for free surface.

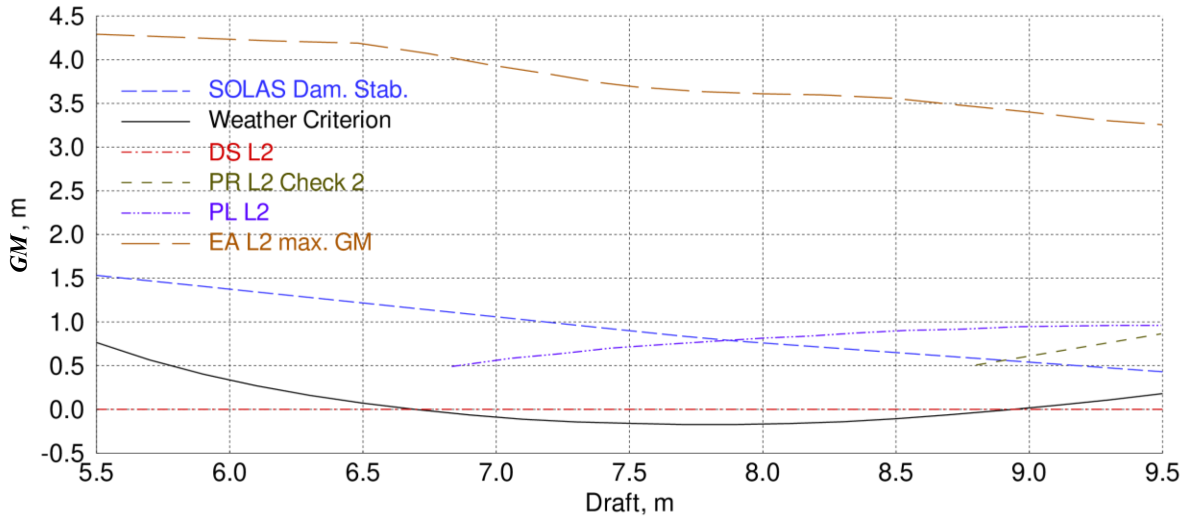


Figure 1.2.6. *GM* limits according to the 2008 IS Code part A, SOLAS damage stability requirements and vulnerability assessment of second-generation intact stability criteria (including maximum *GM* from excessive accelerations criterion) for 1700 TEU containership

1.2.6 For comparison, full probabilistic direct stability assessment was applied for three loading conditions with *GM*=0.5, 1.2 and 1.9 m at a typical loaded draught 9.5 m, table 4.1.1 of chapter 4 of appendix 4. Table 4.2.2 of chapter 4 of appendix 4 shows the resulting "long-term" weighted average $\bar{r}_U$ of the upper boundaries of the 95%-confidence intervals of the "short-term" stability failure rate, which is plotted in figure 1.2.7. The standard $2.6 \cdot 10^{-8}$ 1/s for $\bar{r}_U$ is satisfied for *GM* values greater than 1.788 m, which is larger than the required minimum GM values from the Weather Criterion and damage stability requirements. The direct stability assessment indicates the need to use a GM value higher than the one resulting from the level 2 vulnerability assessment for parametric roll stability failure mode for the considered ship and draught. Since the stability failure rate at small GM values is dominated by the parametric roll stability failure mode, operational measures may be utilized in such loading conditions (see the examples below).

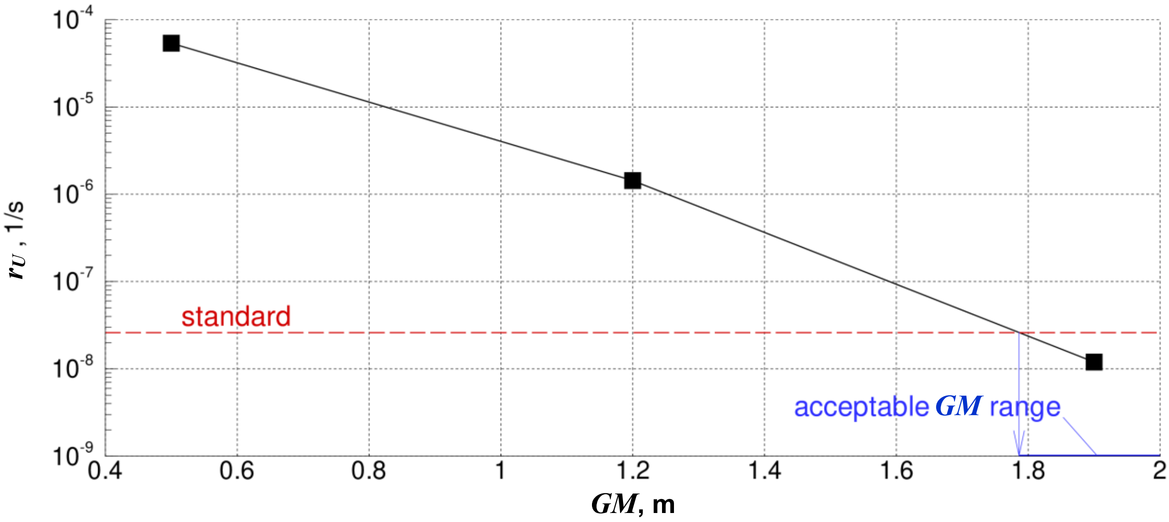


Figure 1.2.7. Computed conservative estimate of upper boundary $\bar{r}_U$ of 95%-confidence interval of average "long-term" stability failure rate vs. GM at draught 9.5 m for 1700 TEU container ship compared with acceptance standard 2.6·10^{-8} 1/s and resulting acceptable GM range

1.2.7 Operational guidance was developed for loading conditions with draught 9.5 m and GM values 0.5, 1.2 and 1.9 m by identifying *unacceptable sailing conditions* (v_0,μ), i.e. those for which the upper boundary of 95%-confidence interval of "short-term" stability failure rate exceeds acceptance standard 10^{-6} s^{-1}, for each sea state (H_s,T_z) in the North Atlantic wave scatter table. Figure 1.2.8 shows the resulting computed "long-term" weighted average $\bar{r}_U$ of the upper boundaries of the 95%-confidence intervals of the "short-term" stability failure rate with and without operational guidance, together with the operability resulting from the use of operational guidance, depending on GM. Since operability exceeds 0.8 for all considered loading conditions, operational guidance is an acceptable option for all of them; note that the upper boundary $\bar{r}_U$ of the 95%-confidence interval of the average "long-term" stability failure rate reduces, due to the use of operational guidance, below the standard of the full probabilistic assessment 2.6·10^{-8} 1/s for all considered loading conditions.

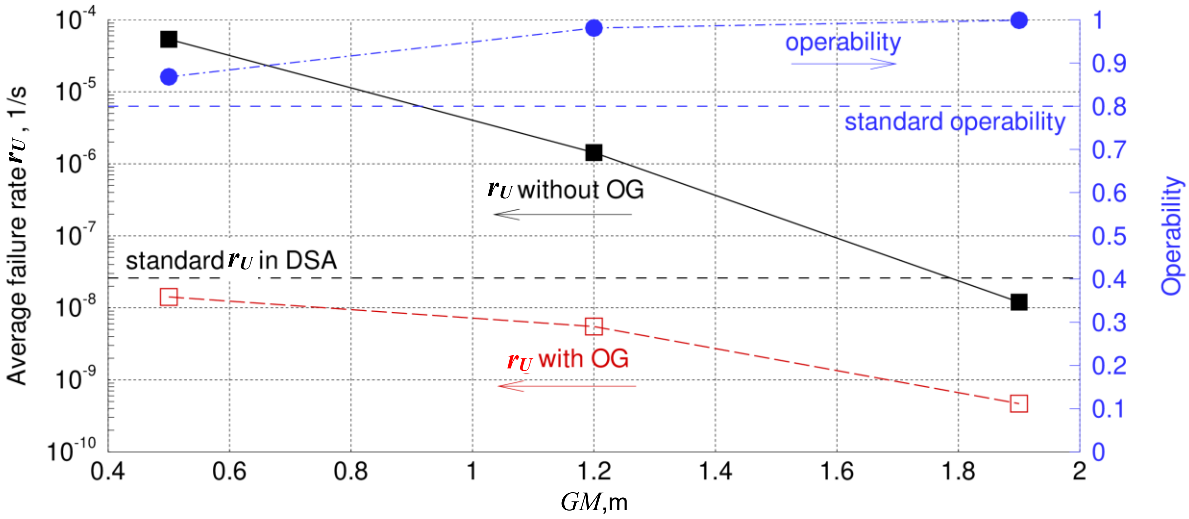


Figure 1.2.8. Computed "long-term" weighted average of upper boundaries of 95%-confidence interval of "short-term" stability failure rate (with and without operational guidance) and operability vs. *GM* at draught 9.5 m for 1700 TEU container ship

1.2.8 Examples of operational limitations related to areas or routes and season concern the same three loading conditions for the sample operational routes and seasons in table 2.2.1, chapter 2 of appendix 5. Table 1.2.1 shows the computed "long-term" weighted average $\bar{r}_U$ of the upper boundaries of the 95%-confidence intervals of the "short-term" stability failure rate for unrestricted operation (area 1) and specific routes and seasons (areas 2 to 6); the red colour indicates unacceptable loading conditions. Although the stability failure rate decreases compared to unrestricted service, this reduction is insufficient to render loading conditions LC01 and LC02 acceptable.

Table 1.2.1. "Long-term" weighted average $\bar{r}_U$ of upper boundaries of 95%-confidence intervals of "short-term" stability failure rate for 1700 TEU container ship; areas or routes and seasons per table 2.2.1, chapter 2 of appendix 5

LC	*GM*, m	Areas or routes and seasons					
		1	2	3	4	5	6
01	0.5	5.362e-5	2.881e-5	1.117e-5	1.323e-5	1.118e-5	1.068e-5
02	1.2	1.432e-6	1.950e-6	1.076e-6	1.226e-6	1.058e-6	7.199e-7
03	1.9	1.198e-8	5.334e-8	3.686e-8	4.588e-8	3.567e-8	1.555e-8

1.2.9 Operational limitations related to maximum significant wave height were developed for the same three loading conditions for the North Atlantic wave scatter table, limited by a systematically varied maximum significant wave height with a step 1.0 m. Figure 1.2.9 shows the resulting computed "long-term" weighted average $\bar{r}_U$ of the upper boundaries of the 95%-confidence intervals of the "short-term" stability failure rate and operability depending on the maximum significant wave height, and table 1.2.2 shows the significant wave height which corresponds to $\bar{r}_U$ matching the required standard $2.6 \cdot 10^{-8}$ 1/s, together with the operability corresponding to this wave height. Note that due to the use of the operational limitations related to maximum significant wave height, loading condition LC02 becomes acceptable (whereas loading condition LC01 remains unacceptable), whereas using operational guidance renders both loading conditions LC01 and LC02 acceptable, and that in the same wave climate, probabilistic operational guidance provides significantly greater operability than operational limitations related to maximum significant wave height, i.e. the latter are less efficient than operational guidance.

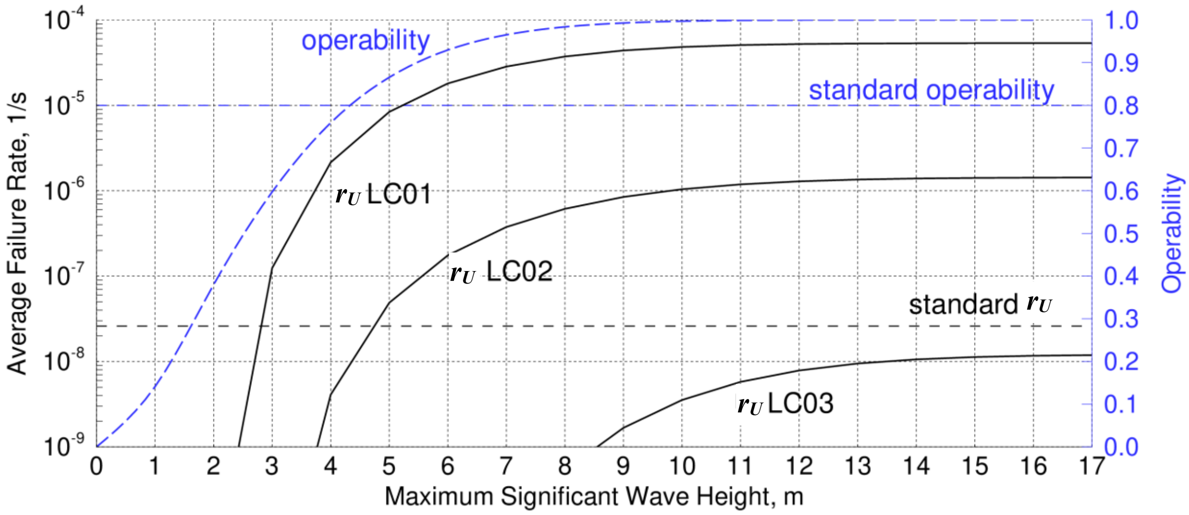


Figure 1.2.9. Computed "long-term" weighted average $\bar{r}_U$ of upper boundaries of 95%- confidence intervals of "short-term" stability failure rate (left y-axis, black solid line) and operability (right y-axis, blue dashed line) vs. maximum significant wave height (x-axis) in North Atlantic wave climate for 1700 TEU container ship

Table 1.2.2. Maximum significant wave height at which "long-term" weighted average $\bar{r}_U$ of upper boundaries of 95%-confidence intervals of "short-term" stability failure rate satisfies acceptance standard $2.6 \cdot 10^{-8}$ 1/s and corresponding operability in North Atlantic wave climate

Loading condition	01	02	03
Metacentric height, m	0.5	1.2	1.9
Maximum significant wave height, m	2.814	4.746	unlimited
Corresponding operability	0.557	0.839	1.0

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