SUB-COMMITTEE ON SHIP DESIGN AND CONSTRUCTION
7th session
Agenda item 5

FINALIZATION OF SECOND GENERATION INTACT STABILITY CRITERIA

Report of the Correspondence Group (Part 1)

Submitted by Japan

SUMMARY

Executive summary: This document provides the first part of the report of the Correspondence Group on Intact Stability established at SDC 6

Strategic direction, if applicable:

Output: 2.6

Action to be taken: Paragraph 27

Related documents: SDC 4/5/1; SDC 5/INF.4; SDC 6/WP.6, SDC 6/13; SDC 7/5/1, SDC 7/INF.2 and MSC.1/Circ.1228

General

1 The Sub-Committee, at its sixth session (4 to 8 February 2019), re-established the Correspondence Group on Intact Stability (IS) under the coordination of Japan (SDC 6/13, paragraph 5.23).

List of participants

2 Representatives from the following Member States participated in the Group:

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and observers from the following non-governmental organizations in consultative status:

INTERNATIONAL ASSOCIATION OF CLASSIFICATION SOCIETIES (IACS)
THE ROYAL INSTITUTION OF NAVAL ARCHITECTS (RINA)
SUPERYACHT BUILDERS ASSOCIATION (SYBAss)

Terms of reference

3 The Group was instructed, based on the comments made and decisions taken at SDC 6, to:

.1 further develop the draft Interim guidelines, based on annexes 1 to 3 to document SDC 6/WP.6, with a view to finalization at SDC 7 by means of a drafting group, in particular, to:

.1 restructure the draft Interim guidelines by using annex 7 to document SDC 6/INF.3 as a base;

.2 consolidate all three draft Interim guidelines under a single set of Guidelines, namely:

.1 draft Interim guidelines on vulnerability criteria for the second generation of intact stability criteria;

.2 draft Interim guidelines on the specification of direct stability assessment procedures; and

.3 draft Interim guidelines on the preparation of operational limitations and operational guidance;

.3 make minor improvements, clarifications and edits for consistency; and

.4 prepare a draft cover sheet for the draft MSC circular, for approval;

.2 develop preamble/introductory section of the draft Interim guidelines;

.3 prepare draft Explanatory Notes, with a view to consideration and finalization at SDC 8, taking into account contributions made during the intersessional discussions; and

.4 submit a report to SDC 7.

Development of draft consolidated Interim guidelines

4 Based on annexes 1 to 3 to document SDC 6/WP.6, the Correspondence Group invited its members to provide their comments on the first draft of the Interim guidelines which had been restructured as proposed in document SDC 6/INF.3, annex 7. After four rounds of comments, the Coordinator completed the work on the draft Interim guidelines, as set out in annex 1.
5 In the first draft, the calculation procedures of long-term indices for different vulnerability level 2 criteria were moved to paragraph 2.7.2 of annex 1. However, due to the diversity among criteria, one member stated that it is more consistent to keep the original structure as set out in annex 3 to document SDC 6/WP.6 where all indices pertaining to a specific failure mode are contained in the chapter of that specific failure mode. In order to simplify the use, the linking of paragraphs and, possibly, also future amendments, these procedures were separately placed in the second and third drafts. However, one member strongly opposed this revision. However, as it is a purely editorial matter the first draft, which is set out in annex 2, can be discussed in the drafting group at SDC 7, if established.

6 One member noted that the minimum requirements for modelled ship motions for the excessive acceleration failure mode do not include sway while the requirements for the validation of numerical methods do not address lateral accelerations. To solve this problem, a simple solution was proposed which was not supported by a majority of the group as validation of roll motions could be sufficient also for lateral acceleration to some extent.

7 As agreed by the Sub-Committee (SDC 6/WP.6, annex 1), model testing for validating numerical methods to be used for direct stability assessment should be based on the ITTC recommended procedure 7.5-02-07-04.1 of 2008. However, a way to deal with possible future revisions of these procedures by ITTC has been discussed for some years. While some delegations proposed to use the latest recommended procedures, others objected on the grounds that model testing could be requested whenever ITTC revises the recommendation. The current text in paragraph 3.3.1.3 of the draft Interim guidelines allows the use of the current recommendation, as well as any future possible revision. One member prefers using the wording "Users are encouraged to follow..." instead of "Users may follow...". This is because, although forcing the use of the most recent ITTC experimental guidelines is perhaps too stringent, having an encouragement in the direction of using the latest ITTC procedures would be appropriate. One observer recommended that this should be amended to read "Reference is made to the ITTC recommended procedure, 7.5-02-06-02 etc." It is not clear to the observer whether the second sentence of the footnote is a comment on the ITTC procedure or a more general comment. If it is a more general comment, then it should be included in the body of the text and not in the footnote.

8 One member proposed to delete subsection 3.5.2 on Verification of failure modes because such verification is not necessary and not always possible and therefore poses an unnecessary burden for designers and flag Administrations, well beyond the scope and possibilities of routine approvals. Moreover, no background information has been submitted for this verification. However, the majority of the Group did not support this proposal because it was already discussed in detail and rejected by SDC 6.

9 One member proposed to revise subsection 3.5.2 as follows:

.1 paragraph 3.5.2.1 "...it is necessary to examine..." should be changed to "...it may be examined whether..."; this suggestion follows and provides a condensed version of previous proposals from Member States; and

.2 paragraph 3.5.2.3 should read in the last sentence "are not addressed".

10 One member proposed to revise subsection 3.5.4 focusing on direct counting method as a first failure passage problem and it was reflected in the tentative version. However, another member claimed that such change could exclude a probabilistic approach using numerical simulation for specified time duration, which was included in the draft agreed at SDC 6 (SDC 6/WP.6, annex 1), and provided the revised text. In order to avoid the significant change from the agreement of SDC 6, it was used for the last revision. Responding to this
revision, the delegation proposing the initial revision stated that such version is technically unsound and practically inefficient and, therefore, the text was recommended to be changed to the initial revision.

11 One member and one observer proposed to delete the guidance on deterministic direct stability assessment in paragraph 3.5.3.4 and on deterministic operational guidance in paragraph 4.5.5. However, the Coordinator and three members noted that these proposals would constitute a significant change to the draft agreed at SDC 6 and were therefore regarded outside the terms of reference but may be revisited after the trial use of the Interim guidelines. The member proposing these deletions expressed the following views:

1 deterministic direct stability assessment and deterministic operational guidance were developed as backup options for a possible situation where probabilistic direct stability assessment and probabilistic operational guidance will not be developed in due time or will be too complex or too expensive to be applied;

2 however, both probabilistic direct stability assessment and probabilistic operational guidance were developed in due time which renders backup options obsolete; moreover, and as shown in the results submitted by Germany to the Sub-Committee, deterministic direct stability assessment and deterministic operational guidance are not simpler and not more efficient compared to probabilistic direct stability assessment and probabilistic operational guidance, respectively; and

3 deterministic direct stability assessment and deterministic operational guidance are not consistent with respect to the probabilistic direct stability assessment, probabilistic operational guidance and levels 1 and 2 vulnerability assessment. Therefore, trial use of deterministic direct stability assessment and deterministic operational guidance will not produce any useful outcomes but may delay the finalization of the Interim guidelines.

12 One observer remarked that a study by Germany showed that these methodologies are not sufficiently accurate and could introduce some inconsistencies with levels 1 and 2 vulnerability criteria. It was therefore suggested to regard deterministic direct stability assessment in design situation and the deterministic operational guidance as undecided issues and that a final decision should be taken by SDC 7.

13 Noting that the proposed removal contradicts SDC 6 decision to implement only minor changes, the member proposed to delete deterministic direct stability assessment and deterministic operational guidance with the aim to prevent delays in the finalization of the draft Interim guidelines by retaining this potentially harmful option.

14 With respect to the first draft, one member and one observer proposed to delete, under the provisions of direct stability assessment, statistical extrapolation methods for which no satisfactory detailed description of the procedure, validation and application examples of full probabilistic assessment have been submitted, namely POT, EPOT, critical wave groups and split-time methods in paragraph 3.5.5.4 and argued that because:

1 the inclusion of these options in the draft text of the Interim guidelines is conditional upon the submission of missing detailed description of the procedure, validation and application examples to the Correspondence Group, which were not provided; and
.2 providing options without detailed procedure description, validation and application examples for the trial use would not be appropriate because designers and Administrations cannot develop and validate such procedures themselves.

15 The observer also requested to note that the situation for all these methods is not the same. Some materials (description of the methods, example and validations) have been provided for critical wave method by Japan. The other methods can be found in literature but nothing has been submitted to the Sub-Committee or the Correspondence Group. A possible solution could be to put the entire section 3.5.5.4 of annex 1 in square brackets with a view to decide the issue during SDC 7.

16 Since excluding the extrapolation methods without a detailed description of the procedure, validation and application examples at the final stage were already agreed (see document SDC 4/WP.4, annex 1, paragraph 5.4.1.8, document SDC 6/5, annex 1, paragraph 5.6.1.8 and document SDC 6/WP.6, annex 1, paragraph 8.8), the first draft was modified accordingly. One member opposed this proposal at this stage and proposed to include other extrapolation methods and was consequently invited to provide such detailed information to SDC 8, for inclusion in the Explanatory Notes. Under this direction at the final stage of this Correspondence Group, the United States submitted the descriptions, sample applications and validations for EPOT and split-time method to be included in the Explanatory Notes.

17 One member argued that, with regards to paragraphs 16, the Experts Group at SDC 6 acted as described in paragraph 8.8 of document SDC 6/WP.6 and extrapolation procedures were listed in document SDC 6/WP.6, annex 1, paragraph 5.5.3.1. As commented previously, this member was of the opinion that the listing of potential extrapolation procedures was decided by the Experts Groups at SDC 6 and that any deviation from that decision is outside the instructions given to the Correspondence Group (SDC 6/13, paragraph 5.23). However, should the Correspondence Group include draft Interim guidelines that omit this agreed list, then no extrapolation procedure should be listed, even as example, in paragraph 3.5.5.4.1. Therefore, this member was of the view that either paragraph 14 must be corrected to alert the Sub-Committee of such a deviation and to propose deletion of the text "such as the critical wave method for broaching failure mode" from paragraph 3.5.5.4.1 or to revert to the text included in document SDC 6/WP.6, annex 1, paragraph 5.5.3.1.

18 One member and one observer proposed to delete the simplified operational guidance based on level 2 assessment for parametric roll in paragraph 4.5.6.2.2, because this approach is not validated and, moreover, available research results indicate that it is not sufficiently accurate for operational guidance. However, three members opposed this proposal because it constituted a significant change from the draft agreed at SDC 6 and is therefore outside the terms of reference.

19 In response to comments from a number of members, formulae were taken from the draft Explanatory Notes to provide a more explicit assessment of the critical number of revolutions that was excluded from paragraph 3.3.5.6 of document SDC 6/WP.6, annex 3 (now included as paragraph 2.6.3.4.6) but it was acknowledged that too detailed procedures in the Explanatory Notes should be avoided. One member expressed that there is no need to state that the calm water resistance can be approximated by using a fifth order polynomial if a lower order polynomial is satisfactory. Therefore, the member recommended to omit the text "fifth order" from the text that explains the coefficients $r_1$, $r_2$, $r_3$, $r_4$, $r_5$. 

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20 Germany submitted further comments to the Correspondence Group; however, there was not sufficient time to discuss them. These comments are therefore included in annex 3, as requested by Germany.

**Development of a preamble and an introductory section for the draft Interim guidelines**

21 With assistance from the members of the Correspondence Group, the Coordinator developed the first draft of the preamble and introductory section of the Interim guidelines. The Coordinator incorporated the comments made during several rounds in order to provide the final draft, as set out in annex 1.

22 One member stated that the ultimate aim of the development of the second generation intact stability criteria, namely that these criteria are intended for inclusion in part A of the International Code on Intact Stability, 2008 (2008 IS Code) should be explicitly mentioned in the preamble. However, another member stated that no such agreement was reached.

23 Regarding the figure for explaining the application procedures of the second generation intact stability criteria, some members wished that the explanations to the procedures were drafted in a more simplified way while others hold the opposite view. Therefore, the Correspondence Group did not conclude on this figure. In case the simplified approach is agreed upon, it could be moved to the Explanatory Notes.

24 There were also differing views on whether or not the references to other IMO instruments should also be in the preamble. However, following the tradition of the Organization and the suggestions from the IMO Secretariat, the references were moved to the introduction part.

**Development of the draft MSC circular for the draft Interim guidelines**

25 The Coordinator provided the first draft of the MSC circular cover sheet for review by the members, based on their comments and suggestions from the IMO Secretariat and the Correspondence Group agreed to the text, as set out in annex 4.

**Development of draft Explanatory Notes**

26 Regarding the development of the draft Explanatory Notes, the draft text and discussion details are provided in document SDC 7/5/1 (Report of the Intact Stability Correspondence Group (Part 2)) and SDC 7/INF.2.

**Action requested of the Sub-Committee**

27 The Sub-Committee is invited to approve the report in general and to agree, in principle, to the restructured draft Interim guidelines including the newly drafted preamble, introductory section and the associated draft MSC circular and to take actions, as appropriate, with a view to finalization of the draft Interim guidelines at this session.

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ANNEX 1

DRAFT INTERIM GUIDELINES ON SECOND GENERATION INTACT STABILITY CRITERIA

Preamble

1 In view of a wide variety of types, sizes of ships and their operating and environmental conditions, problems of safety against accidents related to stability have generally not yet been solved. Administrations shall be aware that some ships are more at risk of encountering critical stability in waves. The Administration may, for a particular ship or group of ships, apply dynamic stability criteria which demonstrate that the safety level of a ship in waves is sufficient.

2 For this purpose, the Organization herewith provides performance-based criteria for assessing five dynamic stability failure modes in waves, namely parametric roll, pure loss of stability, dead ship condition, surf-riding/broaching and excessive acceleration.

3 The physics and evaluation methods for these five stability failure modes were not well understood or developed when the mandatory intact stability criteria were developed. As such, the herewith presented dynamic stability criteria utilize the recent progress using best practices and the most advanced scientific tools available, for practical regulatory-oriented application. Accordingly, the background of the new dynamic stability criteria is principally based on first-principles and latest technology, as opposed to predominant use of casualty records which form the basis of the mandatory intact stability criteria. For this reason, the presented dynamic stability criteria may be considered as the second generation intact stability criteria.

4 The methodologies contained in these Guidelines are based, as far as practical, on general first-principle approaches derived from the analysis of ship dynamics. However, in the development process, it was also necessary to simplify some of the assessment methodologies and to perform also some semi-empirical tuning.

5 In developing the framework of these Guidelines, it was also recognized that an integrated perspective, combining design methods and operational measures, is the most effective way for properly addressing and continuously improving safety against accidents related to stability for ships in a seaway.

6 The Organization hereby recommends that Member States use the second generation intact stability criteria for ensuring a uniform international level of safety for their ships with respect to dynamic stability failure modes in waves.
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1  GENERAL

1.1  Introduction and purpose

1.1.1  Purpose

1.1.1.1  The purpose of these Guidelines is to enable Member States to utilize the second generation intact stability criteria for the assessment of major dynamic stability failure modes in waves, as requested in section 1.2 of Part A of the 2008 Intact Stability (IS) Code. These dynamic stability failure modes are as follows: parametric roll, pure loss of stability, dead ship condition, surf-riding/broaching and excessive acceleration. In this sense, the overarching aim is to use the latest technology and knowledge on ship dynamics to provide guidance for ship designers on dynamic stability failure modes for further evaluating the safety level of a ship beyond the mandatory intact stability criteria.

1.1.1.2  The main purpose of these criteria is to open a door for the direct use of the state-of-the-art numerical simulation techniques for evaluating the safety level of a ship from an intact stability viewpoint. By using such tools for simulating the dynamic ship behaviours in random seaway, the safety level of a ship can be estimated with a probabilistic measure. This approach is hereby called direct stability assessment. However, applying such new tools to all new ships that are subject to the 2008 IS Code is not feasible because of the limitation of required human resources and facilities to be used for experimentally validating the numerical tools. Thus, the Organization recommends to interested parties and Member States that the vulnerability of a ship should be firstly assessed using simpler criteria. Such criteria are hereby called vulnerability criteria. Only in the case that a ship is vulnerable for the stability failure mode is it envisioned that direct stability assessment would be applied to a ship. To facilitate this scheme, the guidance for vulnerability criteria and direct stability assessment are provided in chapters 2 and 3, respectively.

1.1.1.3  On the other hand, even without the performance-oriented criteria, most ships complying with the first generation intact stability criteria (i.e. the criteria contained in Part A of the 2008 IS Code) operate safely. This is because good seamanship, appropriate ship-handling and operation effectively avoid the potential danger of excessive roll, excessive lateral accelerations or even capsizing due to dynamic stability failure mode. Reminding this fact, the Organization requests the Member States to provide appropriate operational limitations or operational guidance for a ship as alternative to the vulnerability criteria or direct stability assessment. For this purpose, the Organization provides the guidelines for operational limitations and operational guidelines in chapter 4. Whereas the natural order of application is from the vulnerability criteria to direct stability assessment and operational measures, all these alternatives are equivalent in the regulatory sense and any of them can be used as a stand-alone set of guidance, independently of others, for the acceptance by Administrations, in the way that is most suitable for the particular design.

1.1.2  Framework

1.1.2.1  For the purpose of this framework, the following definitions apply for the purpose of the framework:

   .1  criterion is a procedure, an algorithm or a formula used for assessment on likelihood of a stability failure;

   .2  standard is a boundary separating acceptable and unacceptable likelihood of a stability failure; and
.3 rule (or regulation) is a specification of a relationship between a standard and a value produced by a criterion.

1.1.2.2 Second generation intact stability criteria are tools to judge the likelihood of intact stability failures; the intact stability failure is defined as the state of inability for a ship to remain within specified limits of roll (heel, list) angle and the combination of rigid body accelerations.

1.1.2.3 Two types of intact stability failures are considered:

.1 Total stability failure, or capsizing, results in total loss of a ship's operability with likely loss of life. Capsizing is defined as a transition from a stable nearly upright equilibrium that is considered safe, or from oscillatory motions near such equilibrium, to another stable equilibrium that is intrinsically unsafe (or could be considered unacceptable from a practical point of view).

.2 Partial stability failure is an event that includes the occurrence of very large roll (heel, list) angles or excessive rigid body accelerations, which will not result in a loss of the ship but impairs normal operation of the ship and could be dangerous to crew, passengers, cargo or ship equipment. Three subtypes of partial stability failure are included:

.1 heel/list exceeding a prescribed limit;

.2 roll angles exceeding a prescribed limit; and

.3 a combination of lateral and vertical accelerations exceeding prescribed limits.

1.1.3 Application Logic

1.1.3.1 Based on the above framework, together with figure 1, application logic is summarized as follows. As the simplest options, the vulnerability criteria are presented in two levels: Level 1 and Level 2. The assessment of the five stability failure modes should begin with the use of these levels. Level 1 is an initial check and then, if the ship in a particular condition of loading is assessed as not vulnerable for the tested failure mode, then the assessment for that failure mode may conclude; otherwise, the design would progress to Level 2. If the ship in a particular condition of loading is assessed as not vulnerable for the tested failure mode in Level 2, then the assessment would conclude. Otherwise, the logic is that the design would progress to the application of direct stability assessment, application of operational limitations, revising the design of the ship or discarding the loading condition. If the ship in a particular condition of loading is not found acceptable with respect to direct stability assessment procedures, then the logic is that the design would then progress to the application of operational limitations or operational guidance, revising the design or discarding the loading condition.

1.1.3.2 Although the user may be guided by the sequential logic of the Guidelines, it is also acceptable that the users, should they so wish, apply any alternative design assessment or operational measure option. For example, a user may wish to immediately commence with the application of direct stability assessment procedures without passing through Levels 1 and 2 of the vulnerability criteria or develop operational measures without performing design assessment.
1.1.4 Testing

1.1.4.1 The second generation intact stability criteria have been developed envisioning a future incorporation into the IS Code. However, they require testing before using them as mandatory criteria. This is because the robustness of the new criteria is not the same for the different stability failure modes.

Specifically, results obtained in the development process, indicate that:

.1 parametric rolling and broaching/surf-riding Level 1 and Level 2 vulnerability criteria have sufficient scientific background and feasible methods for regulatory use;

.2 Level 2 vulnerability criterion for pure loss of stability provides very conservative results for ships with low freeboard; therefore, results of testing for such ships should be treated with care;

.3 Level 1 and Level 2 vulnerability criteria for dead ship stability failure mode sometimes provide non-consistent results, i.e. Level 2 may be more conservative than Level 1 for some ships; and

.4 vulnerability criteria for excessive acceleration may require further refinements.

1.1.4.2 Therefore, the Organization requests Member States to use these criteria on a trial basis at this stage. Such testing procedures, and subsequent reporting, are necessary to gain confidence in them and consequently enable the introduction of a new approach to the analysis of intact stability. It is highly recommended to apply the criteria also to existing ships and to
compare the results with the operational experience to allow the Member States to verify the
criteria.

1.1.5  **Feedback**

1.1.5.1 The second generation intact stability criteria methodology has been developed using
the latest technology and scientific knowledge for assessing ship dynamics in waves. The
methodology has been tested on a number of sample ships and, to this end, these draft Interim
guidelines are intended to generate data and feedback for a large number of ships.

1.1.5.2 These guidelines have been issued as "Interim guidelines" in order to gain experience
in their use. They should be reviewed [four] years after their approval in order to facilitate future
amendments based on the experience gained.

1.1.5.3 Member States and international organizations are invited to submit information,
observations, suggestions, comments and recommendations based on the practical
experience gained through the application of these Interim guidelines. To support the objective
of obtaining robust criteria for regulatory use, suggestions for alternatives to and/or refinements
of the criteria elements contained in the Interim guidelines that compare the outcomes of such
suggestions with the criteria elements included in the Interim guidelines are not only
acceptable but also encouraged.

1.1.5.4 With such feedback, in terms both of the technical results but also of usability and
clarity, the Organization will be able to subsequently refine the second generation intact
stability criteria.

1.1.6  **Relationship with mandatory criteria**

1.1.6.1 These Interim guidelines cannot be used in lieu of the mandatory intact stability criteria
contained in the 2008 IS Code. For the time being, they are intended for the use as a guide for
ship designers to assess different aspects of ship stability than the mandatory criteria and
should be used as a supplementary set of stability assessment methods.

1.1.7  **Exemptions**

1.1.7.1 These Interim guidelines are intended to be applied to ships that are also subject to
the 2008 IS Code.

1.1.7.2 These Interim guidelines have not been specifically developed for multihulls and ships
with extended low weather decks.

1.2  **Definitions**

1.2.1 **Loading condition**, in the context of these Interim guidelines, is the condition of loading
of the ship. It is generally defined by the mean draught \( d \), trim angle \( \theta \), metacentric height \( GM \)
and natural roll period \( T_r \).

1.2.2 **Sea state** is the stationary condition of the free water surface and wind at a certain
location and time, described in these Interim guidelines by the significant wave height \( H_s \), mean
zero-crossing wave period, \( T_z \), mean wave direction \( \mu \), wave energy spectrum \( S_z \), and mean
wind speed, gustiness characteristics and direction; for combined wind sea and swell,
significant wave height, mean zero-crossing wave period and mean wave direction may be
defined separately for each of the two wave systems.
1.2.3 *Sailing condition* is a short notation for the combination of the ship forward speed \( v_s \) and mean wave direction \( \mu \).

1.2.4 *Assumed situation* is a condition of the ship that refers to the sailing condition combined with sea state; thus, a situation is defined by the ship forward speed \( v_0 \), mean wave direction \( \mu \), significant wave height \( H_s \) and mean zero-crossing wave period \( T_{Zc} \), direction and gustiness characteristics of wind.

1.2.5 *Design situation* is an assumed situation representative for a particular stability failure mode.

1.2.6 *Scatter table* is a table containing probabilities of each range of sea states encountered in the considered operational area or operational route; in these Interim guidelines, the probabilities contained in a scatter table are defined to sum to unity.

1.2.7 *Limited scatter table* is a table obtained from the full scatter table by removing all sea state ranges with the significant wave height above a certain limit.

1.2.8 *Operational area* and *operational route* are the geographical areas specified for the ship operation. In the context of these Interim guidelines, operational area or operational route are specified by the long-term wave statistics (scatter table) and wind statistics.

1.2.9 *Nominal ship forward speed* is the ship speed in calm water under action of the ship's propulsion at a given setting.

1.2.10 *Design assessment* corresponds to the application of Level 2 vulnerability criteria according to chapter 2 of these Interim guidelines or direct stability assessment according to chapter 3 of these Interim guidelines or a combination of the two.

1.2.10bis *Operational measures* consist of operational limitation and operational guidance.

1.2.11 *Guidelines for vulnerability assessment* means the content of chapter 2 of these Interim guidelines.

1.2.12 *Guidelines for direct stability assessment* means the content of chapter 3 of these Interim guidelines.

1.2.13 *Guidelines for operational measures* means the content of chapter 4 of these Interim guidelines.


1.3 **Nomenclature**

1.3.1 The general nomenclature used in these Guidelines is set forth in 1.3.2, 1.3.3, 1.3.4, and 1.3.5. Nomenclature that is specific to a particular section is defined in that location and prevails over the general nomenclature reported here. If not otherwise stated, reference should be made to the nomenclature used in the 2008 IS Code.

1.3.2 General ship characteristics

\[
L \quad = \quad \text{length of the ship, as defined in the 2008 IS Code (m)}
\]
\( L_{pp} \) = length between perpendiculars (m)  
\( B \) = moulded breadth of the ship (m)  
\( B_{wl} \) = moulded breadth at waterline (m)  
\( D \) = moulded depth, as defined in the 2008 IS Code (m)  
\( V_s \) = service speed (m/s)  
\( v_0 \) = forward speed (m/s)  
\( F_n \) = Froude number = \( V_s / \sqrt{L \ g} \)  
\( A_t \) = total overall projected area of the bilge keels (no other appendages) (m²)  
\( V_D \) = volume of displacement at waterline equal to \( D \) at zero trim (m³)  
\( D_p \) = propeller diameter (m);  
\( x_i \) = longitudinal distance from the aft perpendicular to a station \( i \) (m), positive forward

1.3.3 Constants  
\( g \) = acceleration due to gravity, taken as 9.81 m/s²  
\( \rho \) = density of salt water, taken as 1025 kg/m³  
\( \rho_{air} \) = density of air, taken as 1.222 kg/m³

1.3.4 Loading condition characteristics  
\( d_{full} \) = draft corresponding to the fully loaded departure condition in calm water (m)  
\( C_{B,full} \) = block coefficient of the fully loaded departure condition in calm water  
\( C_{m,full} \) = midship section coefficient of the fully loaded departure condition in calm water  
\( d \) = mean draught, i.e. draft amidships corresponding to the loading condition under consideration in calm water (m)  
\( L_{WL} \) = length of the ship on the waterline corresponding to the loading condition under consideration (m)  
\( K_B \) = height of the centre of buoyancy above baseline corresponding to the loading condition under consideration (m)  
\( K_G \) = height of the centre of gravity above baseline corresponding to the loading condition under consideration (m)  
\( V \) = volume of displacement corresponding to the loading condition under consideration (m³)  
\( C_B \) = block coefficient corresponding to the loading condition under consideration (-)  
\( \Delta \) = displacement (t)  
\( A_W \) = waterplane area at the draft equal to \( d \) (m²)  
\( I_T \) = transverse moment of inertia of water-plane area (m⁴)  
\( I_{xx} \) = dry roll moment of inertia (t m²)  
\( I_{yy} \) = dry pitch moment of inertia (t m²)
\[ I_{zz} = \text{dry yaw moment of inertia (t m}^2\text{)} \]

\[ m = \text{mass of the ship (t)} \]

\[ k_{xx} = \text{dry roll radius of gyration around axis } x = \sqrt{I_{xx} / m} \text{ (m)} \]

\[ k_{yy} = \text{dry pitch radius of gyration around axis } y = \sqrt{I_{yy} / m} \text{ (m)} \]

\[ k_{zz} = \text{dry yaw radius of gyration around axis } z = \sqrt{I_{zz} / m} \text{ (m)} \]

\[ GM = \text{metacentric height of the loading condition in calm water (m), with or without correction for free surface effect, as required} \]

\[ A_L = \text{projected lateral area of the portion of the ship and deck cargo above the waterline (m}^2\text{)} \]

\[ Z = \text{vertical distance from the centre of } A_L \text{ to the centre of the underwater lateral area or approximately to a point at one-half the mean draft, } d \text{ (m)} \]

\[ T_r = \text{linear natural roll period in calm water (s)} \]

\[ \omega_r = \text{natural roll frequency} = \frac{2 \pi}{T_r} \text{ (rad/s)} \]

\[ \phi = \text{angle of roll, heel, or list (rad or deg)} \]

\[ \theta = \text{angle of pitch or trim (rad or deg)} \]

\[ \psi = \text{angle of yaw, heading or course (rad or deg)} \]

\[ \phi_S = \text{stable heel angle under the action of steady heeling moment calculated as the first intersection between the righting lever curve (GZ curve) and the heeling lever curve, (rad or deg)} \]

\[ \phi_V = \text{angle of vanishing stability. In presence of a heeling moment, it should be calculated as the second intersection between the righting lever curve (GZ curve) and the applied heeling lever curve (rad or deg)} \]

### 1.3.5 Environmental condition characteristics

\[ \lambda = \text{wavelength (m)} \]

\[ H = \text{wave height (m)} \]

\[ H_S = \text{significant wave height for the short-term environmental condition under consideration (m)} \]

\[ s = \text{wave steepness} = \frac{H}{\lambda} \]

\[ T_Z = \text{mean zero-crossing period for the short-term environmental condition under consideration (s)} \]

\[ T_p = \text{Wave period corresponding to peak of spectrum for the short-term environmental condition under consideration (s)} \]

\[ \mu = \text{mean wave direction with respect to ship centre plane} \]

\[ S_{zz} = \text{wave elevation energy spectrum (m}^2/\text{rad/s))} \]

\[ \omega = \text{circular frequency (rad/s)} \]

\[ k = \text{wave number} = \frac{2 \pi}{\lambda} \text{ (rad/m)} \]

### 1.3.6 Other parameters

\[ N_s = \text{number of simulations} \]
Guidelines on vulnerability criteria

2.1 Preface

As described in the section 1.2 of part A of the 2008 IS Code, the Administration may for a particular ship or group of ships apply criteria demonstrating that the safety of the ship in waves is sufficient. For this purpose, the Organization herewith provides performance-oriented criteria for the dynamic stability failure modes in waves which include: dead ship condition, excessive acceleration, pure loss of stability, parametric rolling, and surf-riding/broaching. The Organization recommends that Administrations use these criteria for ensuring a uniform international level of safety of their ships based on these failure modes.

2.2 Assessment of ship vulnerability to the dead ship condition failure mode

2.2.1 Application

2.2.1.1 The provisions given hereunder apply to all ships, except for ships with extended low weather deck.¹

2.2.1.2 For each condition of loading, a ship that:

.1 meets the standard contained in the criteria contained in 2.2.2 is considered not to be vulnerable to the dead ship condition failure mode;

.2 does not meet the standard contained in the criteria contained in 2.2.2 should be subject to more detailed assessment of vulnerability to the dead ship condition failure mode by applying the criteria contained in 2.2.3.

2.2.1.3 Alternatively to the criteria contained in 2.2.2 or 2.2.3, for each condition of loading a ship may be subject to either

.1 direct stability assessment for the dead ship condition failure mode that is performed according to the Guidelines for direct stability assessment in chapter 3; or

.2 operational limitations related to operational area or route and season developed in accordance with the Guidelines for operational measures in chapter 4.

2.2.1.4 A detailed assessment of Level 2 vulnerability according to the criteria contained in 2.2.3 or a direct stability assessment as provided in 2.2.1.3.1 may be performed without the requirement to perform a more simplified assessment in accordance with 2.2.2 or 2.2.3, respectively.

2.2.1.5 Stability limit information for determining the safe zones as functions of GM, draught and trim is to be provided based on matrix calculations according to the criteria contained in

¹ The criteria for this failure mode may not be applicable to a vessel with extended low weather deck due to increased likelihood of water on deck or deck-in-water. For further guidance, refer to the Explanatory Notes for the Second generation intact stability criteria (MSC.1/Circ.xxxx).
2.2.2 or 2.2.3, and, if appropriate, direct stability assessment according to the Guidelines for direct stability assessment. If relevant, the stability limit information for determining safe zones should take into account operational limitations related to specific operational areas or routes and specific season according to the Guidelines for operational measures.

2.2.1.6 Reference environmental conditions to be used in the assessment may be modified when introducing operational limitations permitting operation in specific operational areas or routes and, if appropriate, specific season, according to the Guidelines for operational measures in chapter 4.

2.2.1.7 Free surface effects should be accounted for as recommended in chapter 3 of part B of 2008 IS Code.

**2.2.2 Level 1 vulnerability criteria for dead ship condition**

2.2.2.1 The ability of a ship to withstand the combined effects of beam wind and rolling in the dead ship condition should be demonstrated, with reference to figure 2.2.2.1, as follows:

1. the ship is subjected to a steady wind pressure acting perpendicular to the ship's centreline which results in a steady wind heeling lever ($l_{w1}$);

2. from the resultant angle of equilibrium ($\varphi_0$), the ship is assumed to roll owing to wave action to an angle of roll ($\varphi_1$) to windward. The angle of heel under action of steady wind ($\varphi_0$) should not exceed $16^\circ$ or 80% of the angle of deck edge immersion, whichever is less;

3. the ship is then subjected to a gust wind pressure which results in a gust wind heeling lever ($l_{w2}$); and

4. under these circumstances, area $b$ should be equal to or greater than area $a$, as indicated in figure 2.2.2.1;
Figure 2.2.2.1 - Dead ship condition Level 1 vulnerability criteria

where the angles in figure 2.2.1 are defined as follows:

\[ \varphi_0 = \text{angle of heel under action of steady wind} \]

\[ \varphi_1 = \text{angle of roll to windward due to wave action (see 2.2.2.1.2 and 2.2.2.4)} \]

\[ \varphi_2 = \text{angle of downflooding (} \varphi_f \text{) or 50° or } \varphi_c, \text{ whichever is least,} \]

where:

\[ \varphi_f = \text{angle of heel at which openings in the hull, superstructures or deck-houses which cannot be closed weathertight immerse. In applying this criterion, small openings through which progressive flooding cannot take place need not be considered as open.} \]

\[ \varphi_c = \text{angle of second intercept between wind heeling lever } l_{w2} \text{ and } GZ \text{ curves.} \]

2.2.2.2 The wind heeling levers \( l_{w1} \) and \( l_{w2} \) referred to in 2.2.2.1.1 and 2.2.2.1.3 are constant values at all angles of inclination and should be calculated as follows:

\[ l_{w1} = \frac{P \times A_p \times Z}{1000 \times g \times \Delta} \text{ (m) and} \]

\[ l_{w2} = 1.5 \times l_{w1} \text{ (m)} \]

where:

\[ P = \text{wind pressure of 504 Pa. The value of } P \text{ used for ships [with operational limitations according to 2.2.1.6] may be reduced.} \]

2.2.2.3 Alternative means for determining the wind heeling lever (\( l_{w1} \)) may be used as an equivalent to the calculation in 2.2.2.2. When such alternative tests are carried out, reference should be made to the Guidelines developed by the Organization. \(^4\) The wind velocity used in the tests should be 26 m/s in full scale with uniform velocity profile. The value of wind velocity used for ships with operational limitations according to 2.2.1.6 may be reduced. \(^3\)

2.2.2.4 The angle of roll (\( \varphi_1 \)) referred to in 2.2.2.2 should be calculated as follows: \(^5\)

\[ \varphi_1 = 109 \times k \times X_1 \times X_2 \times \sqrt{R \times S} \text{ (degrees)} \]

where:

\[ X_1 = \text{factor as shown in table 2.2.2.4-1} \]

---

\(^2\) Refer to the Explanatory Notes to the 2008 IS Code (MSC.1/Circ. 1281).

\(^3\) Refer to the Explanatory Notes for the Second generation intact stability criteria (MSC.1/Circ.xxxx).

\(^4\) Refer to the Interim guidelines for alternative assessment of the weather criterion (MSC.1/Circ.1200).

\(^5\) The angle of roll for ships with anti-rolling devices should be determined without taking into account the operation of these devices unless the Administration is satisfied with the proof that the devices are effective even with sudden shutdown of their supplied power.
\( X_2 = \) factor as shown in table 2.2.4-2

\( k = \) factor as follows:
\( k = 1.0 \) for a round-bilged ship having no bilge or bar keels
\( k = 0.7 \) for a ship having sharp bilges
\( k = \) as shown in table 2.2.4-3 for a ship having bilge keels, a bar keel, or both

\( r = 0.73 + 0.6 \frac{OG}{d} \), where: \( OG = KG - d \)

\( s = \) wave steepness shown in table 2.2.4-4

\( A_k = \) total overall area of bilge keels or area of the lateral projection of the bar keel or sum of these areas (\( m^2 \))

The angle of roll (\( \varphi \)) for ships with anti-rolling devices should be determined without taking into account the operation of these devices unless the Administration is satisfied with the proof that the devices are effective even with sudden shutdown of their supplied power.

Table 2.2.4-1 – Values of factor \( X_1 \)

<table>
<thead>
<tr>
<th>B/d</th>
<th>( X_1 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \leq 2.4 )</td>
<td>1.0</td>
</tr>
<tr>
<td>2.5</td>
<td>0.98</td>
</tr>
<tr>
<td>2.6</td>
<td>0.96</td>
</tr>
<tr>
<td>2.7</td>
<td>0.95</td>
</tr>
<tr>
<td>2.8</td>
<td>0.93</td>
</tr>
<tr>
<td>2.9</td>
<td>0.91</td>
</tr>
<tr>
<td>3.0</td>
<td>0.90</td>
</tr>
<tr>
<td>3.1</td>
<td>0.88</td>
</tr>
<tr>
<td>3.2</td>
<td>0.86</td>
</tr>
<tr>
<td>3.4</td>
<td>0.82</td>
</tr>
<tr>
<td>( \geq 3.5 )</td>
<td>0.80</td>
</tr>
</tbody>
</table>

Table 2.2.4-2 – Values of factor \( X_2 \)

<table>
<thead>
<tr>
<th>( C_B )</th>
<th>( X_2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \leq 0.45 )</td>
<td>0.75</td>
</tr>
<tr>
<td>0.50</td>
<td>0.82</td>
</tr>
<tr>
<td>0.55</td>
<td>0.89</td>
</tr>
<tr>
<td>0.60</td>
<td>0.95</td>
</tr>
<tr>
<td>0.65</td>
<td>0.97</td>
</tr>
<tr>
<td>( \geq 0.70 )</td>
<td>1.00</td>
</tr>
</tbody>
</table>
Table 2.2.2.4-3 – Values of factor $k$

<table>
<thead>
<tr>
<th>$\frac{A_2 \times 100}{L_M \times B}$</th>
<th>$k$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.0</td>
</tr>
<tr>
<td>1.0</td>
<td>0.98</td>
</tr>
<tr>
<td>1.5</td>
<td>0.95</td>
</tr>
<tr>
<td>2.0</td>
<td>0.88</td>
</tr>
<tr>
<td>2.5</td>
<td>0.79</td>
</tr>
<tr>
<td>3.0</td>
<td>0.74</td>
</tr>
<tr>
<td>3.5</td>
<td>0.72</td>
</tr>
<tr>
<td>$\geq 4.0$</td>
<td>0.70</td>
</tr>
</tbody>
</table>

Table 2.2.2.4-4 – Values of wave steepness, $s$

<table>
<thead>
<tr>
<th>Natural roll period, $T_r$ (s)</th>
<th>Wave steepness factor, $s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\leq 6$</td>
<td>0.100</td>
</tr>
<tr>
<td>7</td>
<td>0.098</td>
</tr>
<tr>
<td>8</td>
<td>0.093</td>
</tr>
<tr>
<td>12</td>
<td>0.065</td>
</tr>
<tr>
<td>14</td>
<td>0.053</td>
</tr>
<tr>
<td>16</td>
<td>0.044</td>
</tr>
<tr>
<td>18</td>
<td>0.038</td>
</tr>
<tr>
<td>20</td>
<td>0.032</td>
</tr>
<tr>
<td>22</td>
<td>0.028</td>
</tr>
<tr>
<td>24</td>
<td>0.025</td>
</tr>
<tr>
<td>26</td>
<td>0.023</td>
</tr>
<tr>
<td>28</td>
<td>0.021</td>
</tr>
<tr>
<td>$\geq 30$</td>
<td>0.020</td>
</tr>
</tbody>
</table>

(Intermediate values in these tables should be obtained by linear interpolation)

2.2.2.5 For ships subject to operational limitations according to 2.2.1.6, the wave steepness ($s$) in table 2.2.2.4-4 may be modified.2

2.2.2.6 For any ship, the angle of roll ($\phi_1$) may also be determined by alternative means on the basis of the Guidelines developed by the Organization.6

6 Refer to the procedure described in the Interim guidelines for alternative assessment of the weather criterion (MSC.1/Circ.1200).
2.2.3 Level 2 vulnerability criteria for dead ship condition

2.2.3.1 A ship is considered not to be vulnerable to the dead ship condition failure mode if:

\[ C \leq R_{DS0} \]

where:

- \( R_{DS0} = 0.06; \)
- \( C \) is the long-term probability index that measures the vulnerability of the ship to a stability failure in the dead ship condition based on the probability of occurrence of short-term environmental conditions as specified according to 2.2.3.2.

2.2.3.2 The value of \( C \) is calculated as a weighted average from a set of short-term environmental conditions, as follows:

\[ C = \sum_{i=1}^{N} W_i C_{s,i} \]

where:

- \( W_i \) is the weighting factor for the short-term environmental condition, as specified in 2.7.2;
- \( C_{s,i} \) is the short-term dead ship stability failure index for the short-term environmental condition under consideration, calculated as specified in 2.2.3.2.1;
- \( N \) is the total number of short-term environmental conditions, according to 2.7.2.

2.2.3.2.1 The short-term dead ship stability failure index, \( C_{s,i} \), for the short-term environmental condition under consideration, is a measure of the probability that the ship will exceed specified heel angles at least once in the exposure time considered, taking into account an effective relative angle between the vessel and the waves. Each index \( C_{s,i} \) is calculated according to the following formula:

\[ C_{s,i} = 1, \text{ if either:} \]

1. the mean wind heeling lever \( \tilde{h}_{\text{wind,rot}} \) (according to 2.2.3.2.2) exceeds the righting lever (\( GZ \)) at each angle of heel to leeward, or
2. the stable heel angle under the action of steady wind, \( \phi_s \), is greater than the angle of failure to leeward, \( \phi_{\text{fail,+}} \); and

\[ = 1 - \exp(-r_{EA} T_{exp}), \text{ otherwise}; \]
where:

Heel angles are to be taken as positive to leeward and negative to windward;

\[ T_{\text{exp}} = \text{exposure time, to be taken as equal to } 3600 \text{ s}; \]

\[ r_{EA} = \frac{1}{T_{c,C_z}} \left[ \exp \left( -\frac{1}{2 \cdot Rl_{EA}^2} \right) + \exp \left( -\frac{1}{2 \cdot Rl_{EA}^2} \right) \right] (1/\text{s}); \]

\[ Rl_{EA+} = \frac{\sigma_{C_z}}{\delta \phi_{\text{res,EA}+}}; \]

\[ Rl_{EA-} = \frac{\sigma_{C_z}}{\delta \phi_{\text{res,EA}-}}; \]

\[ T_{c,C_z} = \text{reference average zero-crossing period of the effective relative roll motion under the action of wind and waves determined according to 2.2.3.2.3 (s)}; \]

\[ \sigma_{C_z} = \text{standard deviation of the effective relative roll motion under the action of wind and waves determined according to 2.2.3.2.3 (rad)}; \]

\[ \delta \phi_{\text{res,EA}+} = \text{range of residual stability to the leeward equivalent area limit angle, to be calculated as } \phi_{EA+} - \phi_{S}(\text{rad}); \]

\[ \delta \phi_{\text{res,EA}+} = \text{range of residual stability to the windward equivalent area limit angle, to be calculated as } \phi_{S} - \phi_{EA-}(\text{rad}); \]

\[ \phi_{EA+} = \text{equivalent area virtual limit angle to leeward, to be calculated as } \]

\[ \phi_{EA+} = \phi_{S} + \left( \frac{2 \cdot A_{\text{res,+}}}{GM_{\text{res}}} \right)^{1/2} (\text{rad}); \]

\[ \phi_{EA-} = \text{equivalent area virtual limit angle to windward, to be calculated as } \]

\[ \phi_{EA-} = \phi_{S} - \left( \frac{2 \cdot A_{\text{res,-}}}{GM_{\text{res}}} \right)^{1/2} (\text{rad}); \]

\[ \phi_{S} = \text{stable heel angle due to the mean wind heeling lever, } \tilde{I}_{\text{wind, tot}}, \text{ determined according to 2.2.3.2.2 (rad)}; \]

\[ A_{\text{res,+}} = \text{area under the residual righting lever curve (i.e., } GZ - \tilde{I}_{\text{wind, tot}} \text{) from } \phi_{S} \text{ to } \phi_{\text{fail,+}} \text{ (m rad)}; \]

\[ A_{\text{res,-}} = \text{area under the residual righting lever curve (i.e., } GZ - \tilde{I}_{\text{wind, tot}} \text{) from } \phi_{\text{fail,-}} \text{ to } \phi_{S} \text{ (m rad)}; \]
\( GM_{res} \) = residual metacentric height, to be taken as the slope of the residual righting lever curve (i.e., \( GZ - \tilde{I}_{wind,tot} \)) at \( \phi_S \) (m);

\( \phi_{fail,+} \) = angle of failure to leeward, to be taken as \( \min \{ \varphi_{VW,+}, \varphi_{crit,+} \} \) (rad);

\( \phi_{fail,-} \) = angle of failure to windward, to be taken as \( \max \{ \varphi_{VW,-}, \varphi_{crit,-} \} \) (rad);

\( \varphi_{VW,+} \) = angle of second intercept to leeward between the mean wind heeling lever \( \tilde{I}_{wind,tot} \) and the \( GZ \) curve;

\( \varphi_{VW,-} \) = angle of second intercept to windward between the mean wind heeling lever \( \tilde{I}_{wind,tot} \) and the \( GZ \) curve;

\( \varphi_{crit,+} \) = critical angle to leeward, to be taken as \( \min \{ \varphi_{f,+}, 50 \text{deg} \} \) (rad);

\( \varphi_{crit,-} \) = critical angle to windward, to be taken as \( \max \{ \varphi_{f,-}, -50 \text{deg} \} \) (rad);

\( \varphi_{f,+}, \varphi_{f,-} \) = angles of downflooding to leeward and windward, respectively, in accordance with the definition of "angle of downflooding" in 2008 IS Code, Part A, 2.3.1 (rad);

2.2.3.2.2 The mean wind heeling lever \( \tilde{I}_{wind,tot} \) is a constant value at all angles of heel and is calculated according to the following formula:

\[
\tilde{I}_{wind,tot} = \frac{\overline{M}_{wind,tot}}{\rho \cdot g \cdot V} \text{ (m)}
\]

where:

\( \overline{M}_{wind,tot} \) = mean wind heeling moment, to be calculated as

\[
\frac{1}{2} \rho \cdot U_w^2 \cdot C_{whm} \cdot A_L \cdot Z \text{ (N m)}
\]

\( U_w \) = mean wind speed, to be calculated as

\[
\left( \frac{H_S}{0.06717} \right)^{2/3} \text{ (m/s)}
\]

Different expressions can be used when considering alternative environmental conditions, in accordance with 2.2.1.6;

\( C_{whm} \) = wind heeling moment coefficient, to be taken as equal to 1.22 or as determined by other methods;

\( H_S \) = significant wave height for the short-term environmental condition under consideration, according to 2.7.2.

2.2.3.2.3 For the short-term environmental condition under consideration, the reference average zero-crossing period of the effective relative roll motion, \( T_{Z,C_S} \), and the corresponding standard deviation, \( \sigma_{C_S} \), to be used in the calculation of the short-term dead ship stability failure index, \( C_{S,I} \), are determined using the spectrum of the effective relative roll motion under to the action of wind and waves, in accordance with the following formulae:
\[ \sigma_{c_s} = \left( m_o \right)^{1/2} \text{ (rad)} \]
\[ T_{z:C_s} = 2\pi \cdot \left( m_o / m_2 \right)^{1/2} \text{ (s)} \]

where:
- \[ m_o \] = area under the spectrum \( S(\omega) \) (rad²);
- \[ m_2 \] = area under the function of \( \omega^2 \cdot S(\omega) \) (rad⁴/s²);
- \( S(\omega) \) = spectrum of the effective relative roll angle, to be calculated as follows:

\[ H_{rel}^2(\omega) \cdot S_{aa,c}(\omega) + H^2(\omega) \cdot \frac{S_{\delta M_{wind,rel}}(\omega)}{\rho \cdot g \cdot V \cdot GM^2} \text{ (rad}^2/\text{rad/s}) \]

\[ H_{rel}^2(\omega) = \frac{\omega^4 + (2 \cdot \mu_c \cdot \omega)^2}{(\omega_{h,c}^2 - \omega^2)^2 + (2 \cdot \mu_c \cdot \omega)^2} \]
\[ H^2(\omega) = \frac{\omega^4}{(\omega_{h,c}^2 - \omega^2)^2 + (2 \cdot \mu_c \cdot \omega)^2} \]
\[ S_{aa,c}(\omega) \] = spectrum of the effective wave slope, to be calculated as

\[ r^2(\omega) \cdot S_{aa}(\omega) \text{ (rad}^2/\text{rad/s}) \]
\[ S_{aa}(\omega) \] = spectrum of the wave slope, to be calculated as

\[ \frac{\omega^4}{g^2} \cdot S_{zz}(\omega) \text{ (rad}^2/\text{rad/s}) \]
\[ S_{zz}(\omega) \] = sea wave elevation spectrum (m²/(rad/s)). The standard expression for \( S_{zz}(\omega) \) is defined in 2.7.2.1.1.

Different expressions can be used when considering alternative environmental conditions, in accordance with 2.2.1.6;

\[ S_{\delta M_{wind,rel}}(\omega) \] = spectrum of moment due to the action of the gust, to be calculated as

\[ \left[ \rho_{air} \cdot U_\infty \cdot C_{whelm} \cdot A_z \cdot Z \right]^2 \cdot \chi(\omega) \cdot S_{v}(\omega) \]
\[ \chi(\omega) \] = standard aerodynamic admittance function, to be taken as a constant equal to 1.0;
\[ S_{v}(\omega) \] = gustiness spectrum. The standard expression for \( S_{v}(\omega) \) is as follows:
\[ 4 \cdot K \cdot \frac{U_w^2}{\omega} \cdot \frac{X_D^2}{\left(1 + X_D^2\right)^{3/2}} \] 

with \( K = 0.003 \) and \( X_D = 600 \cdot \omega / (\pi \cdot U_w) \). Different expressions can be used when considering alternative environmental conditions in accordance with 2.2.1.6;

\[ \mu_e = \text{equivalent linear roll damping coefficient (1/s), calculated according to the stochastic linearization method. This coefficient depends on linear and nonlinear roll damping coefficients and on the specific roll velocity standard deviation in the considered short-term environmental conditions.}^{7} \]

\[ \omega_{0,\varphi} = \text{modified roll natural frequency close to the heel angle, } \varphi_s, \text{ to be calculated as} \]

\[ \omega_0 \cdot \left(\frac{GM_{\text{res}}}{GM}\right)^{1/2} \text{ (rad/s)}; \]

\[ \omega_0 = \text{upright natural roll frequency} = \frac{2\pi}{T_r} \text{ (rad/s)}; \]

\[ r(\omega) = \text{effective wave slope function determined according to 2.2.3.2.4;} \]

and other variables as defined in 2.2.3.2.1 and 2.2.3.2.2.

2.2.3.2.4 The effective wave slope function, \( r(\omega) \), should be specified using a reliable method, based on computations or derived from experimental data,\(^8\) to the satisfaction of the Administration.

In absence of sufficient information, the standard methodology\(^9\) for the estimation of the effective wave slope function should be used, which is based on the following assumptions and approximations:

.1 The underwater part of each transverse section of the ship is substituted by an "equivalent underwater section" having, in general, the same breadth at waterline and the same underwater sectional area of the original section.

However:

.1 sections having zero breadth at waterline, such as those in the region of the bulbous bow, are neglected; and

.2 the draught of the "equivalent underwater section" is limited to the ship sectional draught;

---

\(^7\) Refer to the Explanatory Notes for the Second generation intact stability criteria (MSC.1/Circ.xxxx).

\(^8\) Refer to the procedure described in the Interim guidelines for alternative assessment of the weather criterion (MSC.1/Circ.1200) as a guide.

\(^9\) Refer to the Explanatory Notes for the Second generation intact stability criteria (MSC.1/Circ.xxxx).
The effective wave slope coefficient for each wave frequency is determined by using the "equivalent underwater sections" considering only the undisturbed linear wave pressure;

For each section a formula is applied which is exact for rectangles.

The standard methodology is applied considering the actual trim of the ship. The standard methodology for the estimation of the effective wave slope is applicable only to standard monohull vessels. For a ship that does not fall in this category, alternative prediction methods should be applied.

2.3 Assessment of ship vulnerability to the excessive acceleration failure mode

2.3.1 Application

2.3.1.1 The provisions given hereunder apply to each ship in each condition of loading provided that:

.1 the distance from the waterline to the highest location along the length of the ship where passengers or crew may be present exceeds 70% of the breadth of the ship; and

.2 the metacentric height exceeds 8% of the breadth of the ship.

2.3.1.2 For each condition of loading and location along the length of the ship where passengers or crew may be present, a ship that:

.1 meets the standard contained in the criteria contained in 2.3.2 is considered not to be vulnerable to the excessive acceleration failure mode;

.2 does not meet the standard contained in the criteria contained in 2.3.2 should be subject to more detailed assessment of vulnerability to the excessive acceleration failure mode by applying the criteria contained in 2.3.3.

2.3.1.3 Alternatively to the criteria contained in 2.3.2 or 2.3.3, for each condition of loading a ship may be subject to either

.1 direct stability assessment for the excessive acceleration failure mode that is performed according to the Guidelines for direct stability assessment in chapter 3; or

.2 operational measures developed in accordance with the Guidelines for operational measures in chapter 4.

2.3.1.4 A detailed assessment of Level 2 vulnerability according to the criteria contained in 2.3.3 or a direct stability assessment as provided in 2.3.1.3.1 may be performed without the requirement to perform a more simplified assessment in 2.3.2 or 2.3.3, respectively.

2.3.1.5 Stability limit information for determining the safe zones as functions of GM, draught and trim is to be provided based on matrix calculations according to the criteria contained in sections 2.3.2 or 2.3.3 and, if appropriate, direct stability assessment according to the provisions in chapter 3 on direct stability assessment. If relevant, the stability limit information for determining safe zones should take into account operational limitations according to the provisions in chapter 4 on operational measures.
2.3.1.6 Reference environmental conditions to be used in the assessment may be modified, according to the Guidelines for operational measures in chapter 4.

2.3.1.7 Free surface corrections should not be applied.

2.3.2 Level 1 vulnerability criteria for excessive acceleration

2.3.2.1 A ship is considered not to be vulnerable to the excessive acceleration stability failure mode if, for each condition of loading and location along the length of the ship where passengers or crew may be present,

\[ \varphi \cdot k_L \cdot \left( g + 4\pi^2 h_r / T_r^2 \right) \leq R_{EA1} \]

where:

- \( R_{EA1} = 4.64 \text{m/s}^2 \)
- \( \varphi \) = characteristic roll amplitude (rad) = \( 4.43 \frac{r}{s} \delta_{p,0.5} \)
- \( k_L \) = factor taking into account simultaneous action of roll, yaw and pitch motions,
  - \( 1.125 - 0.625 \frac{x}{L} \), if \( x < 0.2 L \),
  - \( 1.0 \), if \( 0.2 L \leq x \leq 0.65 L \),
  - \( 0.527 + 0.727 \frac{x}{L} \), if \( x > 0.65 L \);
- \( x \) = longitudinal distance of the location where passengers or crew may be present from the aft end of \( L \);
- \( h_r \) = height above the assumed roll axis of the location where passengers or crew may be present (m), for which purpose, the roll axis may be assumed to be located at the midpoint between the waterline and the vertical centre of gravity;
- \( r \) = effective wave slope coefficient = \( \frac{K_1 + K_2 + (OG)(F)}{12C_B d} - \frac{C_B d}{2} \);  
  - \( K_1 = g \beta T_r^2 (\tau + \sqrt{T_r} - 1 / \sqrt{T_r}) / (4 \pi^2) \);
  - \( K_2 = g \tau T_r^2 (\beta - \cos \bar{b}) / (4 \pi^2) \);
  - \( OG = KG - d \);
  - \( F = \beta (\tau - 1 / \sqrt{T_r}) \);
  - \( \beta = \sin (\bar{b}) / \bar{b} \);
  - \( \tau = \exp(-\sqrt{T_r}) / \sqrt{T_r} \);
  - \( \bar{b} = 2 \pi^2 B / (g T_r^2) \);
  - \( \bar{\tau} = 4 \pi^2 C_B d / (g T_r^2) \);
  - \( s \) = wave steepness as a function of the natural roll period \( T_r \) (see 2.7.1) as determined from table 2.3.2.1; and
  - \( \delta_{p} \) = non-dimensional logarithmic decrement of roll decay.\(^{10}\)

Table 2.3.2.1 – Values of wave steepness, \( s \)

<table>
<thead>
<tr>
<th>Natural roll period, ( T_r ) (s)</th>
<th>Wave steepness, ( s )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \leq 6 )</td>
<td>0.100</td>
</tr>
<tr>
<td>7</td>
<td>0.098</td>
</tr>
<tr>
<td>8</td>
<td>0.093</td>
</tr>
</tbody>
</table>

\(^{10}\) Refer to the Explanatory Notes for the Second generation intact stability criteria (MSC.1/Circ.xxxx).
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>0.065</td>
</tr>
<tr>
<td>14</td>
<td>0.053</td>
</tr>
<tr>
<td>16</td>
<td>0.044</td>
</tr>
<tr>
<td>18</td>
<td>0.038</td>
</tr>
<tr>
<td>20</td>
<td>0.032</td>
</tr>
<tr>
<td>22</td>
<td>0.028</td>
</tr>
<tr>
<td>24</td>
<td>0.025</td>
</tr>
<tr>
<td>26</td>
<td>0.023</td>
</tr>
<tr>
<td>28</td>
<td>0.021</td>
</tr>
<tr>
<td>≥ 30</td>
<td>0.020</td>
</tr>
</tbody>
</table>

2.3.3 **Level 2 vulnerability criteria for excessive acceleration**

2.3.3.1 A ship in the considered condition of loading is considered not to be vulnerable to the excessive acceleration stability failure mode if, for each location along the length of the ship where passengers or crew may be present:

\[ C \leq R_{EA2} \]

where:

\[ R_{EA2} = 0.00039; \]

\[ C = \text{long-term probability index that measures the vulnerability of the ship to a stability failure due to excessive acceleration for the loading condition and location under consideration based on the probability of occurrence of short-term environmental conditions as specified according to 2.3.3.2.} \]

2.3.3.2 The value of \( C \) is calculated as a weighted average from a set of short-term environmental conditions, as follows:

\[ C = \sum_{i=1}^{N} W_i C_{S,i} \]

where:

\[ W_i = \text{weighting factor for the short-term environmental condition, as specified in 2.7.2;} \]

\[ C_{S,i} = \text{short-term excessive acceleration failure index for the short-term environmental condition under consideration, calculated as specified in 2.3.3.2.1;} \]

\[ N = \text{total number of short-term environmental conditions, according to 2.7.2;} \]

2.3.3.2.1 The short-term excessive acceleration failure index, \( C_{S,i} \), for the loading condition and location under consideration and for the short-term environmental condition under consideration is a measure of the probability that the ship will exceed a specified lateral acceleration, calculated according to the following formula:

\[ C_{S,i} = \exp[-R_{E}^2 / (2 \sigma_{LA}^2)]; \]
where:

\[ R_2 = 9.81 \text{ m/s}^2; \]
\[ \sigma_{L,i} = \text{standard deviation of the lateral acceleration at zero speed and in a beam seaway determined according to 2.3.3.2.2 (m/s}^2); \]

2.3.3.2.2 The standard deviation of the lateral acceleration at zero speed and in a beam seaway, \( \sigma_{L,i} \), is determined using the spectrum of roll motion due to the action of waves. The square of this standard deviation is calculated according to the following formula:

\[
\sigma_{L,i}^2 = \frac{3}{4} \sum_{j=1}^{N} \left( a_j(\omega_j) \right)^2 S_{ZZ}(\omega_j) \Delta \omega
\]

where:

\[ \Delta \omega = \text{interval of wave frequency (rad/s) = } (\omega_2 - \omega_1) / N \text{ (rad/s);} \]
\[ \omega_2 = \text{upper frequency limit of the wave spectrum in the evaluation range = } \min(25 / T_r, 2.0) \text{ (rad/s);} \]
\[ \omega_1 = \text{lower frequency limit of the wave spectrum in the evaluation range = } \max(0.5 / T_r, 0.2) \text{ (rad/s);} \]
\[ N = \text{number of intervals of wave frequency in the evaluation range, not to be taken less than 100;} \]
\[ \omega_j = \text{wave frequency at the mid-point of the considered frequency interval = } \omega_1 + ((2j - 1) / 2) \Delta \omega \text{ (rad/s);} \]
\[ S_{ZZ}(\omega_j) = \text{sea wave elevation spectrum (m}^2/(\text{rad/s}). \text{ The standard expression for } S_{ZZ}(\omega) \text{ is defined in 2.7.2.1.1;} \]
\[ a_j(\omega_j) = \text{lateral acceleration = } k_i(\omega_j) \cdot (g + h_r \cdot \omega_j^2) \cdot \phi_i(\omega_j) \text{ per unit wave amplitude ((m/s}^2)/m); \]
\[ k_i, h_r = \text{as defined in 2.3.2.1;} \]
\[ \phi_i(\omega_j) = \text{roll amplitude in regular beam waves of unit amplitude and circular frequency } \omega_j \text{ at zero speed, = } (\phi_i(\omega_j)^2 + \phi_r(\omega_j)^2)^{0.5} \text{ (rad/m);} \]
\[ a, b = \cosine \text{ and sine components, respectively, of the Froude-Krylov roll moment in regular beam waves of unit amplitude } (kN \cdot m \cdot m), \text{ calculated directly or using an appropriate approximation;}^{11} \]
\[ B_e = \text{equivalent linear roll damping factor } (kN \cdot m \cdot s), \text{ with } B_e = 2J_{T,roll} \mu_e \]
\[ J_{T,roll} = \text{roll moment of inertia comprising added inertia} = \frac{1}{1000} \frac{\rho g \mathcal{V} G M T_r^2}{4\pi^2} \text{ (t} \cdot \text{m}^2). \]

\[^{11}\text{Refer to the Explanatory Notes for the Second generation intact stability criteria (MSC.1/Circ.xxxx).} \]
Other suitable formulations for the numerical integration in the range from \( \omega_1 \) to \( \omega_2 \) can be used, as an alternative.

2.4 **Assessment of ship vulnerability to the pure loss of stability failure mode**

2.4.1 **Application**

2.4.1.1 The provisions given hereunder apply to all ships, except for ships with extended low weather deck,\(^\text{12}\) for which the Froude number, \( F_n \), corresponding to the service speed exceeds 0.24.

2.4.1.2 For each condition of loading, a ship that:

1. meets the standard contained in the criteria contained in 2.4.2 is considered not to be vulnerable to the pure loss of stability failure mode; and

2. does not meet the standard contained in the criteria contained in 2.4.2 should be subject to more detailed assessment of vulnerability to the pure loss of stability failure mode by applying the criteria contained in 2.4.3.

2.4.1.3 Alternatively to the criteria contained in 2.4.2 or 2.4.3, for each condition of loading a ship may be subject to either

1. direct stability assessment for the pure loss of stability failure mode that is performed according to the Guidelines for direct stability assessment in chapter 3; or

2. operational measures according to the Guidelines for operational measures in chapter 4.

2.4.1.4 A detailed assessment of Level 2 vulnerability according to the criteria contained in 2.4.3 or a direct stability assessment as provided in 2.4.1.3.1 may be performed without the requirement to perform a more simplified assessment in 2.4.2 or 2.4.3, respectively.

2.4.1.5 Stability limit information for determining the safe zones as functions of GM, draught and trim is to be provided based on matrix calculations according to the criteria contained in sections 2.4.2 or 2.4.3 and, if appropriate, direct stability assessment according to the provisions in chapter 3 on direct stability assessment. If relevant, the stability limit information for determining safe zones should take into account operational limitations according to the provisions in chapter 4 on operational measures.

2.4.1.6 Reference environmental conditions to be used in the assessment may be modified, according to the Guidelines for operational measures in chapter 4.

2.4.1.7 Free surface effect should be accounted for as recommended in chapter 3 of part B of 2008 IS Code.

2.4.2 **Level 1 vulnerability criteria for pure loss of stability**

2.4.2.1 A ship is considered not to be vulnerable to the pure loss of stability failure mode if

\(^{12}\) The criteria for this failure mode may not be applicable to a vessel with extended low weather deck due to increased likelihood of water on deck or deck-in-water. For further guidance, refer to the Explanatory Notes for the Second generation intact stability criteria (MSC.1/Circ.xxxx).
\[ GM_{\text{min}} \geq R_{\text{PLA}} \text{ and } \frac{V_D - V}{A_W (D - d)} \geq 1.0 \]

where:
\[ R_{\text{PLA}} = 0.05 \text{ m}; \]
\[ GM_{\text{min}} \text{ = minimum value of the metacentric height (m) calculated as provided in 2.4.2.2.} \]

2.4.2.2 As provided by 2.4.2.1, \( GM_{\text{min}} \) should be determined according to:
\[ GM_{\text{min}} = KB + I_{\text{T}}/V - KG \]

where:
\[ I_{\text{T}} = \text{transverse moment of inertia of the waterplane at the draft } d_L \text{ (m}^4\text{);} \]
\[ d_L = d - \delta d_L \text{ (m);} \]
\[ \delta d_L = \text{Min}(d - 0.25d_{\text{full}}, \frac{L \cdot s_W}{2}) \text{ (m);} \]
\[ s_W = 0.0334; \]

and \( d - 0.25d_{\text{full}} \) should not be taken less than zero;

2.4.2.3 The use of the simplified conservative estimation of \( GM_{\text{min}} \) described in 2.4.2.2 without initial trim effect can be applied for ships having non-even keel condition.

2.4.3 Level 2 vulnerability criteria for pure loss of stability

2.4.3.1 A ship is considered not to be vulnerable to the pure loss of stability failure mode if, when underway at the service speed, \( V_S \),
\[ \max(CR_1, CR_2) \leq R_{PL0} \]

where:
\[ R_{PL0} = 0.06; \]
\[ CR_1, CR_2 = \text{criteria calculated according to 2.4.3.2.} \]

2.4.3.2 Each of the two criteria, \( CR_1 \) and \( CR_2 \) in 2.4.3.1, represents a weighted average of certain stability parameters for a ship considered to be statically positioned in waves of defined height \( (H_i) \) and length \( (\lambda_i) \) obtained according to 2.4.3.2.2. \( CR_1 \) and \( CR_2 \) are calculated as follows:
\[ CR_1 = \sum_{i=1}^{N} W_i C1_i \]
\[ CR_2 = \sum_{i=1}^{N} W_i C2_i \]

where:
\[ CR_1 = \text{weighted criterion 1, computed using Criterion 1, } C1_i, \text{ as evaluated according to 2.4.3.3;} \]
\[ CR_2 = \text{weighted criterion 2, computed using Criterion 2, } C2_i, \text{ as evaluated according to 2.4.3.4;} \]
\[ W_i = \text{weighting factor for the short-term environmental condition, as specified in 2.4.3.2.2;} \]
2.4.3.2.1 For calculating the restoring moment in waves, the following wavelength and wave heights should be used:

\[
\begin{align*}
\text{Length } & \lambda = L; \text{ and } \\
\text{Height } & h = 0.01 \cdot iL \quad i = 0, 1, \ldots, 10.
\end{align*}
\]

The index for the two criteria, based on \( \phi_v \) and \( \phi_s \), should be calculated according to the formulations given in 2.4.3.3 and 2.4.3.4, respectively, for the loading condition under consideration and the ship assumed to be balanced in sinkage and trim in a series of waves with the characteristics as described above.

In these waves to be studied, the wave crest is to be centred amidships, and at \( 0.1L, 0.2L, 0.3L, 0.4L \) and \( 0.5L \) forward and \( 0.1L, 0.2L, 0.3L \) and \( 0.4L \) aft thereof.

2.4.3.2.2 For each combination of \( H_i \) and \( T_z \) specified in 2.7.2, \( W_i \) is obtained as the value in table 2.7.2.1.2 divided by the amount of observations given in this table, which is associated with a \( H_i \) as calculated in 2.4.3.2.3 below and \( \lambda \) is taken as equal to \( L \). The indices for each \( H_i \) should be linearly interpolated from the relationship between \( h \) used in 2.4.3.2.1 and the indices obtained in 2.4.3.2.1 above.\(^{13}\)

2.4.3.2.3 The 3% largest effective wave height, \( H_i \), for use in evaluation of the requirements is calculated by filtering waves within the ship length. For this purpose, an appropriate wave spectrum shape should be assumed.\(^{13}\)

2.4.3.3 Criterion 1

Criterion 1, \( C_{1i} \), is a criterion based on the calculation of the angle of vanishing stability, \( \phi_v \), as provided in the following formula:

\[
C_{1i} = \begin{cases} 
1 & \text{if } \phi_v < K_{PL1} \\
0 & \text{otherwise}
\end{cases}
\]

where:

\[
K_{PL1} = 30 \text{ degrees}
\]

The angle of vanishing stability, \( \phi_v \), should be determined as the minimum value calculated as provided in 2.4.3.2.1, 2.4.3.2.2 and 2.4.3.2.3 for the ship without consideration of the angle of downflooding.

2.4.3.4 Criterion 2

Criterion 2, \( C_{2i} \), is a criterion based on the calculation of the angle of heel, \( \phi_{sw} \), under action of heeling lever specified by \( l_{PL2} \) as provided in the following formula:

\[
\text{where:}
K_{PL2} = \begin{cases} 
15 \text{ degrees for passenger ships; and} \\
25 \text{ degrees for all other ship types}
\end{cases}
\]

\(^{13}\) Refer to the Explanatory Notes for the Second generation intact stability criteria (MSC.1/Circ.xxxx).
\[ I_{PL2} = 8(H_i/\lambda) dFn^2; \]
\[ H_i = \text{as provided in 2.4.3.2.2 and 2.4.3.2.3;} \]
\[ \lambda = \text{as provided in 2.4.3.2.2;} \]

The angle of heel, \( \varphi_{sw} \), should be determined as the maximum value calculated as provided in 2.4.3.2.1, 2.4.3.2.2 and 2.4.3.2.3, for the ship without consideration of the angle of downflooding.

2.5 **Assessment of ship vulnerability to the parametric rolling failure mode**

2.5.1 **Application**

2.5.1.1 For each condition of loading, a ship that:

.1 meets the standard contained in the criteria contained in 2.5.2 is considered not to be vulnerable to the parametric rolling failure mode;

.2 does not meet the standard contained in the criteria contained in 2.5.2 should be subject to more detailed assessment of vulnerability to the parametric rolling failure mode by applying the criteria contained in 2.5.3.

2.5.1.2 Alternatively to the criteria contained in 2.5.2 or 2.5.3, for each condition of loading a ship may be subject to either:

.1 a direct stability assessment for the parametric rolling failure mode that is performed according to the Guidelines for direct stability assessment in chapter 3; or

.2 operational measures for the parametric rolling failure mode according to the Guidelines for operational measures in chapter 4.

2.5.1.3 A detailed assessment of Level 2 vulnerability according to the criteria contained in 2.5.3 or a direct stability assessment as provided in 2.5.1.2.1 may be performed without the requirement to perform a more simplified assessment in 2.5.2 or 2.5.3, respectively.

2.5.1.4 Stability limit information for determining the safe zones as functions of \( GM \), draught and trim is to be provided based on matrix calculations according to the criteria contained in sections 2.5.2 or 2.5.3 and, if appropriate, direct stability assessment according to the provisions in chapter 3 on direct stability assessment. If relevant the stability limit information for determining safe zones should take into account operational limitations according to the provisions in chapter 4 on operational measures.

2.5.1.5 Reference environmental conditions to be used in the assessment may be modified, according to the Guidelines for operational measures in chapter 4.

2.5.1.6 Free surface effects should be accounted for as recommended in chapter 3 of part B of 2008 IS Code.

2.5.2 **Level 1 vulnerability criteria for parametric rolling**

2.5.2.1 A ship is considered not to be vulnerable to the parametric rolling failure mode if

\[
\frac{\delta GM}{GM} \leq R_{PR} \quad \text{and} \quad \frac{V_D - V}{A_w (D - d)} \geq 1.0
\]
where:

\[ \delta_{GM_i} = \text{amplitude of the variation of the metacentric height (m) calculated as provided in 2.5.2.2.} \]

**2.5.2.2** As provided by 2.5.2.1, \( \delta_{GM_i} \) should be determined according to:

\[ \delta_{GM_i} = \frac{I_{TH} - I_{TL}}{2V} \]

where:

\[ \delta d_H = \text{Min}(D - d, \frac{L \cdot S_W}{2}) \text{ (m)}; \]

\[ \delta d_L = \text{Min}(d - 0.25d_{full}, \frac{L \cdot S_W}{2}) \text{ (m)}; \]

and \( d - 0.25d_{full} \) should not be taken less than zero;

\[ d_H = d + \delta d_H \text{ (m)}; \]

\[ d_L = d - \delta d_L \text{ (m)}; \]

\[ S_W = 0.0167; \]

\[ I_{TH} = \text{transverse moment of inertia of the waterplane at the draft } d_H \text{ (m}^4)\]; and

\[ I_{TL} = \text{transverse moment of inertia of the waterplane at the draft } d_L \text{ (m}^4). \]

**2.5.2.3** The use of the simplified conservative estimation of \( \delta_{GM_i} \) described in 2.5.2.2, without initial trim effect, can be applied for ships having non-even keel condition.

**2.5.3** **Level 2 vulnerability criteria for parametric rolling**

**2.5.3.1** A ship is considered not to be vulnerable to the parametric rolling failure mode if

.1 \( C1 \leq R_{PRI} \); or

.2 \( C2 \leq R_{PRI2} \);

where:

\[ R_{PRI} = 0.06; \]

\[ R_{PRI2} = \]

---

14 Refer to the Explanatory Notes for the Second generation intact stability criteria (MSC.1/Circ.xxxx).
\( R_{PR2} = 0.025; \)
\( C1 = \) criterion calculated according to 2.5.3.2;
\( C2 = \) criterion calculated according to 2.5.3.3.

2.5.3.2 The value for \( C1 \) is calculated as a weighted average from a set of waves specified in 2.5.3.2.3, as:

\[
C1 = \sum_{i=1}^{N} W_i C_i
\]

where:
\( W_i = \) weighting factor for the respective wave specified in 2.5.3.2.3;
\( C_i = 0, \) if the requirements of either the variation of \( GM \) in waves contained in 2.5.3.2.1 or the ship speed in waves contained in 2.5.3.2.2 is satisfied; and
\( = 1, \) if not;
\( N = \) the number of wave cases evaluated, as specified in 2.5.3.2.3.

2.5.3.2.1 For each wave specified in 2.5.3.2.3, the requirement for the variation of \( GM \) in waves is satisfied if:

\[
GM(H_i, \lambda_i) > 0 \quad \text{and} \quad \frac{\delta GM(H_i, \lambda_i)}{GM(H_i, \lambda_i)} < R_{PR}
\]

where:
\( R_{PR} = \) as defined in 2.5.2.1;
\( \delta GM(H_i, \lambda_i) = \) one-half the difference between the maximum and minimum values of the metacentric height calculated for the ship (m), corresponding to the loading condition under consideration, considering the ship to be balanced in sinkage and trim on a series of waves characterized by a wave height \( H_i \) and a wavelength \( \lambda_i \);
\( GM(H_i, \lambda_i) = \) the average value of the metacentric height calculated for the ship (m), corresponding to the loading condition under consideration,\(^{15}\) considering the ship to be balanced in sinkage and trim on a series of waves characterized by a wave height \( H_i \) and a wavelength \( \lambda_i \);
\( H_i = \) wave height specified in 2.5.3.2.3 (m); and
\( \lambda_i = \) wavelength specified in 2.5.3.2.3 (m).

2.5.3.2.2 For each wave specified in 2.5.3.2.3, the requirement for the ship speed in waves is satisfied if:

\( V_{PRI} > V_s \)

where:
\( V_{PRI} = \) the reference ship speed (m/s) corresponding to parametric resonance conditions, when \( GM(H_i, \lambda_i) > 0 \):

\[
V_{PRI} = \left| \frac{2 \lambda_i}{T_i} \sqrt{\frac{GM(H_i, \lambda_i)}{g \lambda_i}} - \sqrt{\frac{\lambda_i}{2\pi}} \right|
\]

\(^{15}\) Refer to the Explanatory Notes for the Second generation intact stability criteria (MSC.1/Circ.xxxx)
\[ GM(H_i, \lambda_i) = \text{as defined in 2.5.3.2.1 (m);} \]
\[ \lambda_i = \text{wavelength specified in 2.5.3.2.3 (m);} \]
\[ || = \text{the absolute value operation.} \]

2.5.3.2.3 The specified wave cases for evaluation of the requirements contained in 2.5.3.2.1 and 2.5.3.2.2 are presented in Table 2.5.3.2.3. In Table 2.5.3.2.3, \( w_i, H_i, \lambda_i \) are as defined in 2.5.3.2.

### Table 2.5.3.2.3
**Wave cases for parametric rolling evaluation**

<table>
<thead>
<tr>
<th>Wave case number</th>
<th>Weight factor ( W_i )</th>
<th>Wavelength ( \lambda_i ) (m)</th>
<th>Wave height ( H_i ) (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.000013</td>
<td>22.574</td>
<td>0.350</td>
</tr>
<tr>
<td>2</td>
<td>0.001654</td>
<td>37.316</td>
<td>0.495</td>
</tr>
<tr>
<td>3</td>
<td>0.020912</td>
<td>55.743</td>
<td>0.857</td>
</tr>
<tr>
<td>4</td>
<td>0.092799</td>
<td>77.857</td>
<td>1.295</td>
</tr>
<tr>
<td>5</td>
<td>0.199218</td>
<td>103.655</td>
<td>1.732</td>
</tr>
<tr>
<td>6</td>
<td>0.248788</td>
<td>133.139</td>
<td>2.205</td>
</tr>
<tr>
<td>7</td>
<td>0.208699</td>
<td>166.309</td>
<td>2.697</td>
</tr>
<tr>
<td>8</td>
<td>0.128984</td>
<td>203.164</td>
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<td>0.000007</td>
<td>630.684</td>
<td>5.950</td>
</tr>
</tbody>
</table>

2.5.3.2.4 In the calculation of \( \delta GM(H_i, \lambda_i) \) and \( GM(H_i, \lambda_i) \) in 2.5.3.2.1, the wave crest should be located amidships, and at 0.1 \( \lambda_i \), 0.2 \( \lambda_i \), 0.3 \( \lambda_i \), 0.4 \( \lambda_i \) forward and 0.1 \( \lambda_i \), 0.2 \( \lambda_i \), 0.3 \( \lambda_i \), and 0.4 \( \lambda_i \) aft thereof.

2.5.3.3 The value of \( C^2 \) is calculated as an average of values of \( C^2(F_n, \beta) \), each of which is a weighted average from the set of waves specified in 2.5.3.4.2, for each set of Froude numbers and wave directions specified:

\[
C^2 = \left[ \sum_{i=1}^{12} C^2(F_n, \beta_i) + \frac{1}{2} \left( C^2(0, \beta_h) + C^2(0, \beta_f) \right) + \sum_{i=1}^{12} C^2(F_n, \beta_f) \right] / 25
\]

where:

\[
C^2(F_n, \beta_h) = C^2(F_n, \beta) \text{ calculated as specified in 2.5.3.3.1 with the ship proceeding in head waves with a speed equal to } V_i;
\]

\[
C^2(F_n, \beta_f) = C^2(F_n, \beta) \text{ calculated as specified in 2.5.3.3.1 with the ship proceeding in following waves with a speed equal to } V_i;
\]

\[
F_n = V_i / \sqrt{Lg} , \text{ Froude number corresponding to ship speed } V_i;
\]

\[
V_i = V_s K_i , \text{ ship speed (m/s); and}
\]

\[
K_i = \text{as obtained from table 2.5.3.3.}
\]
Table 2.5.3.3
Speed factor, $K_i$

<table>
<thead>
<tr>
<th>$i$</th>
<th>$K_i$</th>
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<tbody>
<tr>
<td>1</td>
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</tr>
<tr>
<td>2</td>
<td>0.991</td>
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<tr>
<td>12</td>
<td>0.131</td>
</tr>
</tbody>
</table>

2.5.3.3.1 The weighted criteria $C_2(Fn_i, \beta)$ are calculated as a weighted average of the short-term parametric rolling failure index considering the set of waves specified in 2.5.3.4.2, for a given Froude number and wave direction, as follows:

$$C_2(Fn_i, \beta) = \sum_{i=1}^{N} W_i C_{S,i}$$

where:

- $W_i$ = weighting factor for the respective wave cases specified in 2.5.3.4.2;
- $C_{S,i}$ = 1, if the maximum roll angle evaluated according to 2.5.3.4 exceeds 25 degrees, and = 0, otherwise;
- $N$ = total number of wave cases for which the maximum roll angle is evaluated for a combination of speed and heading.

2.5.3.4 The maximum roll angle in head and following waves is evaluated as recommended in 2.5.3.4.1 for each speed, $V_i$, defined in 2.5.3.3. For each evaluation, the calculation of stability in waves should assume the ship to be balanced in sinkage and trim on a series of waves with the following characteristics:

- wavelength, $\lambda = L$;
- wave height, $h_j = 0.01 \cdot jL$, where $j = 0,1,...,10$.

For each wave height, $h_j$, the maximum roll angle is evaluated.

2.5.3.4.1 The evaluation of roll angle should be carried out using the time domain simulation method with $GZ$ calculated in waves\textsuperscript{16}.

2.5.3.4.2 $W_i$ is obtained as the value in table 2.7.2.1.2 divided by the amount of observations given in the table. Each cell of the table corresponds to an average zero-crossing wave period.

\textsuperscript{16} Refer to the Explanatory Notes for the Second generation intact stability criteria (MSC.1/Circ.xxxx).
$T_\text{s}$, and a significant wave height, $H_s$. With these two values, a representative wave height, $H_{r,i}$, should be calculated by filtering waves within the ship length. The maximum roll angle, corresponding to the representative wave height, $H_{r,i}$, is obtained by linear interpolation of the maximum roll angles for different wave heights, $h_j$, obtained in 2.5.3.4. This maximum roll angle should be used for the evaluation of $C_{S,i}$ in 2.5.3.3.1.

2.6 **Assessment of ship vulnerability to the surf-riding/broaching failure mode**

2.6.1 **Application**

2.6.1.1 For ships that do not meet the standard contained in 2.6.2, the procedures of ship-handling on how to avoid dangerous conditions for surf-riding/broaching recommended in section 4.2.1 of the *Revised guidance to the master for avoiding dangerous situations in adverse weather and sea conditions* (MSC.1/Circ.1228) may apply, subject to the approval of the Administration, as an alternative to 2.6.2.

2.6.1.2 For each condition of loading, a ship that:

.1 meets the standard contained in the criteria contained in 2.6.2 is considered not to be vulnerable to the surf-riding/broaching failure mode;

.2 does not meet the standard contained in the criteria in 2.6.2 should be subject to more detailed assessment of vulnerability to the surf-riding/broaching failure mode by applying the criteria contained in 2.6.3.

2.6.1.3 Alternatively to the criteria contained in 2.6.2 or 2.6.3, for each condition of loading a ship may be subject to either:

.1 direct stability assessment for the surf-riding/broaching failure mode that is performed according to the Guidelines for direct stability assessment in chapter 3; or

.2 operational measures based on the Guidelines for operational measures in chapter 4.

2.6.1.4 A detailed assessment of Level 2 vulnerability according to the criteria contained in 2.6.3 or a direct stability assessment as provided in 2.6.1.3.1 may be performed without the requirement to conduct a more simplified assessment in 2.6.2 or 2.6.3, respectively.

2.6.1.5 For ships that do not meet the standard contained in 2.6.2 and which are not applying MSC.1/Circ.1228 according to 2.6.1.1 above, relevant consistent safety information is provided according to the criteria contained in either paragraph 2.6.3 of these Guidelines, or Guidelines for direct stability assessment in chapter 3 and Guidelines for operational measures in chapter 4, as appropriate.

2.6.1.6 Reference environmental conditions to be used in the assessment may be modified according to the Guidelines for operational measures in chapter 4.

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17 Refer to the Explanatory Notes for the Second generation intact stability criteria (MSC.1/Circ.xxxx).
2.6.2 Level 1 vulnerability criteria for surf-riding/broaching

2.6.2.1 A ship is considered not to be vulnerable to the surf-riding/broaching failure mode if:

1. \( L \geq 200 \text{m}\); or
2. \( F_n \leq 0.3 \).

2.6.3 Level 2 vulnerability criteria for surf-riding/broaching

2.6.3.1 A ship is considered not to be vulnerable to the surf-riding/broaching failure mode if

\[ C \leq R_{SR} \]

where:

\[ R_{SR} = 0.005; \]
\[ C = \text{criterion calculated according to 2.6.3.2.} \]

2.6.3.2 The value of \( C \) is calculated as

\[ C = \sum_{H_s} \sum_{T_z} (W2(H_s, T_z) \sum_{i=1}^{N_a} \sum_{j=1}^{N_a} w_{ij} C_{2_{ij}}) \]

where:

\[ W2(H_s, T_z) = \text{weighting factor of short-term sea state specified in 2.7.2.1 as a function of the significant wave height, } H_s, \text{ and the zero-crossing wave period, } T_z \text{ in which } W2(H_s, T_z) \text{ is equal to the number of occurrences of the combination divided by the total number of occurrences in the table, and it corresponds to the factor } W_i \text{ specified in 2.7.2;} \]

\[ w_{ij} = \text{statistical weight of a wave specified in 2.6.3.3 with steepness } (H_s/\lambda) \text{ and wavelength to ship length ratio } (\lambda/L), \text{ calculated with the joint distribution of local wave steepness and lengths, which is, with specified discretization } N_{\lambda} = 80 \text{ and } N_a = 100. \]

\[ C_{2_{ij}} = \text{coefficient specified in 2.6.3.4.} \]

2.6.3.3 The value of \( w_{ij} \) should be calculated using the following formula:\(^{18}\)

\[ w_{ij} = \frac{4\sqrt{g} L^{5/2} T_{\theta 1} S_j^{3/2}}{\pi v (H_s)^3} \frac{s^2}{\sqrt{1 + v^2}} \frac{1 + \sqrt{1 + v^2}}{1 + \frac{g T_{\theta 1}^2}{2 \pi v L}} \Delta r \Delta s \]

\[ \cdot \exp \left[ -2 \left( \frac{L \cdot \tau_i \cdot s_j}{H_s} \right)^2 \left( 1 + \frac{1}{v^2} \left( 1 - \sqrt{\frac{g T_{\theta 1}^2}{2 \pi v L}} \right)^2 \right) \right] \]

where:

\[ v = 0.425; \]
\[ T_{\theta 1} = 1.086 T_z; \]

\(^{18}\) Refer to the Explanatory Notes for the Second generation intact stability criteria (MSC.1/Circ.xxxx).
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\[ s_j = \left( \frac{H}{\lambda} \right)_j \text{ = wave steepness varying from 0.03 to 0.15 with increment } \Delta s = 0.0012; \text{ and} \]
\[ r_i = \left( \frac{\lambda}{L} \right)_i \text{ = wavelength to ship length ratio varying from 1.0 to 3.0 with increment } \Delta r = 0.025. \]

2.6.3.4 The value of \( C_{2ij} \) is calculated for each wave as follows:

\[
C_{2ij} = \begin{cases} 1 & \text{if } F_n > F_{n_{cr}}(r_j, s_i) \\ 0 & \text{if } F_n \leq F_{n_{cr}}(r_j, s_i) \end{cases}
\]

where:

\[ F_{n_{cr}} = \text{critical Froude number corresponding to the threshold of surf-riding (surf-riding occurring under any initial condition) which should be calculated in accordance with 2.6.3.4.1 for the regular wave with steepness } s_j \text{ and wavelength to ship length ratio } r_i. \]

2.6.3.4.1 The critical Froude number, \( F_{n_{cr}} \), is calculated as

\[ F_{n_{cr}} = \frac{u_{cr}}{\sqrt{Lg}} \]

where the critical ship speed, \( u_{cr} \) (m/s), is determined according to 2.6.3.4.2.

2.6.3.4.2 The critical ship speed, \( u_{cr} \), is determined by solving the following equation with the critical propulsor revolutions, \( n_{cr} \):

\[ T_e(u_{cr}; n_{cr}) - R(u_{cr}) = 0 \]

where:

\[ R(u_{cr}) = \text{calm water resistance of the ship at the ship speed of } u_{cr}, \text{ see 2.6.3.4.3}; \]
\[ T_e(u_{cr}; n_{cr}) = \text{thrust delivered by the ship’s propulsor(s) in calm water determined in accordance with 2.6.3.4.4}; \]
\[ n_{cr} = \text{commanded number of revolutions of propulsor(s) corresponding to the threshold of surf-riding (surf-riding occurs under any initial conditions), see 2.6.3.4.6.} \]

2.6.3.4.3 The calm water resistance, \( R(u) \), is approximated based on available data with a polynomial fit suitable to represent the characteristics of the resistance for the vessel in question.\(^{19}\) The fit should be appropriate to ensure the resistance is continuously increasing as a function of speed in the appropriate range.

2.6.3.4.4 For a ship using one propeller as the main propulsor, the propulsor thrust, \( T_e(u; n) \), in calm water may be approximated using a second degree polynomial:

\[
T_e(u; n) = (1 - t_p) \rho n^2 D_p^4 \left\{ \frac{1}{6} \kappa_0 + \kappa_1 J + \kappa_2 J^2 \right\} (N)
\]

\(^{19}\) Refer to the Explanatory Notes for the Second generation intact stability criteria (MSC.1/Circ.xxxx).
where:

\[ u = \text{speed of the ship (m/s) in calm water;} \]
\[ n = \text{commanded number of revolutions of propulsor (1/s);} \]
\[ t_p = \text{approximate thrust deduction factor;}^{20} \]
\[ w_p = \text{approximate wake fraction;}^{21} \]
\[ \kappa_0, \kappa_1, \kappa_2 = \text{approximation coefficients for the approximated propeller thrust coefficient in calm water;} \]
\[ J = \frac{u(1 - w_p)}{nD_p} = \text{advance ratio.} \]

In case of a ship having multiple propellers, the overall thrust can be calculated by summing the effect of the individual propellers calculated as indicated above.

For a ship using a propulsor(s) other than a propeller(s), the propulsor thrust should be evaluated by a method appropriate to the type of propulsor used.

2.6.3.4.5 The amplitude of wave surging force is calculated as:

\[ f = \frac{\rho g k_i H_{ij}}{2} \sqrt{F_C^2 + F_S^2} \text{ (N)} \]

where:

\[ k_i = \text{wave number} = \frac{2\pi}{r_i L} \text{ (1/m);} \]
\[ H_{ij} = \text{wave height} = s_j r_i L \text{ (m);} \]
\[ s_j, r_i = \text{as defined in 2.6.3.3;} \]
\[ F_C = \sum_{i=1}^{N} \delta x_i S(x_i) \sin k_i x_i \exp(-0.5k_i \cdot d(x_i)) \text{ (m$^3$);} \]
\[ F_S = \sum_{i=1}^{N} \delta x_i S(x_i) \cos k_i x_i \exp(-0.5k_i \cdot d(x_i)) \text{ (m$^3$);} \]
\[ F_C \text{ and } F_S \text{ are parts of the Froude-Krylov component of the wave surging force;} \]
\[ x_i = \text{longitudinal distance from the midship to a station (m), positive for a bow section;} \]
\[ \delta x_i = \text{length of the ship strip associated with station } i; \]
\[ d(x_i) = \text{draft at station } i \text{ in calm water (m);} \]
\[ S(x_i) = \text{area of submerged portion of the ship at station } i \text{ in calm water (m$^2$);} \]
\[ N = \text{number of stations.} \]

2.6.3.4.6 The critical number of revolutions of the propulsor corresponding to the surf-riding threshold, \( n_{cr} \), can be determined by solving the following quadratic equation\(^{21}\)

\[ 2\pi \frac{T_e(c_i, n_{cr}) - R(c_i)}{f} + 8a_0 n_{cr} + 8a_1 - 4\pi a_2 + \frac{64}{3} a_3 - 12\pi a_4 + \frac{1024}{15} a_5 = 0 \]

where:

\[ a_0 = -\frac{\tau_i}{\sqrt{f \cdot k_i \cdot (M + M_s)}} \]

\(^{20}\) Refer to the Explanatory Notes for the Second generation intact stability criteria (MSC.1/Circ.xxxx).
\[ a_i = \frac{r_i + 2r_2c_i + 3r_3c_i^2 + 4r_4c_i^3 + 5r_5c_i^4 - 2\tau_i c_i}{\sqrt{f \cdot k_i \cdot (M + M_x)}} \]

\[ a_2 = \frac{r_2 + 3r_3c_i^2 + 6r_4c_i^3 + 10r_5c_i^4 - \tau_2}{k_i \cdot (M + M_x)} \]

\[ a_3 = \frac{r_3 + 4r_4c_i^2 + 10r_5c_i^3}{\sqrt{k_i^3 (M + M_x)^3}} \cdot \sqrt{f} \]

\[ a_4 = \frac{r_4 + 5r_5c_i}{k_i^2 (M + M_x)^2} f \]

\[ a_5 = \frac{r_5}{\sqrt{k_i^5 (M + M_x)^5}} \sqrt{f^3} \]

\( r_1, r_2, r_3, r_4, r_5 \) = regression coefficients for the calm water resistance under a fifth degree polynomial approximation \( R(u) \approx r_1 u + r_2 u^2 + r_3 u^3 + r_4 u^4 + r_5 u^5 \).

\( M \) = mass of the ship (kg);

\( M_x \) = added mass of the ship in surge (kg). In absence of ship specific data, \( M_x \) may be assumed to be 0.1 \( M \);

\( \zeta_i \) = \( \sqrt{\frac{g}{k_i}} \) = wave celerity.

\( \tau_0 = \kappa_0 (1 - t_p) \rho D_p^4 \)

\( \tau_1 = \kappa_1 (1 - t_p) (1 - w_p) \rho D_p^3 \)

\( \tau_2 = \kappa_2 (1 - t_p) (1 - w_p)^2 \rho D_p^2 \)
2.7 Parameters common to stability failure mode assessments

2.7.1 Inertial properties of a ship and natural period of roll motion

2.7.1.1 In the absence of direct calculations, the roll moment of inertia of the ship comprising the effect of added inertia, $J_{roll}$, may be estimated as follows:

$$J_{T, roll} = \frac{1}{1000} \rho g \frac{\mathcal{V} GM}{4\pi} T_r^2 \text{(t·m}^2\text{)}$$

2.7.1.2 The natural roll period, $T_r$, in a given loading condition, in the absence of sufficient information, direct calculation or measurement, may be approximated using the formulae given in part A, 2.3 of the 2008 IS Code, which is repeated below,

$$T_r = \frac{2 \cdot C \cdot B}{\sqrt{GM}}$$

or its alternatives.$^{21}$

2.7.2 Environmental data

2.7.2.1 A set of standard environmental conditions are assumed. The characterization of the standard environmental conditions refers to both, the short and the long-term. The short-term characterization is given in terms of the spectrum of sea elevation, known as the spectral density of the sea wave elevation. The long-term characterization is given in terms of a wave scatter table. Both the standard short-term and long-term characterizations are given in 2.7.2.1.1 and 2.7.2.1.2, respectively.

2.7.2.1.1 The spectral density of sea wave elevation, $S_{zz}(\omega)$, as a function of the wave frequency, $\omega$, is calculated as follows:

$$S_{zz}(\omega) = \frac{H_s^2}{4\pi} \left(\frac{2\pi}{T_z}\right)^4 \omega^{-5} \exp \left\{ -\frac{1}{\pi} \left(\frac{2\pi}{T_z}\right)^4 \omega^{-4} \right\}.$$  

2.7.2.1.2 The long-term characterization of the standard environmental conditions is given by means of a wave scatter table.$^{22}$ The wave scatter table reports the statistical frequency of occurrence of short-term sea conditions with different significant wave height $H_s$ and mean zero-crossing period $T_z$. The standard wave scatter table is given in table 2.7.2.1.2. For each short-term environmental condition given by the combination of $H_s$ and $T_z$, the corresponding factor $W_i$ corresponds to the frequency of the short-term environmental condition, and it is determined as the number of occurrences of the combination of $H_s$ and $T_z$ divided by the total number of occurrences in the scatter table.

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$^{21}$ Refer to the Explanatory Notes for the Second generation intact stability criteria (MSC.1/Circ.xxxx).

$^{22}$ Refer to International Association of Classification Societies (IACS) Recommendation No.34 (Corr. Nov.2001).
### Table 2.7.2.1.2 Standard wave scatter table

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<th>Tz (s)</th>
<th>Hs (m)</th>
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<th>4.5</th>
<th>5.5</th>
<th>6.5</th>
<th>7.5</th>
<th>8.5</th>
<th>9.5</th>
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</tbody>
</table>

2.7.2.2 Alternative environmental conditions can be used to the satisfaction of the Administration for ships subject to operational limitations according to chapter 4.

2.7.2.2.1 Such alternative environmental conditions should specify the short-term characteristics of wind state and sea state, together with the probability of occurrence of each short-term environmental condition.

2.7.2.2.2 The short-term sea state characteristics should be given in terms of a sea elevation spectrum. The short-term wind state should be given in terms of a mean wind speed and a gustiness spectrum.

2.7.2.2.3 The long-term characterization of the environmental condition should be given in terms of probability of occurrence of each short-term condition. The probability of occurrence of each short-term environmental condition corresponds to the weighting factor, W. The set of short-term environmental conditions and corresponding weighting factors should be such that the sum of the weighting factors, i.e. the probabilities of occurrence, is unity.

2.7.3 **Other common parameters**

2.7.3.1 Other common parameters include wave forces, roll damping, characteristics of roll motions, metacentric height and righting lever curve in waves. Evaluation of these parameters are described in the Explanatory Notes.
3 Guidelines for direct stability assessment

3.1 Objective

3.1.1 These Guidelines provide specifications for direct stability assessment procedures for the following stability failure modes:

- dead ship condition;
- excessive acceleration;
- pure loss of stability;
- parametric rolling; and
- surf-riding/broaching.

3.1.2 The criteria, procedures and standards recommended in these Interim guidelines ensure a safety level corresponding to the average stability failure rate not exceeding $2.6 \times 10^{-3}$ per ship per year.

3.1.3 Direct stability assessment procedures are intended to employ state-of-the-art technology while being sufficiently practical to be uniformly accepted and applied using currently available infrastructure.

3.1.4 The provisions given hereunder apply to all ships, excepting the dead ship and pure loss of stability failure modes for ships with extended low weather deck.

3.2 Requirements

3.2.1 The failure event is defined as:

- Exceedance of roll angle, defined as the minimum of 40 degrees, angle of vanishing stability in calm water and angle of submergence of unprotected openings in calm water; or
- Exceedance of lateral acceleration of $9.81 \text{ m/s}^2$ at the highest location along the length of the ship where passengers or crew may be present.

The Administration may define stricter requirements.

3.2.2 Active means of motion reduction, such as active anti-roll fins and anti-roll tanks, can significantly reduce roll motions in seaway, if appropriately used. However, the safety of the ship should be ensured in cases of failure of such devices, therefore, the assessment according to these Interim guidelines should be conducted with such devices inactive or retracted.

3.2.3 The procedure for direct stability assessment consists of two major components:

- a method that adequately replicates ship motions in waves (see 3.3); and
- a prescribed procedure that identifies the process by which input values are obtained for the assessment, how the output values are processed, and how the results are evaluated (see 3.5).
3.3 Requirements for a method that adequately predicts ship motions

3.3.1 General considerations

3.3.1.1 The motion of ships in waves used for the assessment of stability performance can be predicted by means of numerical simulations or model tests.

3.3.1.2 The choice between numerical simulations, model tests, or their combination should be agreed with the Administration on a case-by-case basis taking into account these Interim guidelines.

3.3.1.3 The procedures, calibrations and proper application of technology involved in the conduct of model tests should follow "Recommended Procedures, Model Tests on Intact Stability, 7.5-02-07-04.1" issued by the International Towing Tank Conference (ITTC) in 2008. Users may follow recent amended versions of the Recommended Procedures at the time of execution of tests.

3.3.1.4 Numerical simulation of ship motions may be defined as the numerical solution of the motion equations of a ship sailing in waves including or excluding the effect of wind (see 3.3.2).

3.3.2 General Requirements

3.3.2.1 Modelling of waves

3.3.2.1.1 The mathematical model of waves should be consistent and appropriate for the calculation of the forces.

3.3.2.1.2 Modelling of irregular waves should be statistically and hydrodynamically valid. Caution should be exercised to avoid a self-repetition effect.

3.3.2.2 Modelling of roll damping: avoiding duplication

3.3.2.2.1 Roll damping forces should include wave, lift, vortex (i.e. eddy-making) and skin friction components.

3.3.2.2.2 The data to be used for the calibration of roll damping may be defined from:

   .1 roll decay or forced roll test;

   .2 CFD computations, if sufficient agreement with experimental results in terms of roll damping is demonstrated;

   .3 existing databases of measurements or CFD computations for similar ships, if suitable range is available; or

   .4 empirical formulae, applied within their applicability limits.

3.3.2.2.3 If the wave component of roll damping is already included in the calculation of radiation forces, measures should be taken to avoid including these effects more than once.

3.3.2.2.4 Similarly, if any components of roll damping (e.g. cross-flow drag) are directly computed whereas others are taken from the calibration data, similar measures should be taken to exclude these directly computed elements from the calibration data used.
3.3.2.2.5 Consideration of the essential roll damping elements more than once can be avoided through use of an iterative calibration procedure in which the roll decay or forced roll tests are replicated in numerical simulations. The results should be determined to be reasonably close to the original calibration model test data set.

3.3.2.3 **Mathematical modelling of forces and moments**

3.3.2.3.1 The Froude-Krylov forces should be calculated using body-exact formulations at least for pure loss of stability, parametric rolling and dead ship condition failure modes, for instance using panel or strip-theory approaches.

3.3.2.3.2 Radiation and diffraction forces should be represented in one of three ways: one is to use approximate coefficients and the other two involve either a body linear formulation or a body-exact solution of the appropriate boundary-value problem.

3.3.2.3.3 Resistance forces should include wave, vortex and skin friction components. The preferred source for these data is model test. The added resistance in waves can be approximated, if this element is not already included in the calculation of diffraction and radiation forces. If the radiation and diffraction forces are calculated as a solution of the hull boundary-value problem, measures must be taken to avoid including these effects more than once.

3.3.2.3.4 Hydrodynamic reaction sway forces, roll moment and yaw moments could be approximated, based on:

1. Coefficients derived from model tests in calm water with planar motion mechanism (PMM) or in stationary circular tests, by means of a rotating arm or an x-y carriage.\(^\text{23}\)

2. CFD computations, provided that sufficient agreement is demonstrated with a model experiment in terms of values of sway force and yaw moment. If the radiation and diffraction forces are calculated as a solution of the hull boundary-value problem, measures must be taken to avoid including these effects more than once.

3. Empirical database or empirical formulae, applied within their applicability range.

3.3.2.3.5 Thrust may be obtained by use of a coefficient-based model with approximate coefficients to account for propulsor-hull interactions.

3.3.3 **Requirements for particular stability failure modes**

3.3.3.1 For parametric rolling, ship motion simulations should include at least the following three degrees of freedom: heave, roll and pitch.

3.3.3.2 For pure loss of stability, ship motion simulations should include at least four degrees of freedom: surge, sway, roll and yaw. For those degrees of freedom not included in the dynamic modelling, static equilibrium should be assumed.

\(^{23}\) The captive model test procedure should be based on the ITTC recommended procedure 7.5-02-06-02, issued in 2014 or amended. The stationary circular test by means of an x-y carriage can reproduce a circular model motion with any specified drift angle by combining the motion of an x-y carriage and a turn table.
3.3.3.3 For surf-riding and broaching:

.1 Ship motion simulations should include at least the following four degrees of freedom: surge, sway, roll and yaw. For those degrees of freedom not included in the dynamic modelling, static equilibrium should be assumed; and

.2 Hydrodynamic forces due to vortex shedding from a hull should be properly modelled. This should include hydrodynamic lift forces and moments due to the coexistence of wave particle velocity and ship forward velocity, other than manoeuvring forces and moments in calm water.

3.3.3.4 For dead ship condition:

.1 Ship motion simulations should include at least the following four degrees of freedom: sway, heave, roll and pitch.

.2 Three-component aerodynamic forces and moments generated on topside surfaces may be evaluated using model test results. CFD results may be admitted upon demonstration of sufficient agreement with a model experiment in terms of values of aerodynamic force and moments. Empirical data or formulae could be applied within their applicability range.

3.3.3.5 For excessive acceleration, the ship motion simulations should include at least the following three degrees of freedom: heave, pitch and roll.

3.3.3.6 For the pure loss of stability and broaching failure modes, an appropriate autopilot should be used.

3.3.3.7 For the pure loss of stability and broaching failure modes, the initial condition should be set with sufficiently small ship forward speed for avoiding artificial surf-riding, which cannot occur for a self-propelled ship.

3.4 Requirements for validation of software for numerical simulation of ship motions

3.4.1 Validation

3.4.1.1 Validation is the process of determining the degree to which a numerical simulation is an accurate representation of the real physical world from the perspective of the intended uses of the model or simulation.

3.4.1.2 Different physical phenomena are responsible for different modes of stability failure. Therefore, the validation of software for the numerical simulation of ship motions is failure-mode specific.

3.4.1.3 The validation data should be compatible with the general characteristics of the ship for which the direct stability assessment is intended to be carried out.

3.4.1.4 The process of validation should be performed in two phases: one qualitative and the other quantitative. In the qualitative phase, the objective is to demonstrate that the software is capable of reproducing the relevant physics of the failure mode considered. The objective of the quantitative phase is to determine the degree to which the software is capable of predicting the specific failure mode considered.
### 3.4.2 Qualitative validation requirements

Table 3.4.2 – Requirements and acceptance criteria for qualitative validation

<table>
<thead>
<tr>
<th>Item</th>
<th>Required for</th>
<th>Objective</th>
<th>Acceptance criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Periodic properties of roll oscillator</td>
<td>Software where hydrostatic and Froude-Krylov forces are calculated with body exact formulation</td>
<td>Demonstrate consistency between calculated roll backbone curve (dependence of roll frequency in calm water on initial roll amplitude) and GZ curve in calm water</td>
<td>Based on the shape of calculated backbone curve. The backbone curve must follow a trend which is consistent with the righting lever</td>
</tr>
<tr>
<td>Response curve of roll oscillator</td>
<td>Software where hydrostatic and Froude-Krylov forces are calculated with body exact formulation</td>
<td>Demonstrate consistency between the calculated roll backbone curve and the calculated roll response curve (dependence of amplitude of excited roll motion on the frequency of excitation)</td>
<td>Based on the shape of the roll response curve. The roll response curve must &quot;fold around&quot; the backbone curve and may show hysteresis when the magnitude of excitation is increased</td>
</tr>
<tr>
<td>Change of stability in waves</td>
<td>Software where hydrostatic and Froude-Krylov forces are calculated with body exact formulation. Additional capability to track the instantaneous GZ curve in waves may be required</td>
<td>Demonstrate capability to reproduce wave pass effect</td>
<td>Typically in head and following waves, the stability decreases when the wave crest is located near the midship section (within the quarter of length) and the stability increases when the wave trough is located near the midship section (within the quarter of length)</td>
</tr>
<tr>
<td>Principal parametric resonance</td>
<td>Software where hydrostatic and Froude-Krylov forces are calculated with a body exact formulation</td>
<td>Demonstrate capability to reproduce principal parametric resonance</td>
<td>Usually, observing an increase and stabilization of amplitude of roll oscillation in exact following or head seas when encounter frequency is about twice of natural roll frequency</td>
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Table 3.4.2 (continued) – Requirements and acceptance criteria for qualitative validation

<table>
<thead>
<tr>
<th>Item</th>
<th>Required for</th>
<th>Objective</th>
<th>Acceptance criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surf-riding equilibrium</td>
<td>Software for numerical simulation of surf-riding and broaching</td>
<td>Demonstrate capability to reproduce surf-riding, while yaw motion is [fixed][restrained]</td>
<td>Observing sailing with the speed equal to wave celerity when the propeller RPM is set for the speed in calm water which is less than the wave celerity. The horizontal position of centre of gravity is expected to be located near a wave trough</td>
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<tr>
<td>Heel during turn</td>
<td>Software for numerical simulation of surf-riding and broaching</td>
<td>Demonstrate capability to reproduce heel caused by turn</td>
<td>Observing development of heel angle during the turn</td>
</tr>
<tr>
<td>Turn in calm water</td>
<td>Software for numerical simulation of surf-riding and broaching</td>
<td>Demonstrate correct modelling of manoeuvring forces</td>
<td>Observing correct direction of turn with large rudder angles</td>
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<tr>
<td>Straight captive run</td>
<td>Software for numerical simulation of surf-riding and broaching</td>
<td>Demonstrate correct modelling of wave forces including effect of wave particle velocity</td>
<td>Observing correct tendency of phase difference of wave force to incident waves</td>
</tr>
<tr>
<td>in stern quartering waves</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heel caused by drift and</td>
<td>Software for numerical simulation of ship motions in dead ship condition</td>
<td>Demonstrate capability to reproduce heel caused by a moment created by aerodynamic load and drag caused by drift</td>
<td>Observing slowly developed heel angle after applying aerodynamic load</td>
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<td>wind</td>
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3.4.3 Quantitative validation requirements

3.4.3.1 There are two objectives of quantitative validation of numerical simulation. The first is to find the degree to which the results of numerical simulation differ from the model test results. The results of a model test carried out in accordance with 3.3.1.3 should be recognized as reference values. The second objective is to judge if the observed difference between simulations and model tests is sufficiently small or conservative for direct stability assessment to be performed for the considered modes of failure.
Table 3.4.3 – Indicative requirements and acceptance criteria for quantitative validation

<table>
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<tr>
<th>Item</th>
<th>Required for</th>
<th>Objective</th>
<th>Acceptance criteria</th>
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</thead>
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<tr>
<td>Response curve for parametric rolling in regular waves</td>
<td>Parametric rolling</td>
<td>Demonstrate agreement between numerical simulation and model tests regarding amplitude of the roll response</td>
<td>Maximum (over encounter frequency) roll amplitude should not be underpredicted by more than 10%, if the amplitude is below the angle of maximum GZ or 20% otherwise. Underprediction less than 2 degrees may be disregarded.</td>
</tr>
<tr>
<td>Response curve for synchronous roll in regular waves</td>
<td>All modes</td>
<td>Demonstrate agreement between numerical simulation and model tests regarding amplitude of the roll response</td>
<td>Maximum (over encounter frequency) roll amplitude should not be underpredicted for more than 10%, if the amplitude is below the angle of maximum GZ or 20% otherwise. Under-prediction less than 2 degrees may be disregarded.</td>
</tr>
<tr>
<td>Variance test for synchronous roll</td>
<td>Software for numerical simulation of dead ship condition and excessive acceleration</td>
<td>Demonstrate correct (in terms of statistics) modelling of roll response in irregular waves</td>
<td>Reproduction of experimental results either within 95% confidence interval or conservative</td>
</tr>
<tr>
<td>Variance test for parametric rolling</td>
<td>Software for numerical simulation of parametric rolling</td>
<td>Demonstrate correct (in terms of statistics) modelling of roll response in irregular waves</td>
<td>Reproduction of experimental results either within 95% confidence interval or conservative</td>
</tr>
<tr>
<td>Wave conditions for surf-riding and broaching</td>
<td>Software for numerical simulation of surf-riding and broaching</td>
<td>Demonstrate correct modelling of surf-riding and broaching dynamics in regular waves</td>
<td>Wave steepness causing surf-riding and broaching at the wavelength 0.75 – 1.5 of ship length is within 15% of difference between model tests and numerical simulations. Speed settings are also within 15% difference between model tests and numerical simulations.</td>
</tr>
</tbody>
</table>
3.5 Procedures for direct stability assessment

3.5.1 General description

3.5.1.1 The procedures for direct stability assessment contain a description of the necessary calculations of ship motions including the choice of input data, pre- and post-processing.

3.5.1.2 The direct stability assessment procedure is aimed at the estimation of a likelihood of a stability failure in an irregular wave environment and because the stability failures may be rare, the direct stability assessment procedure may require a solution of the problem of rarity. This arises when the mean time to stability failure is very long in comparison with the natural roll period that serves as a main timescale for the roll motion process. The solution of the problem of rarity essentially requires a statistical extrapolation; for this reason, the validation must be performed for all elements of the direct stability assessment procedure.

3.5.1.3 These Guidelines provide two general approaches to circumvent the problem of rarity, namely assessment in design situations and assessment using deterministic criteria; besides, mathematical techniques are provided that reduce the required number of simulations or simulation time and can be used to accelerate assessment for both, the full assessment and the assessment performed in design situations.

3.5.2 Verification of failure modes

3.5.2.1 Once a failure is identified in numerical simulation, it is necessary to examine whether it can be regarded as a failure mode for which the numerical method is validated and direct assessment is intended. The suggested judging criteria for this purpose are provided below.

3.5.2.2 If the local period of the obtained roll motion in following waves or in stern quartering waves is nearly equal to the local wave encounter period and the maximum roll angle occurs nearly at the relative wave position in which the metacentric height becomes the smallest, it can be regarded as pure loss of stability.

3.5.2.3 If the local period of the obtained roll motion is nearly equal to twice the local wave encounter period and is nearly equal to the ship natural roll period, it can be regarded as the parametric rolling considered in the vulnerability criteria, which is sometimes called as "principal parametric rolling". Other types of parametric rolling may occur with much smaller probability, which [should be outside][are not addressed by] the second generation intact stability criteria.

3.5.2.4 The condition when the ship cannot keep a straight course despite the application of maximum steering efforts is known as broaching. The second generation intact stability criteria address broaching associated with surf-riding. Other types of broaching may occur at slower speed but are not considered here because the centrifugal force, due to such slow-speed broaching which could induce heel, is much smaller. The broaching associated with surf-riding can be identified if both the yaw angle and yaw angular velocity increase over time under the application of the maximum opposite rudder deflection.

3.5.2.5 If the local period of the obtained roll motion in beam waves is nearly equal to the local wave encounter period, it can be regarded as harmonic rolling, which is relevant to the dead ship condition failure mode, as well as the excessive acceleration failure mode.
3.5.3 Environmental and sailing conditions

3.5.3.1 General approaches for selection of environmental and sailing conditions

3.5.3.1.1 The sea states chosen for the direct stability assessment must be representative for the intended service of the ship.

3.5.3.1.2 Sea states are defined by the type of wave spectrum and statistical data of its integral characteristics, such as the significant wave height and the mean zero-crossing wave period. For ships in unrestricted service, the environment should be described by the wave scatter table shown in table 2.7.2.1.2. For ships of restricted service, the wave scatter table should be accepted by the Administration.

3.5.3.1.3 It is recommended to use the Bretschneider wave energy spectrum and cosine-squared wave energy spreading with respect to the mean wave direction. If short-crested waves are considered impracticable in model tests or numerical simulations, long-crested waves can be used.

3.5.3.1.4 For a given set of environmental conditions, the assessment can be performed using any of the following equivalent alternatives:

.1 full probabilistic assessment according to 3.5.3.2;

.2 assessment in design situations using probabilistic criteria according to 3.5.3.3; and

.3 assessment in design situations using deterministic criteria according to 3.5.3.4.

3.5.3.2 Full probabilistic assessment

3.5.3.2.1 In this approach, the criterion used is the estimate of the mean long-term rate of stability failures, which is calculated as a weighted average over all relevant sea states, wave directions with respect to the ship heading and ship forward speeds, for each addressed loading condition.

3.5.3.2.2 To satisfy the requirements of this assessment, this criterion should not exceed the standard of $2.6 \times 10^{-8}$ 1/s. This standard exceeds the value in paragraph 3.1.2 since the full probabilistic assessment for unrestricted service is conducted assuming full design life operation in a severe North Atlantic wave climate in one loading condition, neglecting routing, heavy-weather avoidance and choice of safer speed and course in heavy weather.

3.5.3.2.3 The probabilities of the sea states are defined according to the wave scatter table (see paragraph 3.5.3.1). For the pure loss of stability, parametric rolling, excessive accelerations and surf-riding/broaching failure modes, the mean wave directions with respect to the ship heading are assumed uniformly distributed and the ship forward speed should be regarded as uniformly distributed from zero to the maximum service speed. For dead-ship condition failure mode, beam waves and wind should be assumed and the ship forward speed should be taken as zero.

3.5.3.3 Assessment in design situations using probabilistic criteria

3.5.3.3.1 Compared to the full probabilistic assessment, this approach significantly reduces the required simulation time and number of simulations since the assessment is conducted in
few design situations which are specified for each stability failure mode as combinations of the
ship forward speed, mean wave direction with respect to the ship heading, significant wave
height and mean zero-crossing wave period for each addressed loading condition.

3.5.3.3.2 In this approach, the criterion is the maximum (over the design situations
corresponding to a particular stability failure mode) stability failure rate, defined in each design
situation as the upper boundary of its 95%-confidence interval.

3.5.3.3.3 To satisfy the requirements of this assessment, this criterion should not exceed the
threshold corresponding to one stability failure every 2 hours in design sea states with
probability density $10^{-5}$ $(m \cdot s)^{-1}$.

3.5.3.3.4 Table 3.5.3.3.4 shows the design situations for particular stability failure modes,
including mean wave direction with respect to the ship heading, ship forward speed and range
of wave periods; the step of the zero-crossing wave period in the specified ranges should not
exceed 1.0 s.

**Table 3.5.3.3.4 – Design situations for each stability failure mode**

<table>
<thead>
<tr>
<th>Stability failure mode</th>
<th>Wave directions</th>
<th>Forward speeds</th>
<th>Wave period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead ship condition</td>
<td>Beam wind and waves</td>
<td>Zero</td>
<td>$T_z/T_r$ from 0.7 to 1.3</td>
</tr>
<tr>
<td>Excessive acceleration</td>
<td>Beam</td>
<td>Zero</td>
<td>$T_z/T_r$ from 0.7 to 1.3</td>
</tr>
<tr>
<td>Pure loss of stability</td>
<td>Following</td>
<td>Maximum service speed</td>
<td>$T_p$ corresponding to wavelengths comparable to ship length</td>
</tr>
<tr>
<td>Parametric rolling</td>
<td>Head and following</td>
<td>Zero</td>
<td>All wave periods in the wave scatter table</td>
</tr>
<tr>
<td>Surf-riding/broaching</td>
<td>Following</td>
<td>Maximum nominal service speed</td>
<td>$T_p$ corresponding to wavelengths in the range from 1.0$L$ to 1.5$L$</td>
</tr>
</tbody>
</table>

3.5.3.3.5 For each mean zero-crossing wave period, the significant wave height is selected
according to the probability density of the sea state in the scatter table as specified in 3.5.3.3.3.
For unrestricted service, the significant wave heights are shown in table 3.5.3.3.4 depending
on the mean zero-crossing wave period.
Table 3.5.3.5 – Significant wave heights for design sea states with probability density $10^{-5} \text{(m-s)}^{-1}$ for unrestricted service

<table>
<thead>
<tr>
<th>$T_z$, s</th>
<th>4.5</th>
<th>5.5</th>
<th>6.5</th>
<th>7.5</th>
<th>8.5</th>
<th>9.5</th>
<th>10.5</th>
<th>11.5</th>
<th>12.5</th>
<th>13.5</th>
<th>14.5</th>
<th>15.5</th>
<th>16.5</th>
<th>17.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_s$, m</td>
<td>2.8</td>
<td>5.5</td>
<td>8.2</td>
<td>10.6</td>
<td>12.5</td>
<td>13.8</td>
<td>14.6</td>
<td>15.1</td>
<td>15.1</td>
<td>14.8</td>
<td>14.1</td>
<td>12.9</td>
<td>10.9</td>
<td>-</td>
</tr>
</tbody>
</table>

3.5.3.4 Assessment in design situations using deterministic criteria

3.5.3.4.1 Probabilistic assessment may require long simulation time even using design situations and, besides, makes it difficult using model tests instead of numerical simulations. Applying deterministic criteria, such as mean three-hour maximum roll amplitude, significantly reduces the required simulation time and, besides, makes it easier using model tests, together with or instead of, numerical simulations. However, the inaccuracy of this approach needs to be compensated by additional conservativeness.

3.5.3.4.2 In this approach, the criteria are the maximum (overall design situations for a particular stability failure mode) mean three-hour maximum roll amplitude and lateral acceleration for each addressed loading condition.

3.5.3.4.3 To satisfy the requirements of this assessment, these criteria should not exceed half of the values in the definition of stability failure in paragraph 3.2.1.

3.5.3.4.4 The simulations or model tests for each design situation should comprise at least 15 hours. This duration can be divided into several parts; the results should be post-processed to provide at least five values of the three-hour maximum amplitude of roll angle and lateral acceleration, which are averaged to define the mean three-hour maximum amplitudes.

3.5.3.4.5 This approach uses design situations with the same mean wave directions with respect to the ship heading, ship forward speeds and the ranges of the mean zero-crossing wave periods for particular stability failure modes as the assessment in design situations using probabilistic criteria (see 3.5.3.3).

3.5.3.4.6 For each mean zero-crossing wave period, the significant wave height is selected according to the probability density of the sea state in the scatter table equal to $f_s = 7 \cdot 10^{-5} \text{(m-s)}^{-1}$. Table 3.5.3.4.6 shows these significant wave heights for unrestricted service depending on the mean zero-crossing wave period.

Table 3.5.3.4.6 Significant wave heights, in metres, for design sea states with probability density, $f_s = 7 \cdot 10^{-5} \text{(m-s)}^{-1}$ for assessment using deterministic criteria for unrestricted service

<table>
<thead>
<tr>
<th>$T_z$, s</th>
<th>4.5</th>
<th>5.5</th>
<th>6.5</th>
<th>7.5</th>
<th>8.5</th>
<th>9.5</th>
<th>10.5</th>
<th>11.5</th>
<th>12.5</th>
<th>13.5</th>
<th>14.5</th>
<th>15.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_s$, m</td>
<td>2.0</td>
<td>4.4</td>
<td>6.9</td>
<td>9.1</td>
<td>10.9</td>
<td>12.1</td>
<td>12.8</td>
<td>13.1</td>
<td>13.0</td>
<td>12.5</td>
<td>11.3</td>
<td>9.0</td>
</tr>
</tbody>
</table>

3.5.4 Direct counting procedure

3.5.4.1 The direct counting procedure uses ship motions resulting from multiple independent realisations of an irregular seaway to estimate the rate of stability failure $r$.

3.5.4.2 The procedure used for direct counting should provide the upper boundary of the 95% confidence interval of the estimated rate of stability failure, which is used in direct stability assessment and operational measures.
3.5.4.3 The counting procedure should ensure independence of the counted stability failure events.

3.5.4.4 The failure rate $r$ and associated confidence interval can be estimated:

1. by carrying out a simulation for each realisation of an irregular seaway only until the first stability failure\textsuperscript{24}, or

2. on the basis of a set of independent simulations with fixed specified exposure time $t_{exp}$ (s), under the assumption that the relation between the probability $p$ of failure within $t_{exp}$ and the failure rate $r$ is $p = 1 - \exp(-r \cdot t_{exp})$\textsuperscript{25}.

3.5.4.5 Alternatively to direct counting, extrapolation procedures can be used as specified in section 3.5.5.

3.5.5 Extrapolation procedures

3.5.5.1 The extrapolation procedures to be used with these Guidelines should only include those procedures that have been successfully validated and applied and which should also include a detailed description of their application.

3.5.5.2 Cautions

3.5.5.2.1 The extrapolation method may be applied as an alternative to the direct counting procedure.

3.5.5.2.2 Caution should be exercised because extrapolation increases uncertainty caused by additional assumptions used for describing ship motions in waves.

3.5.5.2.3 The statistical uncertainty of the extrapolated values should be provided in a form of boundaries of the confidence interval evaluated with a confidence level of 95%.

3.5.5.2.4 To control the uncertainty, caused by nonlinearity, the principle of separation may be used. Extrapolation methods based on the principle of separation consist of at least two numerical procedures addressing different aspects of the problem: "non-rare" and "rare".

3.5.5.2.5 The "non-rare" procedure focuses on the estimation of ship motions or waves of small-to-moderate level for which the stability failure events can be characterized statistically with acceptable uncertainty.

3.5.5.2.6 The "rare" procedure focuses on ship motions of moderate-to-severe level for which numerical simulation are rarely required. Large motions may be separated from the rest of the time domain data to obtain practical estimates of these motions.

3.5.5.2.7 Different extrapolation methods based on the separation principle may use different assumptions on how the separation is introduced.

3.5.5.3 Extrapolation over wave height

3.5.5.3.1 Extrapolation of the mean time to stability failure or mean rate of stability failures over significant wave height is a technique allowing reducing the required simulation time by

\textsuperscript{24} Refer to the Explanatory Notes for the Second generation intact stability criteria (MSC.1/Circ.xxx).

\textsuperscript{25}
performing numerical simulations or model tests at greater significant wave heights than those required in the assessment and extrapolating the results to lower significant wave heights.

3.5.5.3.2 The extrapolation is based on the approximation $\ln T = A + B/H_s^2$, where $T$, $s$, is the mean time to stability failure; $H_s$, m, is the significant wave height; and $A$, $B$ are coefficients which do not depend on the significant wave height but depend on the other parameters specifying the situation (wave period, wave direction and ship forward speed).

3.5.5.3.3 The extrapolation can be performed when at least three values of the stability failure rate are available, obtained by direct counting for a range of significant wave heights of at least 2 m; each of the values used in extrapolation should correspond to the upper boundary of the 95%-confidence interval of stability failure rate and not exceed 5% of the reciprocal natural roll period of the ship. Results should be checked for the presence of outliers and non-conservative extrapolation and corrected, when necessary, by adding or removing points used for extrapolation.

3.5.5.4 Other extrapolation procedures

3.5.5.4.1 Other extrapolation procedures may be used, taking into account 3.5.5.1 and 3.5.5.2, as listed in the Explanatory Notes, such as the critical wave method for broaching failure mode.  

3.5.6 Validation of extrapolation procedures

3.5.6.1 Extrapolation procedures used for direct stability assessment should be validated.

3.5.6.2 Validation of an extrapolation procedure is a demonstration that the extrapolated value is in reasonable statistical agreement with the result of the direct counting, if such volume of data would be available.

3.5.6.3 The data for validation of the extrapolation procedure may be produced by a mathematical model of reduced complexity (e.g. a set of ordinary differential equations instead of a numerical solution of a boundary value problem) or by running the full mathematical model on significantly more severe environmental and/or more onerous loading conditions. The objective is to decrease the computational cost by which a large data set can be obtained (the validation data set). Physical experiments can be used for the same purpose.

3.5.6.4 The direct counting procedure applied to the validation data set should produce "the correct value". The extrapolation procedure applied to a minimally required fraction of the validation data set should re-produce the correct value within 95% confidence.

3.5.6.5 Validation of the extrapolation procedure should be performed for 50 statistically independent data sets and evaluated for a number of ship speeds, relative wave headings and sea states.

3.5.6.6 A comparison should be made between the extrapolation and the "true value" for each data set. The comparison should be considered successful if the extrapolation confidence interval and the confidence interval of the "true value" overlap.

3.5.6.7 The validation should be considered successful if at least 88% of individual data set comparisons are successful.

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25 Refer to the Explanatory Notes for the Second generation intact stability criteria (MSC.1/Circ.xxxx).
4 Guidelines for operational measures

4.1 General principles

4.1.1 A combined consideration of design and operational aspects can effectively be used to achieve a sufficient safety level. In application, this principle requires guidance to be provided for the preparation of operational measures, consistent with the design assessment requirements.

4.1.2 Whereas the principles used in these Guidelines can be applied to consider any operational problems related to ship behaviour in seaway, detailed procedures in these Guidelines cover the following stability failure modes:

.1 dead ship condition;
.2 excessive acceleration;
.3 pure loss of stability;
.4 parametric rolling; and
.5 surf-riding/broaching.

4.1.3 These Guidelines consider the operational limitations and operational guidance, which are defined in 4.3.1. Either operational limitations or operational guidance can be used for the following four stability failure modes: excessive acceleration, pure loss of stability, parametric rolling and surf-riding/broaching. For the dead ship condition failure mode, only operational limitations related to areas or routes and season (4.3.1.1 and 4.5.1) can be applied, i.e. neither operational limitations related to maximum significant wave height nor operational guidance are applicable because the ship's main propulsion plant and auxiliaries are inoperative which means that the ship is not able to either avoid heavy weather or control speed and course in heavy weather.

4.1.4 Operational limitations and operational guidance should provide at least the same level of safety as that provided by the procedures and standards given by the Guidelines for vulnerability criteria in chapter 2 or the direct stability assessment in chapter 3. In particular, the safety level of those loading conditions that fail Design assessment requirements in chapter 2 or chapter 3, as the case may be, should become sufficient if all combinations of the sailing conditions and sea state, period and direction that are not recommended by these operational measures are removed from the design assessment.

4.1.5 Whereas the principle in paragraph 4.1.4 can be directly used to prepare operational measures ensuring a required safety level, more detailed procedures were developed as described in these Guidelines for convenience of ship designers and Administrations. Using the procedures and standards described herein corresponds to setting a safety level in accordance with the Guidelines for direct stability assessment in chapter 3.

4.1.6 Although the application of operational measures can reduce the likelihood of stability failure to a desired low level, a loading condition for which too many situations should be avoided to achieve the required safety level should not be considered as acceptable. Therefore, from practical and regulatory perspectives, operational measures should not be considered as always sufficient for any loading condition.
4.1.7 In case the operational guidance is provided based on these Guidelines, they should be applied instead of the guidance in MSC.1/Circ.1228.

4.2 Stability failure

4.2.1 The definition of stability failure should be consistent with those used in either the Guidelines for vulnerability criteria in chapter 2 or the Guidelines for direct stability assessment in chapter 3, as the case may be.

4.2.2 The provisions given hereunder apply to all ships, except for ships with extended low weather deck for the dead ship failure mode and the pure loss of stability failure mode.

4.3 Operational measures

4.3.1 These Guidelines consider the following operational measures:

   .1 *Operational limitations* which refer to limits on a ship's operation in a considered loading condition:

   .1 *operational limitations related to areas or routes and season* permit operation in specific operational areas (either geographical areas or specific types of operational areas like sheltered waters) or routes and, if appropriate, specific season, in which the ship in the considered loading condition can operate. For the operational area, route and season, the environmental conditions are specified by the joint probability of the ranges of significant wave height and average zero-crossing wave period (scatter table) and corresponding wind statistics;

   .2 *operational limitations related to maximum significant wave height* permit operation in conditions up to a maximum significant wave height for which the environmental conditions are specified by the combination of the scatter table, related to the operational area or route and season and corresponding wind statistics, together with the maximum significant wave height at which the ship can operate; the scatter table limited at a specific significant wave height is referred to as a *limited scatter table*.

   .2 *Operational guidance* which refers to the guidance specific to the ship which specifies the combinations of ship speed and wave direction that are not recommended and that should be avoided in each relevant sea state.

4.3.2 The differentiation between the operational measures specified in paragraph 4.3.1 concerns the amount of control which is required in the application:

   .1 operational limitations related to areas or routes and season do not require weather data during the operation of the ship and thus do not require any specific control;

   .2 operational limitations related to maximum significant wave height need a forecast for the significant wave height and the availability of appropriate routing in a sufficient time before encountering possible storm conditions; and
operational guidance requires detailed forecast information about wave energy spectra and wind characteristics, together with means for indicating combinations of ship speed and wave direction that should be avoided, which should be available for safe routeing in a sufficient time before encountering possible storm conditions.

4.3.3 The operational measures specified in paragraph 4.3.1 can be combined: for example, operational limitations can be applied up to a certain significant wave height and operational guidance for greater significant wave heights. In case of a combination of operational limitations with operational guidance, the requirements for operational guidance apply.

4.4 Acceptance of operational measures

4.4.1 Operational limitations and operational guidance should be accepted by the Administration according to these Guidelines.

4.4.2 Acceptance of a loading condition for unrestricted operation, limited operation or operation using onboard operational guidance should be performed following these Guidelines in combination with the Design assessment requirements according to chapter 2 or chapter 3, as the case may be. A loading condition is considered as:

.1 acceptable for unrestricted operation, if it satisfies the Design assessment requirements for all five stability failure modes specified in paragraph 4.1.2;

.2 acceptable for unrestricted operation under operational limitations, if it is provided with operational limitations for one or more stability failure modes specified in paragraph 4.1.2 for unrestricted area and satisfies the Design assessment requirements for the remaining stability failure modes;

.3 acceptable for unrestricted operation using onboard operational guidance, if it is provided with an accepted operational guidance for one or more stability failure modes specified in paragraph 4.1.2 for unrestricted area and is either provided with operational limitations for unrestricted area or satisfies the Design assessment requirements for the remaining stability failure modes;

.4 acceptable for limited operation in a specified area or on a specified route during a specified season, if it is provided with operational limitations, without specification of maximum operational significant wave height for one or more stability failure modes specified in paragraph 4.1.2 for this area or route and season and satisfies the Design assessment requirements for the remaining stability failure modes;

.5 acceptable for limited operation in a specified area or on a specified route during a specified season, if it is provided with operational limitations for one or more stability failure modes specified in paragraph 4.1.2 for a given significant wave height limit for this area or route and season and either has operational limitations without specification of maximum operational significant wave height for this area or route and season or satisfies the Design assessment requirements for the remaining stability failure modes; and

.6 acceptable for operation using onboard operational guidance in a specified area or on a specified route during a specified season, if it is provided with an approved operational guidance for one or more stability failure modes
specified in paragraph 4.1.2 for this area or route and season and is either provided with operational limitations for this area or route and season or satisfies the Design assessment requirements for the remaining stability failure modes.

4.4.3 Application of the operational limitations related to maximum significant wave height or operational guidance can reduce the stability failure rate to any low level. However, if too many sailing conditions in too many sea states should be avoided for a certain loading condition, such a loading condition cannot be considered as acceptable in practical operation. Therefore,

1. a loading condition cannot be considered as acceptable if the ratio of the total duration of all situations which should be avoided, according to operational limitations related to maximum significant wave height or operational guidance, to the total operational time is greater than 0.2;

2. in the calculation of the ratio in paragraph 4.4.3.1, the probabilities of the sea states are taken according to the full scatter table, wave headings are assumed uniformly distributed and the ship forward speed is assumed uniformly distributed between zero and full-service speed.

4.4.4 Active means of motion reduction, such as active anti-roll fins and anti-roll tanks, can significantly reduce roll motions in seaway, if appropriately used. Therefore, if such devices are not considered in the development and application of the operational measures, the advice to the shipmaster may be suboptimal or misleading. On the other hand, the safety of the ship with specific reference to aspects addressed by the present Guidelines should be ensured also in cases of failure of such devices. Therefore, it is recommended that the development, application and acceptance of the operational measures is done both, with operating and inactive or retracted anti-roll devices.

4.4.5 Operational guidance can indicate some sailing conditions as with respect to roll motion but they may be unattainable due to limits of the propulsion and steering systems of the ship or undesirable due to other problems, such as excessive vertical motions or accelerations and slamming. For example, for parametric rolling in bow waves, roll motions may reduce with increasing forward speed, but high speeds in bow waves could be either unattainable or could lead to excessive vertical motions or loads. Neglecting this contradiction can lead to misleading operational guidance or even put the ship in danger if in some sea state all sailing conditions, acceptable from the point of view of roll motions, are unattainable or dangerous because of other reasons.

4.5 Preparation procedures

4.5.1 Operational limitations related to areas or routes and season

4.5.1.1 Operational limitations are prepared following the same principles as the design assessment by applying the design assessment procedures according to the Design assessment requirements according to chapter 2 or chapter 3, as the case may be, with modified environmental conditions assumed in operation. The modification of the reference environmental conditions is based on the wave scatter table for a specified area or a specified route during a specified season and corresponding wind statistics, acceptable to the Administration.

4.5.1.2 The environmental conditions applied in the preparation of the operational limitations related to areas or routes and season should be consistent with the corresponding vulnerability
criteria if the preparation is based on the Guidelines for vulnerability assessment in chapter 2. If the preparation is based on direct stability assessment these environmental conditions should be consistent with Guidelines for direct stability assessment in chapter 3. Other environmental conditions may be applied, as appropriate.

4.5.1.3 For some Level 1 and Level 2 vulnerability assessment procedures, regular wave cases should be defined, based on the wave statistics. All necessary information for performing the analyses needed for incorporation into operational measures is available in the relevant part of the Explanatory Notes for the Second generation intact stability criteria (MSC.1/Circ.xxxx).

4.5.2 Operational limitations related to maximum significant wave height

4.5.2.1 Operational limitations related to maximum significant wave height are developed using Design assessment procedures in chapter 2 or chapter 3, as the case may be, for a specific environment, which is defined by cutting at a specified significant wave height the wave scatter table for a specified area or a specified route during a specified season and by corresponding modification of wind statistics.

4.5.2.2 The environmental conditions applied in the preparation of the operational limitations related to maximum significant wave height should be consistent with the corresponding vulnerability criteria if the preparation is based on the Guidelines for vulnerability assessment in chapter 2. If the preparation is based on the direct stability assessment, these conditions should be consistent with the Guidelines for direct stability assessment in chapter 3. Other environmental conditions may be applied, as appropriate.

4.5.2.3 For certain Level 1 and Level 2 vulnerability assessment procedures, definition of the corresponding regular wave cases is required; this is done in the same way as for operational limitations without specification of maximum operational significant wave height. All necessary information for performing the analyses needed for incorporation into operational measures is available in the relevant part of the Explanatory Notes for the Second generation intact stability criteria (MSC.1/Circ.xxxx).

4.5.3 General principles of preparation of operational guidance

4.5.3.1 Operational guidance should indicate all sailing conditions that should be avoided for each range of sea states in the relevant wave scatter table.

4.5.3.2 Operational guidance should ensure that the considered condition of loading satisfies the Design assessment requirements in chapter 2 or chapter 3, as the case may be, after removing from the design assessment all sailing conditions that should be avoided. To simplify the preparation and acceptance of operational guidance, three equivalent approaches, recommended for the preparation of operational guidance, are considered below in detail. These options are based on:

.1 probabilistic motion criteria and standards (referred to as probabilistic operational guidance);

.2 deterministic motion criteria and standards (referred to as deterministic operational guidance); and

.3 simplified motion criteria and standards (referred to as simplified operational guidance).
4.5.3.3 Operational guidance may be presented in the form of a polar diagram, which is a customary way to graphically display sea states and ship responses, including the following information/features:

1. The diagram should consist of concentric circles that correspond to speeds from zero to the maximum speed and of directions that correspond to those of the wave encounter angle.

2. Each polar diagram should be prepared for a specific combination of significant wave height, wave period and an identified loading condition.

3. The polar diagram should be multi-coloured in which combinations of speed and heading corresponding to dangerous conditions are coloured in different shades of red as well as amber and yellow.

4. Darker shades should correspond to more extreme ship motions or responses.

5. Areas close to the boundary of acceptability should be coloured amber/yellow to indicate the approximate nature of the position on the polar diagram.

4.5.3.4 Other ways different from polar diagrams could be used for displaying operational guidance, provided that equivalent information is included.

4.5.4 Probabilistic operational guidance

4.5.4.1 This type of operational guidance uses probabilistic criteria, such as probability of stability failure during some time or rate of stability failures, and corresponding probabilistic thresholds to distinguish sailing conditions which should be avoided.

4.5.4.2 Sailing conditions that should be avoided are those for which:

\[ r > 10^{-6} \text{ s}^{-1}; \]

where \( r \text{ (s}^{-1}) \) is the upper boundary of the 95% confidence interval of the stability failure rate.

4.5.4.3 Procedures and numerical methods applied for the determination of the failure rate as referred to in 4.5.4.2 should satisfy the recommendations of the Guidelines for direct stability assessment in chapter 3.

4.5.4.4 If a certain assumed situation should be avoided, assessment for higher significant wave heights with other parameters unchanged is not required. Conversely, if a certain assumed situation does not have to be avoided, assessment for lower significant wave heights with other parameters unchanged is not required.

4.5.5 Deterministic operational guidance

4.5.5.1 Using deterministic criteria, such as maximum roll amplitude in a given exposure time, represent a simpler but less accurate approach than using probabilistic criteria. Therefore, to provide an equivalent safety level, the threshold for deterministic criteria is conservatively selected.

4.5.5.2 Deterministic operational guidance can be prepared either using only model tests,
only numerical simulations or their combination. Numerical methods applied in such
simulations should satisfy the recommendations of the Guidelines for direct stability
assessment in chapter 3.

4.5.5.3 In deterministic operational guidance, sailing conditions that should be avoided are
those for which:

\[ \alpha \cdot x_{3h} > x_{lim}, \]

where \( \alpha = 2 \) is the scaling factor, \( x_{3h} \) is the mean three-hour maximum amplitude of roll or lateral
acceleration, as relevant, and \( x_{lim} \) is the corresponding stability failure threshold, as defined in
the Guidelines for direct stability assessment in 3.2.1.

4.5.5.4 To define the mean three-hour maximum amplitude, the total recommended duration
of test or simulation is 15 hours for each considered situation. This duration can be divided into
several shorter parts. Note that the full duration is required only in marginal cases, whereas
for majority of situations the differentiation between assumed situations that should be avoided
and do not have to be avoided is possible after a shorter time.

4.5.5.5 If a certain assumed situation should be avoided, assessment for higher significant
wave heights, with other parameters unchanged, is not required. Conversely, if a certain
assumed situation does not have to be avoided, assessment for lower significant wave heights
with other parameters unchanged, is not required.

4.5.6 Simplified operational guidance

4.5.6.1 Whereas probabilistic and deterministic operational guidance provides accurate and
detailed recommendations for the ship forward speed and course in each sea state, it requires
model tests or numerical methods of high accuracy. Therefore, simpler conservative
approaches may be used to develop guidance for acceptable forward speed and course when
it is deemed practicable.

4.5.6.2 In principle, any simple conservative estimations for the sailing situations that should
be avoided can be used if they are shown to provide a superior safety level compared to the
design assessment requirements. In particular, Level 1 or Level 2 vulnerability criteria of the
Guidelines for vulnerability assessment in chapter 2 can be used. Some examples of
recommended approaches based on Level 1 and Level 2 vulnerability criteria are included
below:

.1 For the pure loss of stability failure mode, nominal speed corresponding to
the speed in calm-water of \( 0.752 \cdot L^{1/2} \) m/s or greater, should be avoided in
following to beam wave directions in sea states for which \( \max(C_{1i},C_{2i})=1 \),
where \( C_{1i} \) and \( C_{2i} \) are defined in paragraphs 2.4.3.3 and 2.4.3.4,
respectively, of the Guidelines for vulnerability assessment.

.2 For the parametric rolling stability failure mode, forward speed, for which
\( C_{S,i}(v_s,H_s,T_z) \), defined according to paragraph 2.5.3.3.1 of the Guidelines for
vulnerability assessment, is equal to 1, should be avoided in all wave
directions and all sea states.

.3 For the surf-riding/broaching failure mode, either

.1 nominal speed settings corresponding to the nominal ship speed of
0.94 \cdot \frac{L_{pp}}{m/s}, or greater, should be avoided when the wavelength, based on mean wave period, is greater than 80% of the ship length, the significant wave height is greater than 4% of the ship length $L_{pp}$ and the heading angle $\mu$ from the wave direction is less than 45 degrees.

Alternatively, the critical nominal ship speed provided by the Level 2 vulnerability criteria (see 2.6.3) or over should be avoided in following to beam wave directions in sea states for which $c_{HT}>0.005$, where $c_{HT}$ is calculated as:

$$c_{HT}(H_s, T_c) = \sum_{i=1}^{N_i} \sum_{j=1}^{N_j} w_{ij}(H_s, T_c) C_{2ij}$$

where $w_{ij}(H_s, T_c)$ and $C_{2ij}$ should be calculated based on the level 2 vulnerability criteria in 2.6.3.2, but with diffraction component of the wave force taken into account.\textsuperscript{26}

For the excessive acceleration stability failure mode, all forward speeds should be avoided in all sea states where $C_{S,i}>10^{-6}$, where $C_{S,i}$ is defined according to paragraph 2.3.3.2.1 of the Guidelines for vulnerability assessment, whereby the transfer functions $a_j(\omega)$ defined in 2.3.3.2.2 is multiplied by the absolute value of the sine of the wave heading angle $\mu$ and calculated by replacing the wave frequency $\omega_j$ with wave encounter frequency $\omega_{ej}$.

The details on the presentation of the above information in the form of polar diagrams can be found in the Explanatory Notes.

### 4.6 Application

4.6.1 Operational guidance should be provided as easily accessible and understandable information in graphical form which clearly indicates sailing conditions that should be avoided for a given sea state, as well as the relevant stability failure modes. Automatic alert systems can be used for the cases when sailing conditions are close to or within the areas of sailing conditions that should be avoided.

4.6.2 Sailing conditions that should be avoided are derived from the pre-defined databases of probabilistic, deterministic or simplified safety criteria, stored as functions of the ship forward speed and ship heading with respect to the mean wave direction for sea states specified by significant wave height and mean zero-crossing wave period, using as input the actual significant wave height, mean zero-crossing wave period, mean wave direction and ship course.

4.6.3 The effect of non-parallel wave systems (cross sea) can be reproduced using these pre-defined databases by combining separate responses to the wind sea and swell which correspond to the significant wave height, mean zero-crossing wave period and mean wave direction of each of these wave systems by:

1. summing the rate of stability failures for each of these wave systems when using probabilistic operational guidance;

\textsuperscript{26} Refer to the Explanatory Notes for the Second generation intact stability criteria (MSC.1/Circ.xxxx).
.2 summing the maximum responses to each of these wave systems when using deterministic operational guidance; and

.3 overlaying the sailing conditions that should be avoided for each of these wave systems when using simplified operational guidance.

The procedure described above is meant to be a practical approximation tool for addressing cross sea conditions starting from pre-calculations based on simpler standard sea states. However, such procedure is an approximate one and sea states encountered in the ship operation can be characterized by complex spectra combining multiple wind sea and swell systems. It is therefore recommended that particular caution is exercised during operation when making use of operational guidance developed according to the described procedure, if the sea state is characterized by complex combinations of wind sea and swell systems.

4.6.4 The shipmaster should ensure that the vessel, at any time during the voyage and considering the available weather forecasts, satisfies the operational limitations related to maximum significant wave height or operational guidance.

4.6.5 As accurate as practicable data should be available for the loading condition at the departure from the port, including draught, trim, displacement, metacentric height, longitudinal position of the centre of gravity and natural roll period. Estimate of the current state of these parameters should be always available during the voyage, together with the estimated change of these parameters for the time until the arrival in the next port.

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ANNEX 2

ALTERNATIVE TEXTS WITHOUT SEPARATELY PLACING LONG-TERM INDICES
CALCULATION PROCEDURES IN DRAFT INTERIM GUIDELINES

2.2.3 Level 2 Vulnerability Criteria for Dead ship condition

2.2.3.1 A ship is considered not to be vulnerable to the dead ship condition failure mode if:

\[ C \leq R_{DS0} \]

Where, \( R_{DS0} = 0.06 \); \( C \) is a long-term probability index that measures the vulnerability of the ship to a stability failure in the dead ship condition based on the probability of occurrence of short-term environmental conditions as specified according to 2.2.3.2.

2.2.3.2 The value for \( C \) is calculated as recommended in 2.7.2 where \( C_{S,i} \) is the short-term dead ship stability failure index for the short-term environmental condition under consideration calculated as specified in 2.2.3.2.1.

2.2.3.2.5 Short-term environmental conditions used for the assessment of the short-term dead ship stability failure index \( C_{S,i} \) according to 2.2.3.2.1, and weighting factor \( W_i \) used for the determination of the long-term probability index \( C \) according to paragraph 2.2.3.2, are specified in table 2.7.3.2.

2.3.3 Level 2 Vulnerability Criteria for Excessive Acceleration

2.3.3.1 A ship in the considered condition of loading is considered not to be vulnerable to the excessive acceleration stability failure mode if, for each location along the length of the ship where passengers or crew may be present, \( R_{EA2} \) is greater than or equal to \( C \),

Where, \( R_{EA2} = 0.00039 \); \( C \) is a long-term probability index that measures the vulnerability of the ship to a stability failure in the excessive acceleration mode for the loading condition and location under consideration based on the probability of occurrence of short-term environmental conditions as calculated according to 2.3.3.2.

2.3.3.2 The value for \( C \) is calculated as recommended in 2.7.2 where \( C_{S,j} \) is the short-term excessive acceleration stability failure index for the loading condition and location under consideration and for the short-term environmental condition under consideration calculated as specified in 2.3.3.2.1.

2.4.3 Level 2 Vulnerability Criteria for Pure Loss of Stability

2.4.3.1 A ship is considered not to be vulnerable to the pure loss of stability failure mode if the largest value among the two criteria, \( CR_1 \) and \( CR_2 \), is less than or equal to \( R_{PL0} \), calculated according to paragraphs 2.4.3.3 and 2.4.3.4, when underway at the service speed, \( V_S \),

Where, \( R_{PL0} = 0.06 \).
2.4.3.2 Each of the two criteria, \( CR_1 \) and \( CR_2 \), represent a weighted average of certain stability parameters for a ship considered to be statically positioned in waves of defined height \( (H_i) \) and length \( (\lambda_i) \) and are calculated as recommended in 2.7.2 generally and 2.7.2.3.1 specifically.

Where,

\[ CR_1, \quad \text{weighted criterion 1, is computed using Criterion 1, } C_{1i}, \]

as evaluated according to 2.4.3.3; and

\[ CR_2, \quad \text{weighted criterion 2, is computed using Criterion 2, } C_{2i}, \]

as evaluated according to 2.4.3.4.

2.5.3 Level 2 Vulnerability Criteria for Parametric Roll

2.5.3.1 The value of \( C_2(F_{n_i}, \beta) \) is calculated as recommended in 2.7.2 where \( C_{S,i} \) is the short term parametric roll stability failure index for a given Froude number, \( F_{n,i} \), and wave direction.

2.6.3 Level 2 Vulnerability Criteria for Surf-riding/Broaching

2.6.3.1 A ship is considered not to be vulnerable to the surf riding/broaching failure mode if the value of \( C \) calculated according to paragraph 2.6.3.2 is less than or equal to \( R_{SR} \);

Where

\[ R_{SR} = 0.005. \]

2.6.3.2 The value of \( C \) is calculated as

\[
C = \sum_{i=1}^{N_S} \sum_{j=1}^{N_a} W_i C_{2ij}
\]

where

\[ R_{SR} = 0.005 \]

\[ W_2(H_s, T_z) = \] the weighting factor of short-term sea state specified in 2.7.2.1 as a function of the significant wave height, \( H_s \), and the zero-crossing wave period, \( T_z \) in which \( W_i \) is equal to the number of occurrences of the combination divided by 100,000;

\[ W_{ij} = \] a statistical weight of a wave specified in 2.6.3.3 with steepness \( (H/\lambda) \) and wavelength to ship length ratio \( (\lambda/L) \), calculated with the joint distribution of local wave steepness and lengths, which is, with specified discretization \( N_i = 80 \) and \( N_a = 100 \).

\[ C_{2ij} = \] the coefficient specified in 2.6.3.4.

2.7.2 Wave environment data

2.7.2.3 Calculation of the long-term stability failure index is, in general, a summation of the products of a weighting factor, \( W_i \), and the short-term stability failure index, \( C_{S,i} \):

\[
C = \sum_{i=1}^{N} W_i C_{S,i}
\]
where

\[ W_i = \text{the weighting factor for the short-term environmental condition specified in 2.7.2.1.2 for a combination of } H_s \text{ and } T_z \text{ in which } W_i \text{ is equal to the number of occurrences of the combination divided by 100,000;} \]

\[ C_{S,i} = \text{the short-term stability failure index for the short-term environmental condition under consideration calculated as specified in 2.2.3.2.1 for the dead ship condition stability failure mode, and 2.3.3.2.1 for the excessive accelerations stability failure mode, and;} \]

\[ N = \text{the number of considered short-term environmental conditions evaluated.}^1 \]

In the case of the pure loss of stability and parametric rolling stability failure modes, the designation of both the long-term stability failure index and the short-term stability failure index are suited to the respective failure mode as described in 2.7.2.3.1 and 2.7.2.3.2.

2.7.2.3.1. For the pure loss of stability failure mode, the weighted criteria, \( CR_1 \) and \( CR_2 \), are determined for a ship considered to be statically positioned in waves of defined height \( (H_i) \) and length \( (\lambda_i) \) obtained from table 2.7.2.1.2,

Where

\[ CR_1 = \sum_{i=1}^{N} W_i C_{1i} = \text{Weighted criterion 1;} \]

\[ CR_2 = \sum_{i=1}^{N} W_i C_{2i} = \text{Weighted criterion 2;} \]

\[ W_i = \text{a weighting factor obtained from table 2.7.2.1.2;} \]

\[ N = \text{number of wave cases for which } C_{1i}, C_{2i} \text{ are evaluated} = 272; \]

\[ C_{1i} = \text{Criterion 1 evaluated according to 2.4.3.3;} \]

\[ C_{2i} = \text{Criterion 2 evaluated according to 2.4.3.4;} \]

2.7.2.3.1.1 For each combination of \( H_s \) and \( T_z \), \( W_i \) is obtained as the value in table 2.7.2.1.2 divided by the amount of observations given in this table, which is associated with a \( H_i \) as calculated in 2.7.2.3.1.2 below and \( \lambda_i \) is taken as equal to \( L \). The indexes for each \( H_i \) should be linearly interpolated from the relationship between \( h \) used in 2.4.3.2.1 and the indexes obtained in 2.7.2.3.1 above.\(^2\)

2.7.2.3.1.2 The 3\% largest effective wave height, \( H_i \), for use in evaluation of the requirements is calculated by filtering ocean waves within ship length. For this purpose, an appropriate wave spectrum shape should be assumed.\(^3\)

2.7.2.3.2 For the parametric rolling stability failure mode, the weighted criteria \( C2(F_n, \beta) \) is obtained:

\[ C2(F_n, \beta) = \sum_{i=1}^{N} W_i C_{S,i} \]

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\(^1\) Refer to the Explanatory Notes for the Second generation intact stability criteria (MSC.1/Circ.xxxx).

\(^2\) Refer to the Explanatory Notes for the Second generation intact stability criteria, 2.4 (MSC.1/Circ.xxxx).

\(^3\) Refer to the Explanatory Notes for the Second generation intact stability criteria, 2.5 (MSC.1/Circ.xxxx).
Where

\[ W_i = \text{the weighting factor for the respective wave cases specified in 2.7.2.1.2}; \]
\[ C_{S,i} = 1, \text{if the maximum roll angle evaluated according to 2.5.3.4 exceeds 25 degrees, and} \]
\[ = 0, \text{otherwise}; \]
\[ N = \text{total number of wave cases for which the maximum roll angle is evaluated for a combination of speed and ship heading.} \]

2.7.2.3.2.1  \( W_i \) is obtained from table 2.7.2.1.2 or an equivalent table of wave data [satisfactory to the Administration]. Each cell of the table corresponds to an average zero-crossing wave period, \( T_z \), and a significant wave height, \( H_s \). With these two values, a representative wave height, \( H_r \), should be calculated using a procedure.\(^4\) The maximum roll angle, corresponding to the representative wave height, \( H_r \), is obtained by linear interpolation of the maximum roll angles for different wave heights, \( h_j \), obtained in 2.5.3.4.1. This maximum roll angle should be used for evaluation of \( C_{S,i} \).

2.7.2.3.3  For the surf-riding/broaching stability failure mode, the value of \( W_2(H_s, T_z) \) is obtained as the value in table 2.7.2.1.2 divided by the amount of observations given in this table. Other sources of wave statistics can be used at the discretion of the Administration.

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\(^4\) Refer to the Explanatory Notes for the Second generation intact stability criteria (MSC.1/Circ.xxxx).
ANNEX 3

Comments to draft Interim guidelines set out as annex 1

Submitted by Germany to Correspondence Group

Background

1 On 2 October 2019 the Coordinator of the Correspondence Group on intact stability distributed an updated draft of interim guidelines on second generation intact stability criteria and kindly invited to submit comments on this draft by 15 October 2019. This document contains comments from Germany.

Guidelines on vulnerability criteria

2 In paragraphs 2.3.1.5, 2.4.1.5 and 2.5.1.4, the phrase "If relevant the stability limit information for determining safe zones should take into account operational limitations according to the Guidelines for operational measures" should be changed to "If relevant the stability limit information for determining safe zones should take into account operational limitations or operational guidance according to the Guidelines for operational measures" since operational guidance should also be considered in the stability information.

Section 3.5.4 on Direct Counting in the draft guidelines on direct stability assessment

3 The text of section 3.5.4, Direct counting procedure, has been changed compared to the previous version of the guidelines, despite the research results that have been submitted by Germany to the Correspondence Group on 31 July 2019, including background information, validation, detailed procedures and application examples, as well as a revised text of this section, which was used in the previous version of the guidelines. These results show that the present version is technically unsound and practically inefficient; therefore, Germany proposes to return to the text used in the previous version of the guidelines and, correspondingly, use the submitted background information, detailed procedures and application examples, submitted by Germany to the Correspondence Group on 31 July 2019 in the Explanatory Notes.

4 It should be noted in particular that procedures for direct counting proposed so far assume a Poisson process. However, the new version of section 3.5.4 does not ensure a Poisson process in numerical simulations or model tests. Namely, it does not address transient and self-repetition effects. The new text addresses only auto-correlation of large roll motions. However, this is done in an unfeasible way: the first option, simulation until first stability failure, is impossible due to self-repetition effects, whereas the second option, simulations for fixed time, is not efficient since the time history after the first stability failure is disregarded.

5 Moreover, the new text disables the background information, detailed procedures and application examples submitted by Germany to the Correspondence Group on 31 July 2019, despite solid scientific background, validation and big number of practical applications, including the assessment examples.

6 On the contrary, the text of section 3.5.4, submitted by Germany to the Correspondence Group on 31 July 2019, allows using the option employed by Germany in the detailed procedures and application examples as well as both options contained in the new text and any other option that the designer may find convenient as long as a Poisson process is ensured.
Therefore, we propose to change the text of section 3.5.4 with the following text:

3.5.4.1 Direct counting is counting of the number of stability failures per given exposure time to estimate the rate of stability failures.

3.5.4.2 The procedure used for direct counting should provide the estimate of the upper boundary of the 95%-confidence interval of the rate of stability failures, which is used in the probabilistic direct stability assessment in design situations, full probabilistic direct stability assessment and operational measures.*

3.5.4.3 The procedures for performing numerical simulations, model tests and direct counting should ensure stationarity and independence of counted stability failures, particularly prevent from self-repetition effects due to too long duration of simulations, transient hydrodynamic effects at the beginning of simulations and auto-correlation effects of big roll motions.

3.5.4.4 Alternatively to direct counting, extrapolation procedures can be used as specified in section 3.5.5.

Other comments to guidelines on direct stability assessment

8 The minimum requirements to modelled ship motions for excessive acceleration failure mode do not include sway; moreover, the requirements to numerical methods in sections 3.4.2 and 3.4.3 do not include requirements to validation of lateral accelerations. This means that accurate definition of lateral accelerations in numerical simulations is not addressed by the guidelines. To solve this problem, Germany repeats a proposal to allow an approximate treatment of lateral acceleration in a simple conservative way by using an equivalent roll amplitude. Note that this solution allows replacing the two stability failure definitions in paragraphs 3.2.1.1 and 3.2.1.2 with a single definition which significantly simplifies numerical simulations and model tests. Namely, the following paragraph 3.2.1.3 should be added in the definition of stability failure:

3 To simplify the evaluation of motions, instead of the requirement in 3.2.1.2, an equivalent maximum acceptable roll angle, defined as $57.3/(1+h_{ac}^2/9.81)$, in degree, can be used. For this calculation, the roll axis can be assumed at the midpoint between the waterline and the centre of gravity of the ship.

9 Section 3.5.2 should be deleted because the proposed verification of failure mode is not necessary and not possible. In particular,

1 not necessary since the designer, performing direct stability assessment for a particular stability failure mode, is required to use a validated numerical method for this failure mode. Therefore, all relevant failures will be counted correctly, and if the code also counts, in addition, stability failures corresponding to non-relevant stability failure modes, this introduces a conservative error, which does not need to be controlled by Administrations;

2 identification of stability failure mode for each stability failure event simply from a time history of ship motions is not always possible (e.g. in stern-quartering waves, it may be not possible to differentiate synchronous resonance, fundamental parametric resonance, broaching-to not related to surf-riding and pure loss) and instead, may require in-depth research including multiple simulations and modifications of the simulation method,

* Refer to the Explanatory Notes for the Second generation intact stability criteria (MSC.1/Circ.xxxx).
which is well beyond the possibilities of designers, flag Administrations and classification societies in routine approval;

.3 we note that there have been no studies submitted to IMO confirming the feasibility of the proposal in section 3.5.2: no verification, no detailed procedures and no application examples, despite multiple requests to provide the missing information. Since this task is difficult even for the best experts who are working on the guidelines, leaving it to designers and Administrations is not feasible even for the trial period; and

.4 we also note that the argument against the proposed removal referred to the formal limitation of the scope of work, namely the recommendation of SDC 6 to implement only minor changes in the guidelines. Note, however, that the sense of this limitation is to prevent from further development iterations, case studies and discussions and a removal of an unnecessary and potentially unfeasible requirement, not supported by background information, contributes to the same aim.

Deterministic direct stability assessment and deterministic operational guidance

10 Germany proposes to delete deterministic direct stability assessment (section 3.5.3.4) and deterministic operational guidance (section 4.5.5) because

.1 deterministic direct stability assessment and deterministic operational guidance were developed as back-up options for the case that probabilistic direct stability assessment and probabilistic operational guidance will not be developed in due time or will be too complex or too expensive in use; however, both probabilistic direct stability assessment and probabilistic operational guidance were developed in due time and are simple and efficient enough, which renders back-up options obsolete;

.2 moreover, deterministic direct stability assessment and deterministic operational guidance are not consistent with respect to the probabilistic direct stability assessment, probabilistic operational guidance and Level 1 and Level 2 vulnerability assessment; therefore, their trial use will not produce any meaningful outcomes but may harm the finalization of the Interim guidelines; and

.3 the argument against removal of these options was the formal limitation of the work scope, namely the recommendation of SDC 6 to implement only minor changes in the Interim guidelines. However, the aim of this limitation was to avoid further development iterations, case studies and discussions, whereas a removal of a redundant option, especially a potentially harmful one, from several available options reduces the work amount and increases the likelihood of successful finalisation of the guidelines.

Other comments to guidelines on operational measures

11 In paragraph 4.1.7, the text "In case the operational guidance is provided based on these Guidelines, they supersede the guidance based on MSC.1/Circ.1228" should be replaced with (the changes are underlined) "In case the operational measures are provided based on these Guidelines, they supersede the guidance based on MSC.1/Circ.1228", because in operation, ship-specific operational limitations differentiate between acceptable and not acceptable sailing conditions in the same way as operational guidance, thus a ship...
sailing with accepted ship-specific operational limitations does not require a generic guidance based on MSC.1/Circ.1228.

12 Paragraph 4.5.6.2.2, providing an approach for simplified operational guidance based on Level 2 assessment for parametric roll, should be deleted. Since the aim of operational guidance is to recommend a safe ship speed, Level 2 methods could be used to develop operational guidance if the most critical ship speed defined by Level 2 is the same as the most critical ship speed defined by DSA. However,

.1 such validation has not been submitted; moreover, as show the results of research submitted by Germany to the Correspondence Group on 30 April 2018, the dependency on forward speed differs between the failure index in Level 2 assessment and stability failure rate in DSA for parametric roll;

.2 despite multiple requests to provide the missing information, the research community was not able to do this until now. Leaving such a difficult task to designers and Administrations means a too heavy burden for routine approval; and

.3 the argument against this removal referred to the formal limitation of the scope of work, namely the recommendation of SDC 6 to implement only minor changes in the Interim guidelines. Such limitation is understandable if big changes lead to further development iterations, but here the situation is different since a removal of one option, especially a potentially harmful one, from several available options does not endanger the finalization of the Interim guidelines in due time but makes this more likely.

Other comments to all guidelines

13 The term "short-term environmental condition" is not defined but used several times in the draft Interim guidelines. If it means the same as the term "sea state", defined in paragraph 1.2.2, it should be everywhere replaced with this term (correspondingly, the term "short-term environmental conditions" should be replaced with "sea states"); if it means something different, it should be defined in the nomenclature.

14 According to SI requirements, the hyphen in units, e.g. in $1/(m\cdot s)$ in paragraph 1.3.6, should be replaced everywhere with either blank space, e.g. $1/(m\ s)$, or dot, e.g. $1/(m\cdot s)$.

15 Numbers and units should be in roman font, not italics, e.g. $\phi$, should be replaced with $\varphi$, etc.

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ANNEX 4

DRAFT MSC CIRCULAR

INTERIM GUIDELINES ON SECOND GENERATION INTACT STABILITY CRITERIA

1 The Maritime Safety Committee, at its [102nd session (13 to 22 May 2020)], recognizing that performance-oriented criteria for dynamic stability phenomena in waves need to be developed and implemented to ensure a uniform international level of safety as specified in part A, 1.2 of the International Code on Intact Stability, 2008 (resolution MSC.267(85), as amended, approved the Interim guidelines for second generation intact stability criteria, as set out in the annex.

2 The Committee agreed to keep the Interim guidelines under review, taking into account experience in design and operation gained during their application.

3 Governments and Administrations are invited to use the annexed Interim guidelines when applying the requirements of the mandatory criteria of part A of the Intact Stability Code, to bring the aforementioned Guidelines to the attention of all parties concerned, in particular shipbuilders, shipmasters, shipowners, ship operators and shipping companies and to recount their experience gained through the trial use of these Interim guidelines to the Organization.

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