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REVISION OF THE INTACT STABILITY CODE

Report of the intersessional Correspondence Group on Intact Stability

Submitted by Germany

SUMMARY	
Executive summary:	This document contains the report of the intersessional Correspondence Group on Intact Stability
Strategic direction:	5.2
High-level action:	5.2.1
Planned output:	5.2.1.1
Action to be taken:	Paragraph 14
Related documents:	SLF 50/WP.2, SLF 50/19, SLF 50/4, SLF 50/4/3, SLF 50/4/4, SLF 50/4/4, SLF 50/4/6, SLF 50/4/9, SLF 50/4/11, SLF 50/4/12, SLF 50/INF.2, SLF 50/INF.3 and SLF 47/6

INTRODUCTION

1 The Sub-Committee, during its fiftieth session, re-established the intersessional Correspondence Group on Intact Stability (SLF 50/19, paragraph 4.19), under the co-ordination of Germany.

2 Germany would like to thank the delegations of Australia, Canada, China, Denmark, Finland, France, Greece, Italy, Iran (Islamic Republic of), Japan, the Republic of Korea, the Marshall Islands, the Netherlands, Norway, Poland, Portugal, Romania, Spain, Sweden, Turkey, the United Kingdom, the United States and Hong Kong, China for their participation in the correspondence group's efforts.

3 The terms of reference given to the correspondence group were as follows:

.1 to continue to work on the items contained in the updated plan of action for intact stability work, as set out in annex 6 to document SLF 50/WP.2, taking into account documents SLF 50/4/3, SLF 50/4/4, SLF 50/4/6, SLF 50/4/9, SLF 50/4/11, SLF 50/4/12, SLF 50/INF.2, SLF 50/INF.3 and relevant documents from previous sessions;

.2 to collect information on experience on the reduction of the pressure P to be used in the application of weather criterion (paragraph 2.3.2 of part A of the Intact Stability Code);

.3 to complete the tasks 2.1 and 2.2 of the updated plan of action (SLF 50/WP.2, annex 6); and

.4 to submit a report to SLF 51.

IS CODE 2008

Ships with Large B/D ratio: Multi-Hull Craft

4 At SLF 50, the working group agreed to apply the Offshore Supply Vessel Criterion, as proposed by the delegation of Italy, to ships with large B/D and/or B/T ratio which show difficulty in complying with the criterion of the minimum angle (25 degrees) of the maximum GZ value. This group of ships includes, but is not limited to, large passenger ships and multi-hull craft.

5 The delegation of Italy expects that since new performance-based criteria will be developed on clear physical bases, different ship typologies will be handled in the future, as far as possible, with the same first-principle tools. This proposal was supported by the delegations of Japan and the United Kingdom.

Information on experience on the reduction of the pressure P to be used in the application of the weather criteria

6 The correspondence group was instructed to collect information on experience in the reduction of the pressure P to be used in the application of weather criterion (paragraph 2.3.2 of part A of the Intact Stability Code).

7 The delegation of the United Kingdom has commissioned some research on this item and intends to submit two reports, "Severe wind and rolling" and "Intact stability equivalent criteria" to SLF 51 for further consideration. In the meantime, a first contribution is that "United Kingdom experience on reducing the pressure 'P' in the severe wind criterion is simply that this seldom produces a workable solution if the sea state, hence roll back angle, are unchanged. The ships which have difficulty satisfying this criterion are frequently those with 'early peaking' GZ curves. The difficulty may therefore be compounded by using a roll back angle derived from dynamic seaway response, in comparison of roll energies assuming a still water GZ curve".

8 The delegation of Japan has provided a procedure to reduce the pressure P for ships engaged in restricted services. In the Japanese criteria, the ships are classified into three categories based on their navigational area and for each category, a standard wind velocity and respective wind pressure are assigned and the wave steepness is calculated. Annex 1 contains the detailed explanatory report.

UPDATED PLAN OF ACTION (SLF 50/WP.2, ANNEX 6)

Framework for the new generation intact stability criteria

9 After extensive discussion, the group agreed on the framework for the new generation intact stability criteria as contained in annex 2. The framework is based on the concept of intact stability failure. An intact stability failure is a state of inability of the ship to remain within design limits of roll angle and combination of lateral and vertical accelerations. There are two categories of intact stability failures, a total stability failure or capsizing which results which results in total loss of a ship's operability with likely loss of lives and a partial stability failure which will not result in the loss of the ship but will impair her normal operation. Different criteria types are considered based on how a stability failure is judged, directly with performance-based criteria or indirectly with empirical criteria.

10 It was decided by the group that the new generation intact stability criteria will be applicable to unconventional types of ships, assessed by vulnerability criteria. These criteria will evaluate if the applicability of the existing intact stability regulations is adequate and will cover the major dynamic modes of stability failures already listed in the section 1.2 of the Intact Stability Code, part A.

11 The group agreed that minimum requirements to ship-specific operational guidance should be developed. The revised guidance to the master for avoiding dangerous situations in adverse weather and conditions, MSC.1/Circ.1228, provides guidance for surf-riding and broaching, reduction of stability when riding a wave crest amidships, parametric and synchronous rolling but without ship specific data. The group is of the opinion that to supplement the performance-based criteria, quantitative guidance should be provided for all the above phenomena with ship specific data by using the same methods applied in developing the design criteria.

Terminology for the new generation intact stability criteria

12 The group took initially as basis the list developed by the working group at SLF 50 contained in document SLF 50/WP.2, annex 6. After the conclusion on the discussion on the framework, the group decided, for the moment, to restrict the draft terminology to the terms which are contained in the framework. Annex 3 contains the draft terminology for the new generation intact stability criteria by the group.

13 The group anticipates that the working group envisaged to be established at SLF 51 on intact stability will further consider some items of the terminology for the new generation intact stability criteria.

ACTION REQUESTED OF THE SUB-COMMITTEE

14 The Sub-Committee is invited to consider the information provided in this report and annexes and take action as appropriate.

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ANNEX 1

EXPERIENCE ON THE REDUCTION OF THE PRESSURE P TO BE USED IN THE APPLICATION OF WEATHER CRITERION TO JAPANESE SHIPS ENGAGED IN RESTRICTED SERVICES

Submitted by Japan

Regarding terms of reference of ISCG No.2, i.e., collection of information on experience of the pressure P to be used in the application of weather criterion, Japan provides some information on our domestic or original weather criterion applied to ships engaged in restricted services.

1 WIND PRESSURE USED IN THE JAPANESE STABILITY STANDARDS FOR PASSENGER SHIPS

1.1 As explained in the explanatory notes to the 2008 IS Code (IMO, 2007), the weather criterion in the 2008 IS Code (hereafter the IMO criterion) is based on the Japanese stability standards for passenger ship. This criterion keeps the framework of the Japanese original weather criterion (hereafter the Japanese criterion) but includes the Russian Federation's calculation formula for roll angle.

1.2 In the Japanese criterion, ships are classified into three categories, namely 'Ocean-going', 'Coasting-I' and 'Coasting-II', based on their navigating area. Here, Coasting-II category ships are those navigating only in the Seto Inland Sea or navigating in the coastal area (figure 1), which is basically the area within 20 nautical miles of the coast of Japan, for not more than two hours. Coasting-I category ships navigate within the coastal area; and Ocean-going category ships go beyond the coastal area.

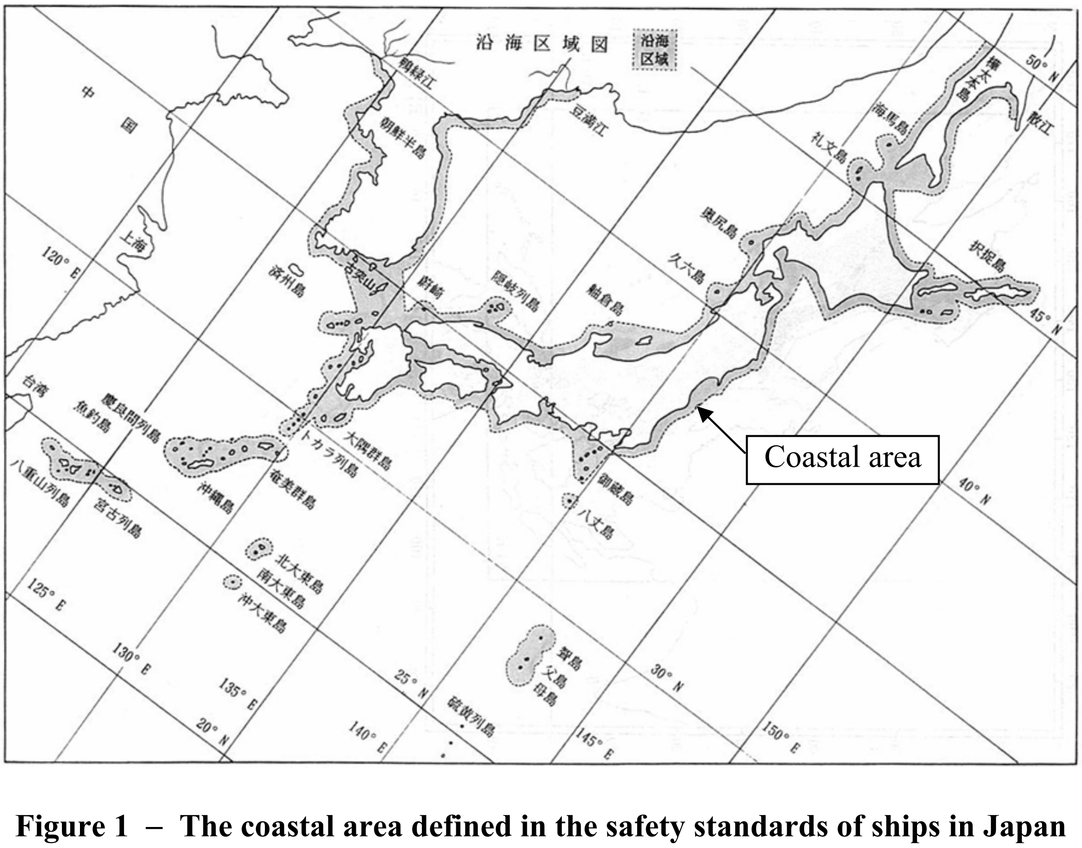

Figure 1 – The coastal area defined in the safety standards of ships in Japan

1.3 For each category, a standard wind velocity Vw, which was determined to ensure the adequate safety against capsizing of a ship in a beam wind and wave condition, is assigned as table 1 (Watanabe *et al.*, 1956; Yamagata, 1959). Standard wind velocities in table 1 are assigned based on that severity of ocean wind, which a ship may be encounter at sea, is varied according to its navigating area. A procedure to assign these standard wind velocities is explained in section 2.

1.4 In the Japanese criterion, the wind pressure (P) and the calculation formula for wave steepness (s) used in the criterion are set up for each category of ships (table 1) corresponding to the standard wind velocities. Different from the IMO criterion where the wave steepness is given in table form, the calculation formula for wave steepness from natural roll period is given in the Japanese criterion (Watanabe *et al.*, 1956; Yamagata, 1959).

1.5 Procedures to set up these values of wind pressure and the calculation formulae for wave steepness are also explained in section 2. As explained in the explanatory notes to the 2008 IS Code (IMO, 2007), the wave steepness used in the criterion is a function of wind velocity and natural roll period. Therefore, it should be noted that if the wind velocity varies the sea state supposed in the criterion is also changed.

1.6 The Japanese criterion is applied to ships engaged in restricted services with the values of wind pressure P and calculation formulae of wave steepness s for Coasting-I and Coasting-II category of ships summarized in table 1.

Table 1 – Standard wind velocities (V_w), and the corresponding wind pressure (P) and calculation formula for wave steepness (s) in the Japanese criterion

Category of ships	V_w (m/s)	P (Pa)	s* (wave steepness)
Coasting-II	15	168	0.155-0.0130T**
Coasting-I	19	269	0.153-0.0100T**
Ocean-going	26	504	0.151-0.0072T**

* If "s" obtained by these formulae is larger than 0.1, then s shall be set to 0.1.
If "s" obtained by these formulae is smaller than 0.035, then s shall be set to 0.035.

** T is natural roll period of a ship. This means that T corresponds to the wave period for resonant roll.

1.7 The Japanese stability standard, which has been enforced from 1 February 1957, requires that passenger ships shall comply with the weather criterion along with other criteria on GM and maximum stability arm. As for passenger ships in Japan, several intact capsizing accidents were reported before this standard; however, over 50 years, no capsizing accident has been observed in vessels complying with the standard. This implies that the corresponding wind pressure to the standard wind velocities and the calculation formulae for wave steepness, summarized in table 1, are quite adequate for ensuring the safety against capsizing of a ship under dead ship condition, considering the number of passenger ships registered in Japan, i.e. about 600 ships in 2007 and several thousand ships over 50 years.

2 PROCEDURES TO SET UP THE CORRESPONDING WIND PRESSURE TO THE STANDARD WIND VELOCITIES AND THE CALCULATION FORMULAE FOR WAVE STEEPNESS IN THE JAPANESE CRITERION

In this section, procedures to assign the standard wind velocities and to set up the corresponding wind pressure and calculation formula for wave steepness in the Japanese criterion are summarized.

2.1 Procedures to assign the standard wind velocity (V_w)

2.1.1 *Worst possible weather condition that may be encountered at sea*

In the course of developing the Japanese criterion, the worst weather condition that may be encountered at sea was supposed for each category of ships. It was fronts for Coasting-II category ships and lows for Coasting-I category ships. Ocean-going category ships were supposed to be encountered typhoons in the worst case. These suppositions were made based on manner of navigation for each category of ships at that time.

Next, based on observation data of ocean wind (Watanabe *et al.*, 1955), type of wind and its velocity to be considered in ensuring safety navigation for each category of ships was specified as shown in table 2. After some consideration for the situation where the criterion should be based on, it was determined that that Japanese criterion was intended to ensure the safety against capsizing of a ship in a beam wind and wave condition in intermediate area between the centre of typhoon or low and the trailing steady wind zone (Watanabe *et al*., 1956; Yamagata, 1959).

Table 2 – Worst possible weather conditions that may be encountered at sea (Watanabe *et al.*, 1956, Yamagata, 1959)

Category of ships	Average velocity of trailing steady wind	Maximum wind velocity at centre	Cause of Wind
Coasting-II	15 m/s	–	Front
Coasting-I	15 m/s	32 m/s	Low
Ocean-going	20 m/s	50 m/s	Typhoon

2.1.2 *Determination of the standard wind velocity for each category of ships*

However there was a wide choice of the wind velocity in intermediate area, it was unclear that the irregularity of waves varied in this area. As explained in the explanatory notes to the 2008 IS Code (IMO, 2007), the Japanese criterion introduced probabilistic assumptions for determining gust and roll in irregular waves. These procedures make the final probabilistic safety level unclear. Thus, it was considered that the standard wind velocity for the criterion should be determined taking account of these uncertain factors.

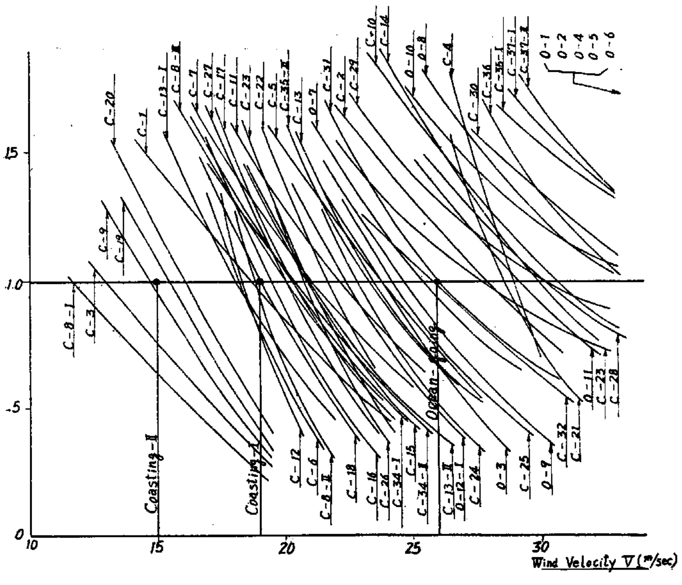

Figure 2 – Results of test calculations for determining standard wind velocity in table 1 (Watanabe *et al.*, 1956; Yamagata, 1959)

Therefore, with the standard wind velocity as a parameter, test calculations for 50 ships were conducted, 37 Coasting-I and Coasting-II category ships and 13 Ocean-going category ships. Based on these calculated outcomes (figure 2), the standard wind velocity in table 1, which corresponds to the steady wind velocity in the 2008 IS Code, was determined to distinguish ships having insufficient stability from other ships.

Namely the standard wind velocities for Coasting-I and Coasting-II category ships were assigned to 19 m/s and 15 m/s respectively. For Ocean-going category ships it was determined as 26 m/s. And later on the IMO also adopted 26 m/s as critical wind velocity for the IMO criteria. It is noteworthy that these critical wind velocities are obtained from casualty statistics for ships and are not directly obtained from actual wind statistics. However, it should also be noted that compared to the specified values of wind velocity in table 2, which is based on the observation data of ocean wind (Watanabe *et al.*, 1955), the obtained critical wind velocities seems to be quite realistic.

2.2 Wind pressure (P)

Using the standard wind velocity V_w, assigned to each category of ships the wind pressure P used in the Japanese criterion was determined by equation (1).

$$P = \frac{1}{2}\rho C_D V_w^2 \qquad (1)$$

where:

ρ = air density (1.225 kg/m^3)
C_D = drag coefficient (1.22)

As a result, the wind pressure used in the application of the criterion to each category of ships is set up as in table 1. Namely, the wind pressure for Ocean-going category ships is 504 Pa, which is identical to the one used in the IMO criterion. And for Coasting-I and Coasting-II category ships it is reduced to 269 Pa and 168 Pa, respectively.

2.3 Wave steepness (s)

As explained in the explanatory notes to the 2008 IS Code (IMO, 2007), the wave steepness used in the criterion is based on the wind velocity. This means that if the standard wind velocity is given, the corresponding wave steepness is determined (Watanabe *et al.*, 1956; Yamagata, 1959). The procedure to determine the corresponding wave steepness to the given wind velocity is outlined in the explanatory notes to the 2008 IS Code (IMO, 2007). Here further detailed explanation is given for deriving the calculation formula of wave steepness for each category of ships shown in table 1 and so on. In this subsection "δ" is used to express wave steepness.

2.3.1 *Relationship between wave age and wave steepness*

Figure 3 shows a relationship between wave age (the horizontal axis) and wave steepness (the vertical axis) of significant wave used by Sverdrup and Munk (1947) for forecasting sea and swell from weather data. Here the wave age β is defined as follows.

$$\beta = \frac{C}{V} \qquad (2)$$

where:

C = wave phase velocity
V = wind velocity

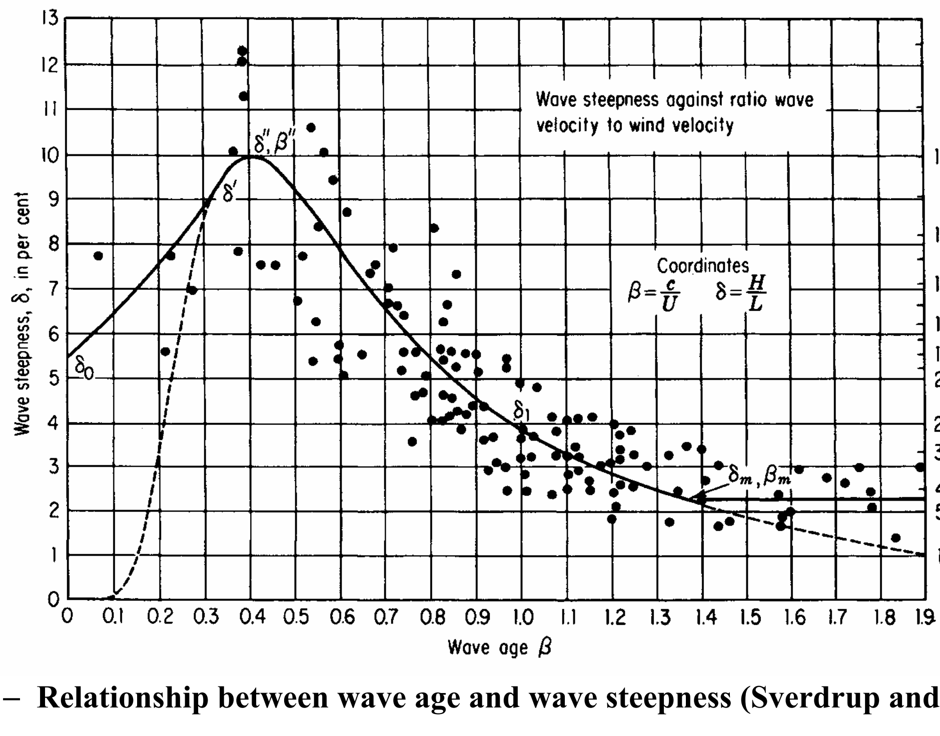

Figure 3 – Relationship between wave age and wave steepness (Sverdrup and Munk, 1947)

Based on observation data, indicated by black circles in figure 3, and theoretical consideration, Sverdrup and Munk (1947) derived the relationship between wave age and wave steepness of significant wave, indicated by the solid line. This β-δ relationship line consists of three parts for $0 \le \beta \le 0.350$, $0.350 \le \beta \le 1.369$ and $1.369 \le \beta$. For details of this relationship, reference should be made to the original paper (Sverdrup and Munk, 1947).

2.3.2 *Relationship between wave period and wave steepness*

The wave steepness used in the criterion corresponds to the one in the resonant roll motion of a ship. This implies that the wave period in the criterion is assumed to be the same as the ship natural roll period. Therefore, in place of the relationship between wave age and wave steepness shown in figure 3, it is necessary to clarify the relation between wave period and wave steepness.

There is the relationship between wave phase velocity (C), and wave period (T_w,), which is known as the dispersion relationship of water waves, as expressed in equation (3).

$$C = \frac{gT_w}{2\pi} \quad (3)$$

Here g is the gravity acceleration.

Using equations (2) and (3) the relationship between wave age and wave period is derived as follows:

$$\beta = \frac{gT_w}{2\pi V} \quad (4)$$

Substituting the standard wind velocity assigned for each category of ships (table 1) to equation (4), the relationship between wave age and wave steepness shown in figure 3 can be converted to that between wave period and wave steepness (dotted lines in figure 4).

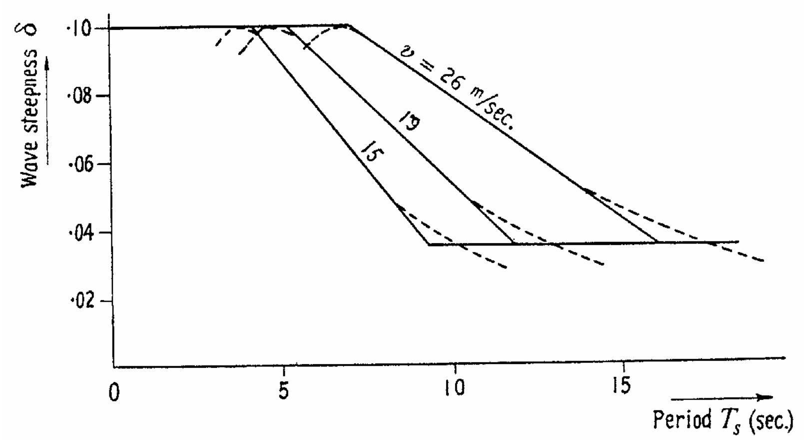

Figure 4 – Relationship between wave period and wave steepness for the standard wind velocities in the Japanese criterion (Yamagata, 1959)

2.3.3 *Calculation formula of wave steepness for each category of ships*

In the Japanese criterion as shown in figure 4 the original relationship between wave period (natural roll period) and wave steepness is modified in regions of the maximum and minimum steepness because of possible spectrum of ocean waves (IMO, 2007). For simplicity of calculation, the middle range of the relationship is approximated with a linear function of roll period, shown as solid lines in figure 4, and the formula listed in table 1 is derived for each category of ships (Watanabe *et al.*, 1956; Yamagata, 1959).

2.3.4 *Tabular form of wave steepness*

In the course of developing the IMO criterion, resolution A.562(14), it was reported that using the calculation formula of wave steepness in table 1 sometimes gave improper results in the vicinity of both ends of the linear approximation. Therefore, in order to eliminate this impropriety, the relationship between natural roll period and wave steepness used in the criterion was modified further to get smooth connections between the maximum and minimum constant regions and the middle range approximated with the linear function. And in the IMO criterion this modified relationship between natural roll period and wave steepness is given in a tabular form as table 3.

Table 3 could be applied to the Ocean-going category ships in the Japanese criterion. Tables 4 and 5 are made in the same manner as for table 3 and could be applied to Coasting-I and Coasting-II category ships respectively.

Table 3 – Wave steepness for the IMO criterion (Ocean-going category ships)

T (s)	6.0	7.0	8.0	12.0	14.0	16.0	18.0	20.0
δ	0.100	0.098	0.093	0.065	0.053	0.044	0.038	0.035

Table 4 – Wave steepness for Coasting-I category ships

T (s)	4.5	5.5	6.0	7.0	9.0	11.0	12.0	13.0	14.0
δ	0.100	0.099	0.093	0.083	0.063	0.046	0.041	0.037	0.035

Table 5 – Wave steepness for Coasting-II category ships

T (s)	3.5	4.0	4.5	5.0	7.0	9.0	9.5	10.0	10.5
δ	0.100	0.099	0.096	0.900	0.064	0.042	0.038	0.037	0.035

Figure 5 overviews the relationship between natural roll period or wave period and wave steepness for each standard wind velocity or each category of ships as explained above.

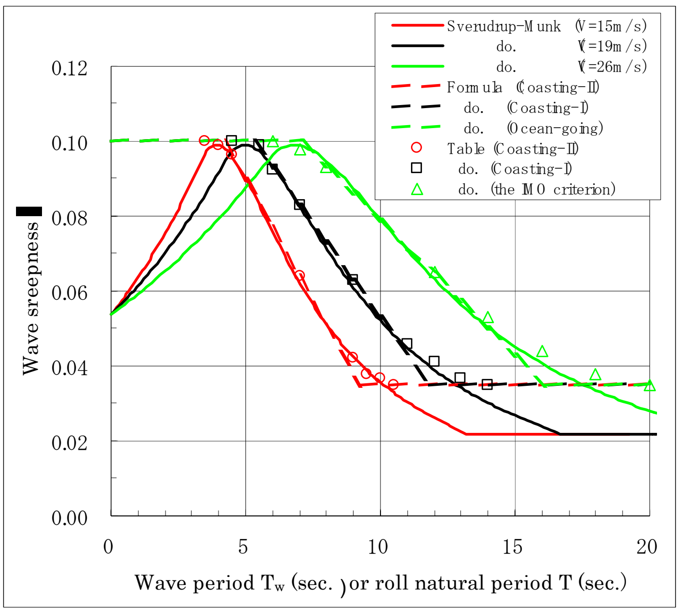

Figure 5 – Relationships between roll period and wave steepness for each category of ships (Solid lines: the original form of Sverdrup and Munk; broken lines: the calculation formula in the Japanese criterion; and marks: tabular form in the IMO criteria; and so on)

2.3.5 *Summary of procedure*

In this subsection, a procedure to derive the corresponding calculation formula of wave steepness to the standard wind velocity assigned for each category of ships in table 1 is explained. This formula represents the relationship between natural roll period and wave steepness assumed in the Japanese criterion. A technical background is also explained for the table of wave steepness used in the IMO criterion. The above procedure could be summarized as a flowchart in figure 6. It is quite straightforward to rationally set up the corresponding calculation formula or table of wave steepness in the similar manner to those in table 1 when adequate wind velocity in the restricted service area is given.

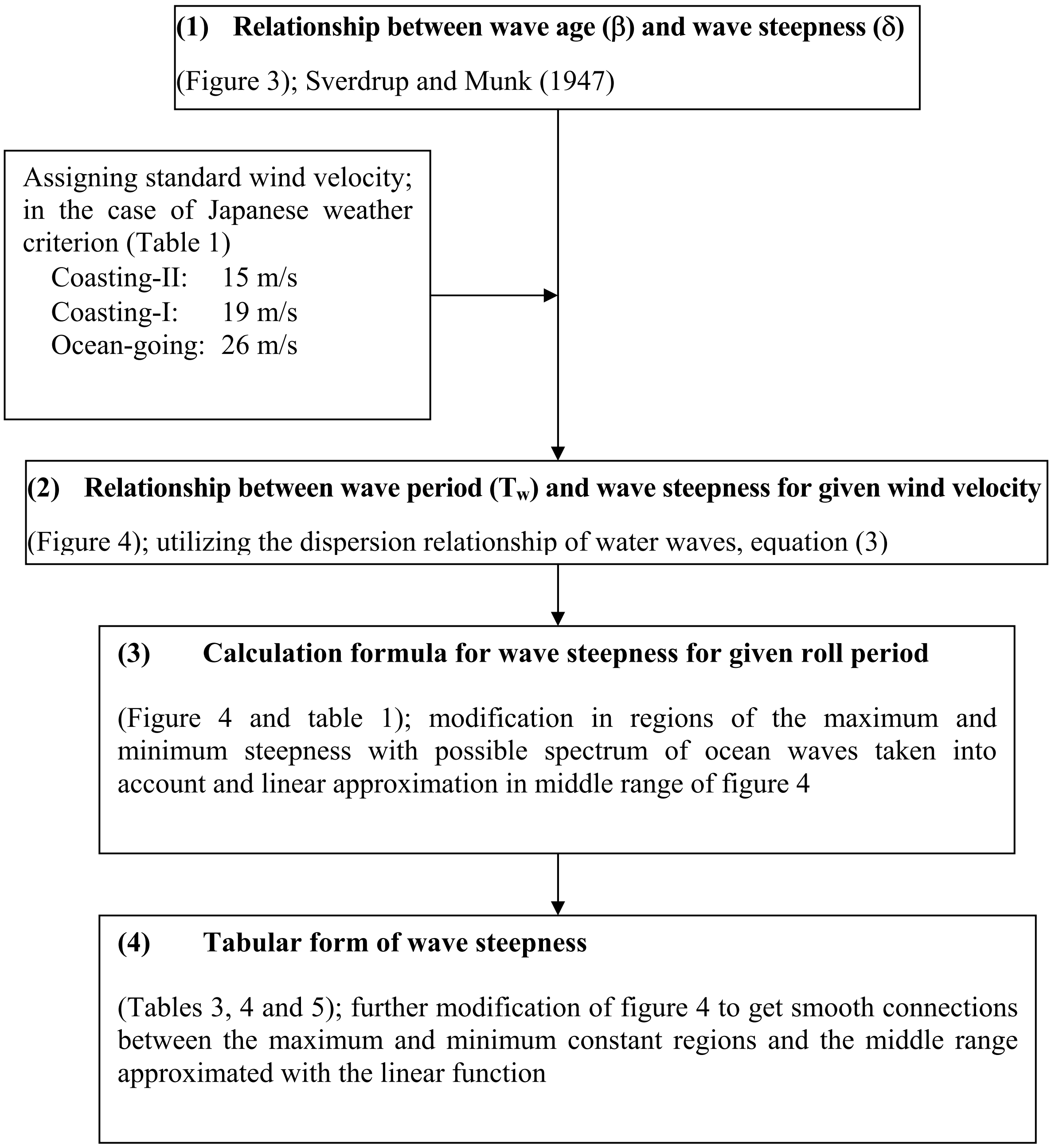

Figure 6 – Procedure to set up the corresponding relation between roll period and wave steepness from the standard wind velocities

2.4 Conclusions

In conclusion, procedures to set up the corresponding wind pressure to the standard wind velocities and the calculation formulae for wave steepness in the Japanese criterion are outlined. The procedures explained here has a sound basis from both theoretical and practical viewpoints so that they could be utilized as a reference in the application of weather criterion to ships engaged in restricted services in other administrations.

Finally it should be noted that the safety level of the criterion is tuned with the standard wind velocity, therefore careful deliberation is necessary in assigning wind velocity and in determining the corresponding wind pressure and wave steepness.

References

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ANNEX 2

FRAMEWORK FOR THE NEW GENERATION INTACT STABILITY CRITERIA

1 DEFINITIONS

1.1 General definitions

For the purpose of this development, the following definitions of general terms are assumed:

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

.2 a *standard* is a boundary separating acceptable and unacceptable likelihood of failure; and

.3 a *rule* (or regulation) is a specification of a relationship between a standard and a value produced by a criterion.

1.2 Definitions of Intact Stability Failures

New generation intact stability criteria are tools to judge the likelihood of intact stability failures:

.1 *Intact stability failure* is a state of inability of a ship to remain within design limits of roll (heel, list) angle and combination of lateral and vertical accelerations.

Two types of intact stability failures are distinguished:

.1 *Total stability failure*, or capsizing, results in total loss of a ship's operability with likely loss of lives. Capsizing could be formally defined as a transition from a nearly stable upright equilibrium that is considered safe, or from periodic 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 angles and/or excessive accelerations, which will not result in loss of the ship, but which would impair normal operation of the ship and could be dangerous to crew, passengers, cargo or ship equipment. Two subtypes of partial stability failure are intended to be included in the development:

.2.2 roll angles exceeding a prescribed limit; and

.2.3 combination of lateral and vertical accelerations exceeding prescribed limits.

1.3 Criteria types

Definitions for the types of criteria are given below. These definitions distinguish the criteria on the basis of how they judge stability failure – that is, whether they judge on stability failure directly (performance-based) or indirectly (empirical), and how the environment is described:

.1 a *probabilistic performance-based criterion* is a criterion based on a physical model of a stability failure considering this phenomenon as a random event (for example, documents SLF 48/4/6, SLF 49/5/5 and SLF 49/INF.7);

.2 a *deterministic performance-based criterion* is a criterion based on a physical model of a stability failure considering this phenomenon in a deterministic manner (for example, document SLF 49/5/6);

.3 a *probabilistic parametric criterion* is a criterion based on a measure of a quantity related to a phenomenon, but does not contain a physical model of the phenomenon, and includes one or more stochastic values for this criterion (for example, the new probabilistic damage stability criterion contained in resolution MSC.216(82)); and

.4 a *deterministic parametric criterion* is a criterion based on a measure of a quantity related to a phenomenon, but does not contain a physical model of the phenomenon, while all the input values are deterministic (for example, the GZ curve criterion contained in section 2.2 of the draft 2008 IS Code, part A).

2 APPLICABILITY

2.1 The new generation intact stability criteria will establish minimum requirements for ship design, applicable to unconventional types of ships and major dynamic modes of stability failures. Distinction between conventional and unconventional ships is to be determined with vulnerability criteria.

2.2 The major dynamic modes, as listed in the section 1.2 of the 2008 IS Code, part A should address:

.1 restoring arm variation problems such as parametric excitation and pure loss of stability;

.2 stability under dead ship condition defined by SOLAS regulation II-1/3-8; and

.3 manoeuvring related problems in waves such as broaching-to.

2.3 The new generation intact stability criteria are to be considered, for the time being, as a complement or as an alternative to the existing criteria.

2.4 It is also the intention of the IS Working Group to establish requirements for ship-specific operational guidance to complement the new generation intact criteria as an integral part of the IS Code.

3 "SAFETY LEVEL"

3.1 The safety level is a quantity related to a likelihood of failure, including, but not limited to, a probability of failure during finite period of time. The term "safety level" is further understood to be a level of safety from stability failure.

3.2 Any time new generation intact stability criteria are proposed, the associated safety level should be evaluated.

3.3 In the case of a probabilistic performance-based criterion, a safety level is a standard (see section 1.1).

3.4 Deterministic criteria, both parametric and performance-based, and probabilistic parametric criteria do not provide a likelihood of failure directly. Therefore it may be necessary to evaluate the associated safety level by assessment with probabilistic performance based criteria or application of another appropriate procedure.

3.5 Safety level may be different for different stability failures.

4 VULNERABILITY CRITERIA

4.1 Existing intact stability regulations provide deterministic criteria associated with physical typologies and sizes of ships operated approximately 40 years ago. Ships that have typologies or sizes outside the scope of those for which the existing regulations were developed may be susceptible to different modes of stability failures.

4.2 Vulnerability criteria would check for this susceptibility and should be based on simplified physical models, simple mathematical formulations or analytical solutions. These criteria will likely require separate development for different failure modes. Generally, unconventional stability failure is a stability failure not explicitly covered by the existing intact stability regulations. If a ship is susceptible to such an unconventional stability failure judging from the relevant vulnerability criterion, the ship is regarded as an “unconventional ship” for this particular stability failure within this framework.

4.3 Ships that pass a vulnerability test would be considered safe with respect to the particular mode of stability failure for which it was developed. Therefore, these criteria should reflect a conservative envelope of the vessel performance when a minimum of technical and operational data is available.

5 PARAMETRIC CRITERIA

5.1 Parametric stability criteria are expressed in simple mathematical form and are intended to reproduce the prescribed safety level associated with a dynamic mode of stability failure.

5.2 Parametric criteria are intended to be easy to use. They may be derived from the results of the direct safety assessment procedures for a sufficiently large set of vessels, using regression, discriminate analysis, or similar methods. They also may be defined using parameters effectively related with the stability failures.

5.3 The acceptance boundary imposed by parametric criteria reproduces as closely as possible the separation of vessels into “safe” (i.e. demonstrating safety level higher than the acceptable minimum) and “unsafe” obtained by, for example, direct performance-based assessment.

5.4 Caution should be exercised when employing parametric criteria based on empirical data, in order not to exceed the range of applicability.

6 PERFORMANCE-BASED CRITERIA

6.1 General

Performance-based criteria provide physically robust solutions and can use procedures including model tests, numerical simulations and analytical solutions as well as a combination of these methods.

Probabilistic performance-based criteria can be expressed in a form of probability of failures during a specified time or as an average rate of failure.

Deterministic performance-based criteria result in binary output for the stability failure, e.g., capsizing or non-capsizing.

To quantify the safety level demonstrated by a ship, as well as to compare it with the prescribed level of safety, a corresponding performance-based assessment is required.

6.2 Possible formulations for Performance-Based Assessment

Two formulations are, in principle, possible:

.1 long-term formulation, where the safety level of a ship is evaluated for a set of possible assumed situations (environmental conditions and operational parameters) and loading conditions. Evaluation of the probability of assumed situations requires data on environmental conditions and operational parameters. These data may be obtained from, for example, route simulations. In order to obtain realistic results, a realistic model of operator action may be included; and

.2 short-term formulation requires development of a list of assumed situations. The assumed situations in short-term approach can be formulated in terms of irregular or regular waves.

6.3 Issues to be addressed

For probabilistic performance-based criteria development, the following issues need to be considered.

6.3.1 *Time dependence*

For probabilistic performance-based criteria, the dependence of the probability of a stability failure on the exposure time requires consideration. One possible solution would be to use the rate of failures, which eliminates the need of fixing a reference time.

6.3.2 *Problem of rarity*

The problem of rarity arises when the average time before the stability failure may occur is very long in comparison with the natural roll period that serves as a main time scale for the roll motion process. As stability failures are rare for the cases for which application of probabilistic performance-based criteria may be required, the need of obtaining estimates of the rate of stability failures means performing many time-domain numerical simulations or model tests for long durations. To mitigate this problem, several possible solutions have been considered, for example but not limited to:

.1 using theoretical distributions of extreme values for large roll angles;

.2 extrapolation of the rate of stability failure over significant wave height;

.3 methods using the Blume criterion (SLF 49/5/2); and

.4 the time scale split method: uses separation of the entire problem of evaluation of probability of stability failure into one "rare" and one (or several) "non-rare" problems. Separate numerical simulations and/or analytical solutions are used for each problem. Solutions are combined with the up-crossing problem.

To apply these or similar methods, it should be demonstrated that the probability estimates of stability failures provided are sufficiently precise.

7 MINIMUM REQUIREMENTS TO SHIP-SPECIFIC OPERATIONAL GUIDANCE

The Revised Guidance to the master for avoiding dangerous situations in adverse weather and sea conditions, MSC.1/Circ.1228, provides guidance for the following phenomena but without ship specific data:

.1 surf-riding and broaching;

.2 reduction of stability when riding a wave crest amidships;

.3 parametric rolling; and

.4 synchronous rolling.

To properly supplement the performance-based design criteria, quantitative guidance should be provided for all the above phenomena with ship specific data by using the same methods applied in developing the design criteria.

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ANNEX 3

DRAFT TERMINOLOGY FOR THE NEW GENERATION INTACT STABILITY CRITERIA

1 General

Stability	A ship is stable if, upon being inclined by external forces, it returns to the initial position when action of these forces ceases to exist.
Intact stability	Stability of a ship without any damage to its watertight buoyant space, hull structure or to any onboard system that could lead to loss of buoyancy due to water ingress.
Standard	is a boundary separating acceptable and unacceptable likelihood of failure.
Operational guidance	Recommendation, information or advice to an operator aimed at decreasing the likelihood of stability failures and/or their consequences.
Loading condition	Characterization of the components of a ship mass and its distribution. A typical description of loading conditions includes mass displacement, co-ordinates of the centre of gravity and radii of inertia for three central axes and tanks with free surfaces and corresponding inertia effects.
Operational parameters	Parameters that can be controlled by a ship operator; for a self-propelled ship which may include, but not limited to, commanded course angle, commanded propeller revolution, trim, heel, rudder angle, operational GM.
Environmental conditions	A set of parameters and functions describing parameters of wind, waves and currents and that are sufficient for an adequate modelling of possible stability failures, including but not limited to: Waves: number, significant wave height, characteristic period (modal/peak, mean, zero-crossing period), directional spectrum; Wind: direction, mean speed, spectrum of wind speed fluctuations, spectrum of transversal fluctuations, profile, coherence. Current: direction, mean speed, width and speed profile.
Safety level	is a number related to a likelihood of failure, including, but not limited to a probability of failure during finite period of time. The term “Safety level” is further understood as a level of safety from stability failure. Safety level is a standard for probabilistic performance based criterion.
Rule/Regulation	is the specification of a relationship between a standard and the value produced by a criterion.

2 Criteria

Criterion	is a procedure, an algorithm or a formula used for judgment on likelihood of failure.
Vulnerability criterion	Vulnerability criterion are intended to distinguish between conventional and unconventional ships.
Unconventional ships	Ships that are vulnerable to unconventional stability failures.
Parametric criterion	A criterion based on a measure of a quantity which is related to a phenomenon, but does not contain a physical model of the phenomenon. [probabilistic (e.g., the new damage stability criterion in r*esolution MSC.216(82)*) or deterministic (e.g., the *GZ* curve criterion in paragraph 2.2 of the *Revised IS Code*)]
Performance-based criterion	A criterion based on a physical model of a stability failure. [probabilistic (e.g., *SLF 49/5/5* and *SLF 49/INF.7*) or deterministic (e.g., *SLF 49/5/6*)]
Probabilistic criterion	A criterion considering stability failure as a random event. [performance-based (e.g., *SLF 49/5/5* and *SLF 49/INF.7*) or parametric (e.g., the new damage stability criterion in *resolution MSC.216(82)*)]
Deterministic criterion	A criterion considering stability failure in a deterministic manner. [performance-based (e.g., *SLF 49/5/6*) or parametric (e.g., the GZ curve criterion, paragraph 2.2 of the *Revised IS Code*)]
Probabilistic performance-based criterion	is a criterion based on a physical model of a stability failure considering this phenomenon as a random event.
Deterministic performance-based criterion	is a criterion based on a physical model of a stability failure considering this phenomenon in a deterministic manner.
Probabilistic parametric criterion	is a criterion based on a measure of a quantity related to a phenomenon, but does not contain a physical model of the phenomenon, and includes one or more stochastic values.
Deterministic parametric criterion	is a criterion based on a measure of a quantity related to a phenomenon, but does not contain a physical model of the phenomenon, while all the input values are deterministic.

Direct safety assessment	A means of assessing risk from theoretical calculation or model experiments rather than by comparison with empirical or semi-empirical criteria.
Conservative envelope	Is a boundary based on operational parameters intended to separate safe from unsafe ships but with a large inbuilt safety margin.
Rate of failures	Expected number of failures per unit time.

3 Intact Stability Failure Events

Heel	is the degree to which a ship leans transversely as a result of variable and dynamic external forces.
Roll	is the continuous response of the ship in a transverse direction to variable and dynamic external forces.
List	is a transverse rotation of the ship about a vertical axis through the centreline arising from static forces in equilibrium and is usually measured by the difference in draught amidships between the port and starboard sides.
Intact stability failure	a state of inability of a ship to remain within design limits of roll (heel, list) angle and combination of lateral and vertical accelerations.
Total stability failure *or capsizing*	Total loss of a ship's operability with likely loss of lives. Capsizing could be formally defined as a transition from a nearly stable upright equilibrium that is considered to be safe, or from periodic motions near such equilibrium, to another stable equilibrium that is intrinsically unsafe (or could be considered fatal from a practical point of view).
Partial stability failure	Occurrence of very large roll angles and/or excessive roll accelerations, which will not result in loss of the ship, but which would impair normal operation of the ship and could be dangerous to crew, passengers, cargo or ship equipment.
Unconventional stability failure	Is a stability failure not explicitly (and/or sufficiently) covered by Part A – chapter 2 "General Criteria" and chapter 3 "Special Criteria for Certain Types of Ships", and in particular a type of stability failure addressed by Part A – paragraph 1.2 "Dynamic stability phenomena in waves".
Vertical acceleration	Acceleration component perpendicular to the deck, positive downward.
Lateral acceleration	Acceleration component parallel to the deck, positive starboard.

4 Measurement

Probability of stability failure	is a probability or an estimate of probability that at least one stability failure will occur during an exposure time.
Exposure time	It is the time interval to be used for stability judgement using short-term probabilistic criteria.
Long-term formulation	A way to estimate the probability of a stability failure in the time scale of days, months or years, where changing sea state, course and speed, as well as variation of loading condition, are taken into account.
Short term formulation	A way to estimate the probability of a stability failure in a time scale within the range of several hours, using the assumption of stationary (in statistical sense) environmental conditions.
Assumed situation	A combination of loading conditions, environmental conditions and operational parameters, as well as time of exposure.

5 Modes of stability failures

Regular waves	A strictly periodic wave characterized by one fundamental harmonic component and possible additional, usually small, harmonic components due to the non-linearities of the free surface.
Irregular waves	A sea surface process that cannot be characterized as a regular wave. It is usually, but not only, defined by means of a spectrum.
Parametric rolling	is an effect of amplification of roll motion of a ship due to periodic changes of restoring moment causing parametric resonance. Periodic changes of restoring moment may be caused by wave pass effect and or coupling with other degrees of freedom (e.g., MSC.1/Circ.1228 for phenomena explanation).
Synchronous rolling	roll motion induced by an external excitation force having its frequency equal to the natural roll frequency.
Broaching-to	a phenomenon where a ship cannot keep constant course despite maximum steering efforts and experiences a significant yaw motion in an uncontrolled manner.
Surf-riding	a phenomenon where mean speed of a floating body is shifted from the original one to wave celerity because of wave actions (e.g., MSC.1/Circ.1228 for phenomena explanation).
Dead-ship condition	Condition under which the main propulsion plant, boilers and auxiliaries are not in operation due to the absence of power (SOLAS regulation II-1/3.8).
Pure loss of stability	Condition under which static balance in heel is lost due to reduction of righting lever curve or increase of heeling moment.

6 Methodology

Physical model	In this framework this term is used to indicate a theoretical model based on a physical description of the involved phenomena.
Numerical simulation	A method of replicating to an approximate degree the results of physical model tests using numerical methods on a computer model of the hull with due allowances for environmental conditions.
Analytical solution	Solution expressed in a form of well-known operations, including elementary and special functions as well as infinite series.
The time scale split method	A method in which the problem of irregular roll and capsizing (or reaching large roll angle) is divided in two (or more) sub-problems.
Statistical extrapolation	A method that uses an assumed theoretical distribution to fit an available set of data and to eventually extrapolate the results outside the original data range. It is usually used to obtain information on the tails of the distribution of roll angles and/or rolling amplitude.

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