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REVISION OF THE INTACT STABILITY CODE

A proposal of new generation intact stability criteria as an example

Submitted by Japan

SUMMARY

Executive summary:	This document provides an example of the new generation intact stability criteria, based on the framework agreed in the intersessional correspondence group, for the Sub-Committee's consideration to the revision of the International Code on Intact Stability, 2008
Strategic direction:	5.2
High-level action:	5.2.1
Planned output:	5.2.1.2
Action to be taken:	Paragraph 18
Related documents:	SLF 36/INF.4; SLF 49/5/5, SLF 49/5/6, SLF 49/5/7/Corr.1; SLF 50/4/4, SLF 50/WP.2; SLF 51/4, SLF 51/4/1; MSC/Circ.707, MSC.1/Circ.1228 and 2008 IS Code

Introduction

1 The Sub-committee, at its fiftieth session, instructed the intersessional correspondence group to provide a framework of development of new generation intact stability criteria to supplement prescriptive provisions of the International Code on Intact Stability, 2008 (2008 IS Code). The intersessional correspondence group, co-ordinated by Germany, developed the framework, which is based on document SLF 50/4/4 submitted by Japan, the Netherlands and the United States. This framework requests the new generation intact stability criteria to cover three major phenomena: restoring variation problems such as parametric rolling, stability under dead ship condition and manoeuvring-related problems such as broaching-to and to consist of vulnerability criteria to judge whether subject ships are vulnerable to these unconventional phenomena or not, and direct stability assessment with first-principle tools, such as numerical simulations, analytical solutions and model experiments for the subject ships vulnerable to the unconventional phenomena.

2 As described in the action plan of the Sub-Committee, the next step for new generation stability criteria is to develop a draft of vulnerability criteria and direct stability assessments for the three major phenomena. Taking this situation into account, Japan attempts to provide an example of draft criterion set to facilitate consideration at the Sub-Committee, based on the framework agreed in the intersessional correspondence group.

Restoring variation problems

3 The restoring variation due to relative wave elevation along the ship length could result in parametric rolling or pure loss of stability on a wave crest. The parametric rolling is a resonant roll induced by the time-varying restoring moment. The pure loss of stability on a wave crest is the static loss of roll moment balance due to reduction of restoring moment. For both phenomena, it is essential to evaluate restoring variation for the subject ship. For a vulnerability criterion, it can be calculated with the Froude-Krylov assumption for simplicity sake. For more accurate evaluation in the direct stability assessment, the radiation, diffraction and hydrodynamic lift components should be taken into account.

4 The calculation of the Froude-Krylov component of restoring variation is not so complicated but it is not so common as the conventional calculation of roll restoring moment in calm water. Thus it is desirable to develop a simple formula at least for the vulnerability criterion. This is partly because some major ship-types, such as a tanker or a bulk carrier, are most likely not relevant to the restoring variation problems but the vulnerability criterion will be applied to these ships as well. It is important to avoid complicate calculations for such ships when the vulnerability criterion is applied. Thus, as an example, Japan proposes the following formula.

$$\Delta GM = BM \frac{\Delta I}{I} + \Delta BB$$

where:

$$\Delta BB = -\frac{1}{V}\int_{AE}^{FE} b(x)\{\zeta_W(x)\}^2\,dx\,,\ \ \Delta I = -2\int_{AE}^{FE}\{b(x)\}^2\frac{\partial b(x)}{\partial z}\zeta_w(x)dx\,,\ \ \zeta_W = \frac{H}{2}\cos\frac{2\pi}{L}x$$

Here *b(x)* and $\frac{\partial b(x)}{\partial z}$ are local breadth and side-wall slope at the calm water surface, respectively. *I*: the moment of inertia of waterplane, *BM*: metacentric radius, *V*: displacement volume, *H*: wave height, *L*: ship length between perpendiculars, *FE*: the ship fore end and *AE*: the ship aft end. It is noteworthy that this formula is applicable only for the case that wavelength is equal to the ship length and the ship centre is situated on a wave crest or trough.

5 Once the restoring variation is evaluated by either the simple formula, either the Froude-Krylov calculation or more advanced hydrodynamic calculation, the occurrence of parametric rolling and its magnitude can be roughly evaluated by analytical formulae deduced from nonlinear dynamics. Examples of these formulae can be found in the guidelines of the International Towing Tank Conference (ITTC) registered as 7.5-02-07-04.3.

6 It is noteworthy here that, other than the amplitude of restoring variation, the linear roll damping coefficient is required for the above formulae. Currently a semi-empirical method proposed by Ikeda (2004) is effective for most of passenger and cargo ships. For the vulnerability criterion, however, this method could be still complicated. Thus, further simplification, particularly for its wave-making component, and verification of its eddy-making components for unconventional ships are now under way.

7 Regarding the pure loss of stability on a wave crest, Japan proposed a simplified method to judge its danger in document SLF 38/INF.10 for the development of MSC/Circ.707. Here the danger of pure loss of stability can be conservatively judged with the combination of reduction of restoring moment due to longitudinal waves and synchronized roll due to beam waves, although actual situation requires smaller reduction of restoring moment and smaller synchronized roll because of stern quartering waves. Thus this methodology seems to be suitable for the vulnerability criterion.

8 Japan attempted to examine the applicability of the simplified formula of restoring variation on the above vulnerability criteria for five cargo ships and a passenger ship. As shown in Figure 1, the amplitude estimated with the simplified formulae are comparable with those with the Froude-Krylov component. Thus, the simplified formulae can be used as an alternative to the Froude-Krylov calculation. In these sample calculations Japan tentatively used the wave steepness of 1/30. Further discussion is necessary for the choice of wave steepness.

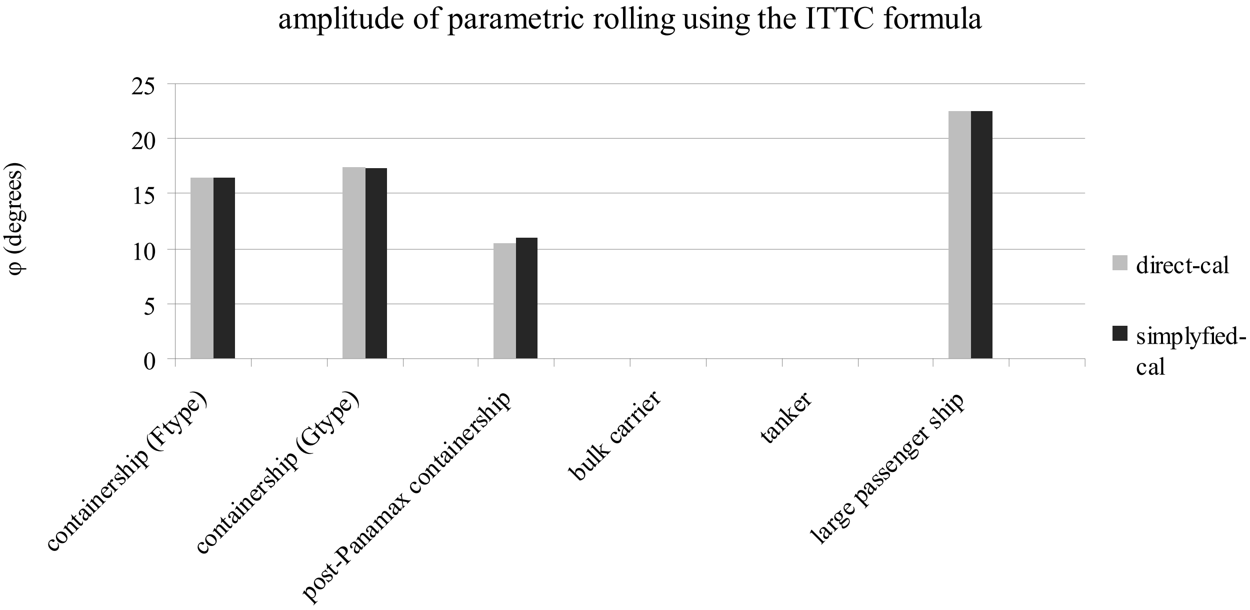

Figure 1 – Comparison in the amplitude of parametric rolling for passenger and cargo ships between calculation with the direct Froude-Krylov restoring moment calculation and that with the simplified estimation (Here the wave steepness is 1/30 and the wavelength to ship length ratio is 1.0. Parametric rolling does not occur for the bulk carrier and the tanker in both calculations.)

9 If the subject ship fails to comply with the vulnerability criterion, the direct stability assessment should be applied to it. This means that the maximum amplitude of parametric roll in irregular head and following waves should be calculated by numerical simulation in the time domain. This is partly because the excessive acceleration which could result in onboard container damage or loss mainly consists of its gravitational component (Ogawa *et al.*, 2008) so that the prediction of maximum amplitude of parametric roll is essential to this partial stability failure problem as well. One of the major difficulties here is “practical non-ergodicity”, which means a time average of one realization could be different from an ensemble average of many realizations. Thus, it is necessary to repeat many realizations.

10 Although the prediction of parametric roll amplitude in irregular head waves is not always satisfactory (SLF 49/5/7/Corr.1), ensemble averages of many realizations could provide a reasonable comparison between the model experiment and numerical simulation in the time domain, at least for its 1/10 highest mean amplitude as shown in Figure 2.

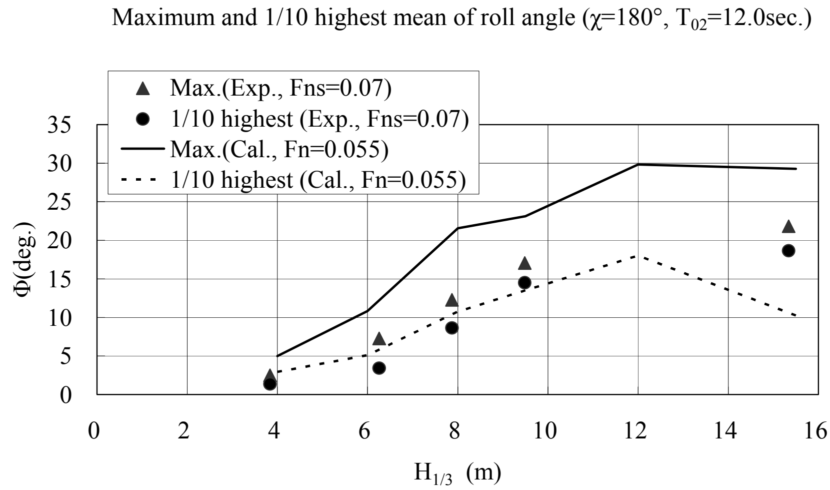

Figure 2 – Comparison of maximum angle of parametric rolling in irregular head waves with the zero-crossing period of 12.0 seconds as a function of the significant wave height for a post-Panamax containership (Ogawa, 2007)

Stability under dead ship condition

11 For this purpose, a weather criterion was developed because a ship without propulsive power could suffer beam wind and waves for long duration if a ship is longitudinally symmetric. Its applicability to recent unconventional hull forms which have a large beam-draft ratio is not always satisfactory because criteria for calculating roll damping and effective wave slope coefficient were empirically developed with the database of conventional ships. Thus, the 2008 IS Code allows us to use model experiments for estimating roll back angle and wind heeling lever within the framework of the weather criterion. The use of model experiment, however, could require a well-equipped towing tank and could consume redundant time and cost. Therefore, it is desirable to utilize analytical or semi-analytical method of roll damping and effective wave slope coefficient in place of the current empirical formulae. If they are available, the weather criterion supplemented with them could be a candidate of the vulnerability criterion for stability under dead ship condition. This is partly because the weather criterion itself is well familiar to most of the Administrations.

12 The effective wave slope coefficient, which represents wave-exciting roll moment, can be estimated by a linear strip theory of coupled sway-roll equation. Although its agreement with the model experiment is not always satisfactory, the recent systematic survey (Sato *et. al*, 2008) indicates the estimation of the strip theory usually does not underestimate the experimental results. In addition, a simplified formula, which coincides with a strip theory but does not require us to numerically solve a simultaneous equation, is also available. (Umeda & Tsukamoto, 2008) As a result of this simplified formula or model experiment, the weather criterion could be less stringent for large passenger ships and RoPax ships. For the roll damping, a simplified method based on physics is now under development as explained in the paragraph 6 but with its nonlinear component.

13 As the direct stability assessment for ships failing to comply with the vulnerability criterion, it can be recommended to directly calculate capsizing probability in irregular beam wind and waves. For minimizing computational efforts, a piece-wise linear approach for approximating the restoring moment is available. Here it can be calculated as the product of the probability of out-crossing the border in the positive slope zone of the restoring arm and the conditional probability diverging in the negative slope zone of the restoring arm. Although the dead ship condition does not directly mean the beam wind and wave condition, it can be most dangerous in the calculation of capsizing probability among different heading angles for a RoPax ship (SLF 49/5/5).

14 If a ship operator abandons his operational effort, a ship will tend to this dead ship condition. Since the capsizing probability of a ship steaming in waves could be larger than that under dead ship condition because of reduction of the restoring in longitudinal waves and so on. Thus, the capsizing probability under dead ship condition can be regarded as the base of safety level without human effect. Therefore, it can be useful to calculate annual capsizing probability of the subject unconventional vessel under the dead ship condition by using sea state statistics in relevant operational areas and then to compare it with that for conventional vessel.

Manoeuvring-related problems such as broaching

15 Broaching could occasionally happen when a ship is surf-ridden in following or stern quartering seas. Ship suffers surf-riding if her propeller revolution is larger than a threshold. Here a ship is accelerated by waves from her self-propulsion speed to the wave celerity and then captured by a wave downslope where even a directionally stable ship in calm water can be directionally unstable. This threshold of surf-riding is smallest in pure following waves and increases with increasing heading angle from the wave direction. Therefore, threshold of surf-riding in regular following waves can be used as a vulnerability criterion for broaching. Other type of broaching can occur at lower speed but it is not directly relevant to ship capsizing.

16 The threshold of surf-riding in regular following waves can be estimated by several methods. One of the simplest methods is the formula in the MSC/Circ.707 amended as MSC.1/Circ.1228: $V(kt) > 1.8\sqrt{L(m)}$ where V is the ship velocity in calm water and L is the ship length. This indicates that low-speed ships are not relevant to this danger. This is based on results of the phase plane analyses of uncoupled surge equation for typical ships (SLF 36/INF.4). Alternatively, a direct numerical analysis can be applied for identifying the trajectory connecting two unstable equilibria (SLF 49/5/6). Furthermore, some approximated but validated analytical formulae are also available in the literature. It is noteworthy here that the resistance and the propeller thrust in calm water as well as the hull form geometry is required for these numerical or analytical methods.

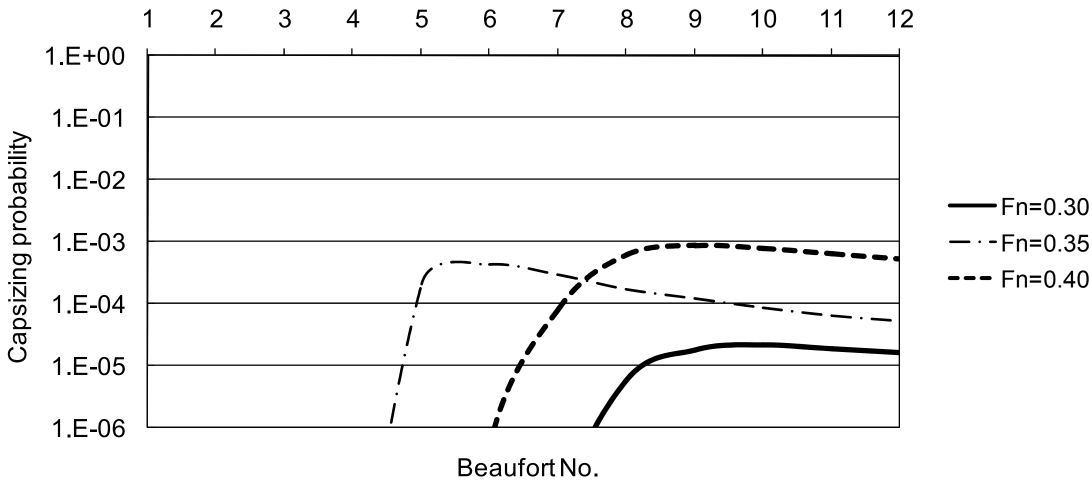

Figure 3 – Probability of capsizing due to broaching per encounter wave cycle for a fishing vessel of 34.5 m in length in stern quartering waves with the desired course of 5 degrees from the wave direction and the rudder gain of 1.0 (Umeda *et al*., 2008)

17 For the direct stability assessment of broaching, it is desirable to calculate probability of capsizing due to broaching in irregular following and stern quartering waves. It is, however, extremely time-consuming to calculate such probability by repeating many realizations with different random wave phases in the time domain. To overcome this difficulty, the capsizing probability can be obtained by integrating a joint probability density of local wave height and local wave period within the zones of capsizing due to broaching in regular waves, which can be determined by numerical simulation in the time domain or its equivalent. This methodology is well validated with the random simulation (Umeda *et al*., 2007). An example of the probability of capsizing due to broaching for a fishing vessel is shown in Figure 3 as a function of the Beaufort wind scale. This result can be utilized not only as the design criteria but also for a ship-specified operational guidance within the frame work of new generation intact stability framework.

Action requested of the Sub-Committee

18 The Sub-Committee is invited to take into account the above example of draft criteria for its consideration on the revision of the 2008 IS Code and take actions as appropriate.

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