Regulatory Aspects of Implementation of IMO Second Generation Intact Stability Criteria

William S. Peters, *USCG Office of Design and Engineering Standards*
Vadim Belenky, *Naval Surface Warfare Center Carderock Division*

ABSTRACT

Development of second generation intact stability criteria at IMO began in 2005, but is based on research that has been carried out over many decades. While research can identify algorithms or processes that can successfully replicate or describe physical phenomena of ship stability failure, a regulation requires an assessment about whether or not a standard has been satisfied. Even if presented in a probabilistic format, the assessment of regulatory compliance ultimately comes to an evaluation of whether there is an acceptable likelihood of failure. The development of the second generation intact stability criteria acknowledges both the contribution of intact stability research through the use of levels of vulnerability criteria and the challenge of identifying methods of assessment that are simultaneously reliable, consistent, and robust. This challenge is further complicated by understanding that a given ship may be assessed to have both an acceptable and unacceptable likelihood of failure based upon the ship's loading condition. This paper discusses these and related aspects of the development of regulations for the second generation intact stability criteria. In particular, procedures for revision and rectification of the criteria, standards and explanatory notes are discussed. The industry already provided valuable feedback on consistency between the levels of vulnerability criteria on pure loss of stability. More feedback is expected in the next few years, so the regulator has to be ready to process and use this feedback

Keywords: *IMO, Second Generation Intact Stability Criteria, 2008 IS Code.*

1. INTRODUCTION

The development of the IMO second generation intact stability criteria has been an intense effort spanning many years. Even while the work to restructure the 1993 intact stability code was underway, the goal to address the problems against accidents related to stability which generally had not yet been solved was understood. Indeed, the preamble to the 2008 IS Code recognizes this: "*…the safety of a ship in a seaway involves complex hydrodynamic phenomena which up to now have not been fully investigated and understood. Motion of ships in a seaway should be treated as a dynamical system and relationships between ship and environmental conditions such as wave and wind excitations are recognized as extremely important elements. Based on hydrodynamic aspects and stability analysis of a ship in a seaway, stability criteria development poses complex problems that require further research*." That the work to realize this goal is coming to fruition is a testament to the perseverance and diligence of those persons involved in the effort.

The care by which the outcomes of this work are placed into a regulatory framework is no less important than the work itself. Further, the introduction of these new criteria into a recognized international instrument such as the 2008 IS Code represents - at least for some entities in the maritime industry – added regulatory encroachment where – they believe - none is really needed. Machiavelli identified the problem: "*There is nothing more difficult to take in hand, more perilous to conduct, or more uncertain in its success, than to take the lead in the introduction of a new order of things.*" That the second generation intact stability criteria regulation is an initiation of a new order of things is a view difficult to successfully oppose.

The development of the second generation stability criteria recognizes that stability failure may be caused by different physical mechanisms, and, as identified in section 1.2 of Part A of the

2008 IS Code on dynamic stability phenomena in waves, the different modes of stability failure are explicitly considered:

- Restoring arm variation problems, such as parametric excitation and pure loss of stability;
- Stability under dead ship condition, as defined by SOLAS regulation II-1/3-8;
- Maneuvering related problems in waves, such as broaching-to (initiated by surf-riding; and
- Excessive accelerations (SLF 53/19, paragraph 3.28).

As has been discussed previously, the appearance of novel hull forms renewed interest in dynamic stability, (see e.g. France, et al. 2003) and in development of methods to assess dynamic stability. The development has emphasized an adequate replication of the physics of stability failure and on making the new criteria performance-based (Belenky, et al. 2008). In other words, instead of addressing certain types of ships, the new criteria bases ship assessments on the hull geometry, the loading condition, and the physics of the stability failure.

The multi-tiered structure of new criteria addresses the potential complexity of the application of the new criteria. The first-level vulnerability check is very simple and quick, but conservative. If vulnerability to a particular stability failure mode is determined not to occur, no further assessments are needed. If not, then a more detailed, but less conservative analysis follows, which is the second-level vulnerability assessment.

2. THE CURRENT STATUS

The IMO Sub-committee on Ship Design and Construction (SDC) finalized the five elements of the criteria as Draft amendments to Part B of the 2008 IS Code for:

- Vulnerability Criteria of Levels 1 And 2 for the Pure Loss of Stability Failure Mode (Annex 1 of SDC 2/WP.4);
- Vulnerability Criteria of Levels 1 And 2 for the Parametric Rolling Failure Mode (Annex 2 of SDC 2/WP.4);
- Vulnerability Criteria of Levels 1 And 2 for the Surf-Riding / Broaching Failure Mode (Annex 3 of SDC 2/WP.4).
- Vulnerability Criteria of Levels 1 And 2 for the Dead Ship Condition Failure Mode (Annex 1 of SDC 3/WP.5).
- Vulnerability Criteria of Levels 1 And 2 for the Excessive Acceleration Failure Mode (Annex 2 of SDC 3/WP.5).

The criteria and standards for each of these five stability failure modes are addressed in the foregoing documents. The development of the explanatory notes for the second generation instability criteria is expected to ensure uniform interpretations and application of the new criteria such that two assessments of the same ship's loading condition yields a common result. The technical background of these criteria is described in Peters, *et. al.* (2011). Annexes 3 through 7 of document SDC 3/WP.5 contain the current drafts of the explanatory notes for each of the five stability failure modes.

3. GENERAL CONSISTENCY ISSUES

A critical element of the robustness of the criteria is a reliable and repeatable assessment method. Common difficulties are the implied relationships between Parts A and B in the Code that, currently, are handled as footnotes. Mandatory criteria in part A refers to loading conditions defined in Part B (Sections 3.3. and 3.4, respectively). Part A criteria regarding righting lever properties allows for alternative criteria for cases where the angle of the maximum righting lever when less than 25 degrees.

Further, the last paragraph of the section (2.3.5) on the weather criterion points out that the criterion was based on ships having certain parameters, the most significant of which is probably the beam to draft ratio (*B/d*) to be less than 3.5. The current requirement permits the angle of roll to be determined by model tests using the procedures in MSC.1/Circ.1200. Given the costs associated with model tests the desirability of permitting an analytical method as an alternative is clear. The challenge for this is to ensure that the alternative method provides reliably consistent outcomes for ships with loading conditions that satisfy the weather criterion and those loading conditions with parameters beyond those provided.

4. CONSISTENCY ISSUES IN PURE LOSS OF STABILITY

Large values of *B/d* seem to contribute to consistency issues of vulnerability criteria for pure loss of stability. Inconsistency between Levels 1 and 2 of the vulnerability criteria has been reported in Annex of SDC 3/6/2, when analyzing results for cruise ships for values of drafts and *GM*, i.e. maximizing *B/d* ratio. To explore this, a case study was performed with a notional cruise ship to determine the underlying reason for inconsistency. The geometry and principal particulars of the notional ship are presented in Figure 1 and Table 1. With the value of *B/d* = 4.75, the notional ship's characteristics are similar to other ships for which the inconsistency has been observed.

Table 1 Principal particulars of notional ship for the case study

Length BP, m	260
Length OA, m	271.7
Beam, m	38
Draft, m	8
Speed, kt	25

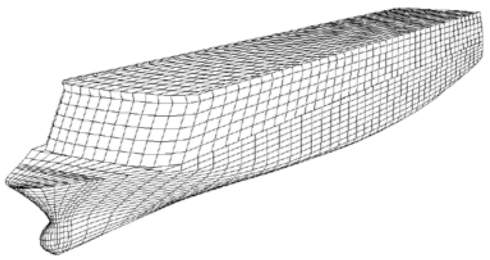

Figure 1 Geometry of notional ship for the case study

The main control parameter for the study was the Depth to the freeboard deck, which was varied from 15 to 18 m in 1 meter increments. The following steps were carried out for each value of depth:

- Step 1: Calculate the limiting KG value based on 2008 IS Code (Part A, 2.2 only – the weather criterion was not evaluated since the *B/d* ratio is out of applicable range).
- Step 2: Carry out the vulnerability criterion Level 1 check for the critical KG. If the case is found not to satisfy the Level 1 standard, the KG is reduced and the case is re-checked. If the case is still found not to satisfy the Level 1 standard, the KG is reduced again. This process is repeated until the Level 1 criterion is satisfied.
- Step 3: Carry out the vulnerability criterion Level 2 check for the step 2 determined KG

The results are shown in Table 2. The third column in the table identifies the limiting factor from the 2008 IS Code, A/2.2. The inconsistency between the Level 1 and 2 is observed for the values of depth of 16 and 17 m

Table 2 Vulnerability check for pure loss of stability

D, m	KG, m	Limit factor	Level 1 GM, m	Level 2 CR1	Level 2 CR2
Standard values =			> 0.05m	< 0.06	< 0.06
15	16.74	f_{max}	3.0935	0.0005	0.00039
16	19.5	f_{max}	0.33	0.089	0.036
17	19.78	GM_{min}	0.053	0.073	0.048
18	19.78	GM_{min}	0.053	0.036	0.048

The mechanism of inconsistency may be partially understood from Figure 2, which shows the GZ curves for different wave steepness, when the wave crest is near amidships. One can see that somewhere between above the steepness 0.03 (actually above 0.0334 as the Level 1 criterion is satisfied), the GZ curve becomes completely negative. Because there are a sufficient number of wave cases from the wave scatter table that are capable of causing such a deterioration of the GZ curve, the total probability exceeds the standard value of 0.06.

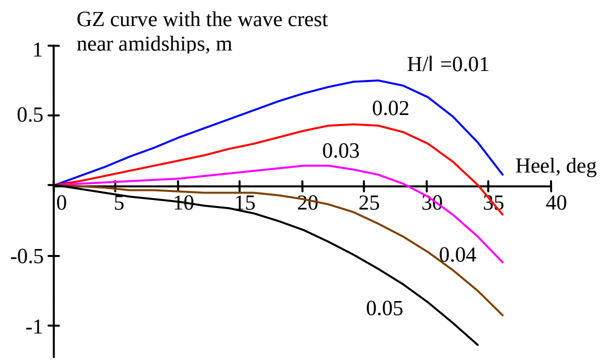

Figure 2 GZ curves in waves for different values of wave steepness, D=17 m

As the inconsistency has been discovered, two questions should be answered: why is the vulnerability criterion inconsistent and what can be done to insure consistency in the future?

Possible Reason for Inconsistency

The Level 1 criterion is based on the minimum GM value calculated during the wave pass. As is well-known, the GM does not characterize the stability of a ship in large heel angles. At the same time, the Level 2 criteria include stability characteristics at large angles of heel such as the minimum value of the angle of vanishing stability in waves and minimum value of the heel angle under specified heeling moment. Thus, a consistency between Levels 1 and 2 is not automatic.

Such an answer may lead to another question: more than a hundred sample ships have been tested during the development of the vulnerability criteria, but why has this inconsistency not been discovered earlier in the criteria development as the consistency between the levels was one of the items checked when testing the vulnerability criteria?

The parameters of the GZ curve are not independent values. Further, testing of the second generation intact stability criteria generally assumed that the first generation criteria are satisfied. A possible reason, therefore, why it was not discovered earlier is probably that the consistency was implicitly provided by this dependence. Thus, when the parameters of a ship to be tested were out of the usual range (B/d = 4.75), the “traditional” means of providing consistency was no longer available.

Resolving the Inconsistency

Once the inconsistency has been discovered and its reason understood, it must be resolved. For the multi-tiered second generation intact stability criteria, the following three-step procedure may be considered:

Step one – establish the ground truth: is a ship where the inconsistency between the levels is discovered, actually vulnerable to the stability failure of interest?

Step two –consider if refining the calculation method for cases where the inconsistency is found, solves the problem. If it does, then, the explanatory notes can be revised with the identified process, which may be considered as a new interpretation.

Step three – consider if changing a standard solves the problem. If it does, the regulation document may be updated, but there would not be a need to redo the sample calculations.

Consideration of revising the criteria should occur only if both step two and three are unsuccessful and the compelling need to resolve the inconsistency remains evident.

Step One: Ground Truth

The inconsistency between Level 1 and 2 means that Level 1 criteria indicate vulnerability, while the Level 2 criterion does not. As an approved direct stability assessment procedure is not yet available, the ground truth has to be established based on practical experience. As it is noted in SDC 3/6/2, there are no reliable data on vulnerability of cruise ships to pure loss of stability. Three cases of stability failure attributable to pure loss of stability have occurred with passenger and ro-ro ferries, not cruise ships (Maritime New Zealand, 2007; Swedish Accident Investigation Board, 2008; Transportation Safety Board, 2011). Indeed, caution has to be exercised, but for the time being assume the notional ship is non-vulnerable to pure loss of stability.

Step Two: Refinement of Calculation Method

Inclusion of the weathertight volume as buoyant volume into the stability calculations could be an example of such refinement. Why is it a good idea?

Consider the following scenario: when a ship heels due to degradation of stability near the wave crest, superstructures will immerse and provide additional drag; speed will decrease and the wave will take over the ship. Once the wave crest passes, stability will be partially regained and a ship may return to the upright position. As a result, the duration of the immersing of the superstructure may be not sufficient for progressive flooding to occur through the closed weathertight openings. Thus, the exclusion of the weathertight volume may make the Level 2 assessment too conservative. Is this possible?

Table 3 shows results of calculations for the notional ships with the volume of superstructure included as it was assumed “weathertight.” Figure 3 shows GZ curves for different wave steepness, when the wave crest is near amidships calculated with the superstructure included. This inclusion lead to a decrease of the CR1 values in the Level 2 check as they are related to the range of stability. As expected, there is no effect on the CR2 value since this reflects stability at smaller angles. Formally, the inconsistency has been resolved because the Level 2 criterion no longer indicates vulnerability

Table 3 Vulnerability check for pure loss of stability with the weathertight volume included

D, m	KG, m	Limit factor	Level 1 GM, m	Level 2 CR1	Level 2 CR2
Standard values =			> 0.05m	< 0.06	< 0.06
15	16.74	f_{max}	-	-	-
16	19.5	f_{max}	0.33	0.0028	0.036
17	19.78	GM_{min}	0.053	0.0035	0.048
18	19.78	GM_{min}	0.053	0.0035	0.048

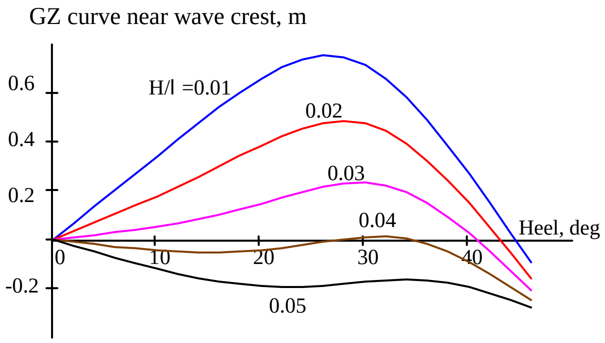

Figure 3 GZ curves in waves for different values of wave steepness, D=17 m with superstructure included

Step Three: Changing Standards

While in a formal sense the inconsistency has been resolved, the values in Table 3 are quite close to the standard. So, a re-consideration of the standard value may be appropriate.

The current standards are set by comparison of the criteria values for a ship with known vulnerabilities and ships known not to be vulnerable. Usually, the gap between these quantities is large enough that a change of the standard value may be allowed towards less conservative side without introducing new inconsistencies.

Alternatively, the standard may be customized for different size of ships (say, on the basis of length). The GZ curves in Figure 2 and Figure 3 computed for the wave steepness 0.05 look very dangerous with or without including the superstructure. However for a ship with length of 260 m, the wave height is 13 m for steepness of 0.05. There is a low likelihood that a ship of this size and power (and under control) would encounter a wave of this size by the stern.

The Level 2 vulnerability criterion for pure loss of stability is, in fact, a long-term probabilistic criterion. As it was shown by the simulation study (Boonstra, *et al* 2004, ter Bekke, *et al*, 2006, van Daalen, *et al* 2005) carried out in the Netherlands and summarized in SLF 49/INF.7, the long-term probabilistic assessment performed without including any (even extremely simple) operator model may lead to overconservative results. Thus, it may be meaningful to include such considerations when customizing the standard for different sizes of ships.

5. SUPPORT OF REGULATIONS

Regulations or rules define a relationship between a criterion and a standard. When a regulation comes into effect, it does so only after a normally lengthy process that includes identification of compelling need, development, testing, proposal, notice and comment, revision, approval and adoption. Each of these stages adds to the support that is necessary for the regulation application to be consistent not only for the ships that are tested but also for those that are not tested. Hence, the regulation support includes interpretations on the implementation of the regulation as well as providing for regulatory updating to reflect changes in accepted safety level and design, construction and operation practices. In this way, regulations may be conceived as similar to published software.

There is a constant opposite pull between the need for easily amendable regulations and the need for regulatory stability to aid commerce. Outside the scope of this discussion there exist international issues that are bogged down because of the difficulties of regulatory amendment. This experience, like similar others, demonstrate that regulations should include flexible amendment procedures based on the needed support.

While the support issues are not explicitly considered in the framework of IMO's second generation intact stability criteria (Annex 1 to SLF 54/3/1), the explicit separation of criteria and standards facilitates rational and transparent organization of regulation support.

The criteria reflect current understanding of physics of stability failure expressed with the different level of complexity, depending on the level. The standards reflect the operational experience and empirical safety level. Adjusting the standard allows the regulation or rule to be “tuned” as experience is gained; thus being the principal channel of support of the second generation IMO intact stability criteria.

6. SUMMARY

The paper briefly reviews the current status of implementation of the second generation of IMO intact stability criteria, recalls its main idea and refers to the most important technical publications on the topic.

The main focus is on the consistency aspects of the implementation of the new criteria. The most important one is the consistency between the mandatory and recommendation parts – *i.e.* between the parts A and B of the 2008 IS code as the implementation of the second generation criteria is expected in part B.

The other consistency aspect is how to handle new information indicating inconsistency between Level 1 and 2 of the vulnerability criteria. The paper discusses an idea of three-step procedure that may be useful for these issues. The three steps are: establishing the ground truth (what level needs adjustment), consider adjustment through calculation method and the adjustment of the standard.

Finally, the paper discusses general issues of regulation support, concluding that the structure of the second generation intact stability criteria allows robust and transparent support through adjusting the standards as application experience is gained.

7. ACKNOWLEDGEMENTS

The portion of this paper describes work performed by NSWCCD and funded by the USCG Office of Design and Engineering Standards.

Discussions of the consistency issues on the vulnerability criteria for pure loss of stability with G. Streppel (Mayer Werft), K. Spyrou's (National Technical University of Athens), N. Umeda (Osaka University) and G. Bulian (University of Trieste) were very fruitful.

Opinions expressed in this paper are those of the authors and do not necessarily express the position of the United States Government.

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