On regulatory consistency of criteria for dead ship condition and pure loss of stability

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ABSTRACT

The paper examines different aspects of consistency between the levels 1 and 2 of vulnerability assessment within the second generation IMO intact stability criteria (SGISC). Dead ship condition and pure loss of stability failure modes are considered. The most important aspect of consistency for dead ship condition is its possible influence on integrity of the existing mandatory stability regulations, as the consistency between the levels of vulnerability criteria is in fact representative of consistency between the 2008 IS Code and SGISC. The paper describes possible solution for the between-the-levels consistency of the pure loss of stability.

The main idea is to assess the safety level of the deterministic level-1 criterion. Then, the standard for the probabilistic level-2 criterion has to be set to higher level than the assessed level 1 safety level. For this approach to work, both level 1 and 2 should use the same mathematical models of the stability failure or the model for the level 1 should be inherently more conservative compared to the level 2.

Keywords: *dead-ship condition, pure loss of stability, second generation intact stability criteria (SGISC), vulnerability criteria, Weather Criterion 2008 IS Code.*

1. INTRODUCTION

The tiered sctucture of the second generation intact stability criteria (SGISC) in the final stages of development by the International Maritime Organization (IMO) allows effective management of the complexity of calculations. If the vulnerability of a ship to a particluar mode of dynamic stability failure is not indicated on the lower lever, there is no need for further assessment. On the other hand, the criteria for the same mode of failure must be consistent for the different levels: if the level one assessment shows no vulnrability, so also should be the result of the level 2 assessment.

Unfortunately, it is not always the case. Since the correspondence group on intact stablity has started systematic sample calculations, the reports on the inconsistencies were fairly frequent as well the attempts to resolve these inconsitencies, e.g. see Tompuri, *et al.* (2017).

This paper considers between-the-level inconsistency for both the dead ship condition and the pure loss of stability modes of failure, continuing and extending the approach formulated by the authors in the previous workshop (Peters & Belenky, 2017).

2. DEAD SHIP CONDITION

There are several aspects of inconsistency of vulnerability criteria for dead ship conditions as described in Annex 3 SDC 6/WP.6: application consistency, probabilistic consistency and physical consistency.

Application Consistency

The dead ship condition is the only mode of failure included in the second generation intact stability criteria that also is covered in Part A of the 2008 IS Code. The severe wind and rolling criterion (weather criterion), described in the section 2.3 of the 2008 IS Code has loading condition limitations for use of the formula and table for calculation of the roll back angle in the paragraph 2.3.5. These limitations are described in the paragraphs 2.3.5 and include breadth to draft ratio, KG to draft ratio and natural roll period.

To address these applicability limitations, MSC Circular 1200 (MSC.1/Circ.1200) describes an alternative way to obtain the roll-back angle through the performance of model tests. However, the assessment of the weather criterion is unchanged.

The level 1 vulnerability criterion uses the extended roll period table from MSC.1/Circ.1200, so the limitation for two other parameters remain to be addressed at the level 2 assessment, which is a probabilistic long-term criterion based on an averaged upcrossing rate. As the level 2 assessment does not provide the roll back angle outside the applicability range of the weather criterion, the level 2 assessment is essentially an alternative outside of the current stability regulatory framework.

Probabilistic Consistency

Consistency between the level 1 and level 2 criteria has been considered, apart from the applicability and general regulatory issues. As the level 1 vulnerability criterion is the weather criterion with an extended table for the roll period, the consistency problem essentially focuses on the probabilistic interpretation of the weather criterion. The problem attracted attention of Naval Architects long ago (e.g. Dudziak & Buczkowski, 1978) abridged version available in (Belenky & Sevatsianov, 2007).

One of the authors touched this problem in an attempt to assess probability capsizing of a series of ships in KG-critical condition based on the criteria to be included in the 2008 IS Code (Belenky, 1995). With some surprise at the time, the value of the capsizing probability had shown significant variation. This outcome meant that compliance with the weather criterion does not necessarily mean that a probability of stability failure will fall within a certain range.

Annexes 1, 7 and 12 of IMO document SDC 5/INF.4 describe a probabilistic study, that addresses the inconsistency between the levels of vulnerability criteria for dead ship condition.

A data sample satisfied the following conditions:

- Weather criterion is fully applicable: B/d≤3.5, $0.3 \leq KG/d - 1 \leq 0.5$ and T≤20 s.
- Area a exactly equals area b or the static angle equals to 16 degrees.

This data sample can be created by using a ship loading condition within the applicability range of the weather criterion and simultaneous adjusting the KG value and windage area to achieve the equivalency. The sample contained 74 points (i.e., loading conditions). Fig. 1 shows a histogram of the level 2 criteria value, computed as described in Annex 3 of SDC 6/WP.6. The "weighted data" refers to the adjustment of statistical weight to match the distribution of ship lengths in the world fleet.

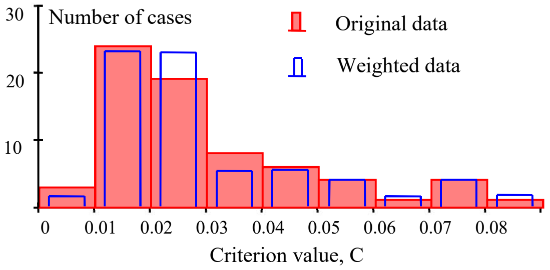

Figure 1: Distribution of the criterion value C based on original and weight data

The inconsistency between the levels manifests itself in the form of a distribution, while consistency would look like a deterministic function.

The histogram in Fig. 1 can be approximated with log-normal distribution and then used to set the standard with specified "probability of inconsistency" that may be treated in a similar way as safety level, see for details Annexes 7 and 12 of SDC 5/ INF.4.

Physical Consistency

The second possible source between the levels is the difference in a mathematical model describing stability failure in a dead ship condition. Annex 15 of SDC 4/INF.4/Add.4 and Annex 1 of SDC 5/ INF.4 contain formulations of an alternative level 2 criterion, which uses the same general scheme of application of the weather criterion, but in which the input parameters are given a probabilistic interpretation, see Fig. 2.

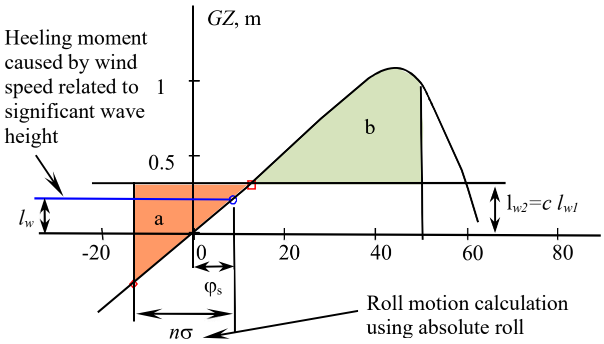

Figure 2: On the formulation of the alternative level 2 vulnerability criterion

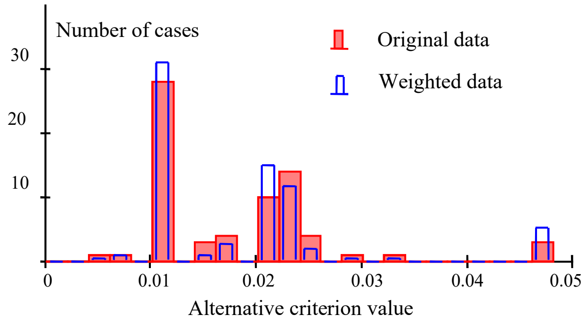

Figure 3: Distribution of the alterative criterion value based on original and weight data

The alternative criterion helped to decrease the amount of inconsistency, but did not resolve it completely. Being applied to the data sample, described in the previous subsection, it still produced the distribution, see Fig. 3. Its “randomness”, however seems to be decreased, compare to the one shown in Fig. 1.

Calculations, presented in Annex 12 of SDC 5/INF.4, have shown that a standard has to be largely non-conservative, unless some degree of inconsistency is allowed. Having in mind that this inconsistency is associated with mandatory criteria, this approach is not attractive. Thus, it makes sense to change the role of the level 2 vulnerability criteria to be considered as an independent assessment of safety level in dead ship condition.

3. PURE LOSS OF STABILITY

Now we consider a theoretical reason for inconsistency between levels 1 and 2 of vulnerability criteria for pure loss of stability. The level 1 criterion is essentially a GM value approximated for a wave of steepness of 0.0334 in which the wave length is considered to be equal to the ship length (Paragraph 1.2.2 of Annex 3 of SDC 6/WP.6). The level 2 criterion is an estimate of a long-term probability that the static angle caused by a specified heeling moment or angle of vanishing stability to exceed required boundary values. Both angles are computed for worst GZ curve during a wave pass. Thus, level 1 criterion is deterministic and the level 2 criterion is probabilistic. This difference, by itself, can lead to an inconsistency between the levels, unless special provisions are considered.

Probabilistic Consistency

To gain insight into the probabilistic aspect of inconsistency, we consider a notional pure loss of stability criterion: a static or dynamic angle of heel achieved under a specified heeling moment with the worst GZ curve during the passing of a longitudinal wave (i.e., a wave pass). This criterion is applied for both level 1 and level 2. To compute this criterion, one needs to know wave length and wave height.

Following the procedure agreed for the level 2 vulnerability criteria for the pure loss of stability failure mode, as described in draft explanatory notes (paragraph 7.3.1 of Annex 19 of SDC 5/INF.4/Add.1), Grim’s effective wave is used to represent stability variation in a particular sea state. As the length of the Grim’s effective wave is equal to ship length, there is only one random variable left – the wave height. Thus, for a given ship length, each cell of a wave scatter table (e.g IACS Recommendation 34) corresponds to a particular value of the effective wave height, H_{eff}:

$$H_{eff} \approx 5.97\sqrt{V_H} \qquad (1)$$

V_H is the variance of the effective wave:

$$V_H = \int_{\omega_1}^{\omega_2} RAO_{eff}^2(\omega) s(\omega|H_S,T_z) d\omega \qquad (2)$$

Here, $s(\omega|H_S,T_z)$ is a spectral density of the wave elevations, ω is a frequency, $\omega_{1,2}$ are the limits of integration, H_S is the signficiant wave height, T_z is the mean wave zero-crossing period and RAO_{eff} is the RAO of the effective wave amplitude:

$$RAO_{eff}(\omega) = \frac{\omega^2 Lg^{-1} \cdot \sin(0.5\omega^2 Lg^{-1} \cdot)}{\pi^2 - 0.5\omega^2 Lg^{-1}} \qquad (3)$$

where L is a ship length and g is gravity acceleration.

As each cell of the scatter also corresponds to a statistical frequency, one can easily compute an estimate of the cumulative distribution function (CDF) by sorting the effective wave heights in ascending order and integrating all the statistical frequencies below the current value:

$$P(H_{eff}) = P(H_S, T_z) \qquad (4)$$

$$P_1(H_{eff}) = sort(P(H_{eff}), H_{eff}) \qquad (5)$$

$$CDF(H_{eff}) = \int_0^{H_{eff}} P_1(h)\, dh \qquad (6)$$

The CDF, shown in Fig. 4, also can be interpreted as a dependence between the safety level for the level 1 criterion and a wave steepness for a ship with length of 260 m. The safety level of a deterministic criterion is a probability that a ship satisfying this criterion will nevertheless suffer from the failure. As the ship stability is a subject of random meteorological factors, the safety level theoretically cannot be zero.

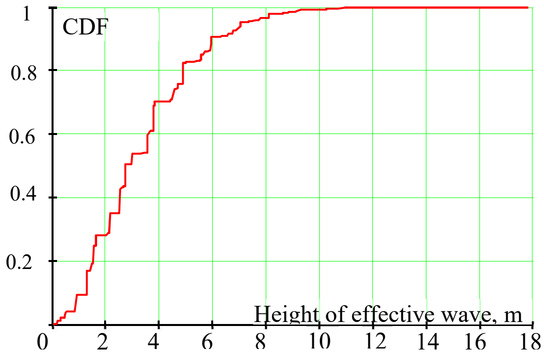

Figure 4: Estimate of CDF of the effective wave height computed for ship length L=260 m.

For example, we set the safety factor to 1%. Then, the effective wave height corresponding to the 99 percentile equals approximately 9.2 m for a ship length of 260 m. Thus, the steepness of the effective wave is 9.2 m /260 m = 0.035. If the ship satisfies the level 1 criterion for the wave steepness 0.035, there is only 1% probability over the lifetime that the stability will not be sufficient to withstand the pure loss of stability failure. Keeping the safety level constant, one will get another wave stiffness for another length, coming to an idea of the level-1 wave steepness that depends on a ship length. Originally, this idea was proposed in SDC 5/6/5.

It is assumed here that the heeling moment is created by wind. The relation of mean wind speed U_{Wm} is taken from paragraph 4.3.2.2 of Annex 3 of SDC 6/WP.6:

$$U_{Wm} = \left(\frac{H_S}{0.06717}\right)^{2/3} \qquad (7)$$

Then the aerodynamic pressure p_A can be computed as:

$$p_A = \frac{\rho_A U_{Wm}^2}{2} \cdot C_m \qquad (8)$$

where C_m is wind heeling moment coefficient. Its value is taken as 1.22 from paragraph 4.3.2.2 of Annex 3 of SDC 6/WP.6, while ρ_A is density of air.

This pressure is also a random variable, as it depends on the significant wave height. As each value of significant wave height in the scatter diagram has an associated statistical frequency, one can compute the CDF for the significant wave height:

$$CDF(H_S) = \int_0^{H_S} P_H(h)\, dh \qquad (9)$$

P_H is a statistical frequency of the significant wave height, available from a wave scatter table (e.g., IACS Recommendation 34). The CDF of the wind pressure is essentially a rescaling of the CDF (9) with the formula (8), see Fig. 5. The values of mean wind pressure can be expressed as a function of the safety level:

$$SL = 1 - CDF \qquad (10)$$

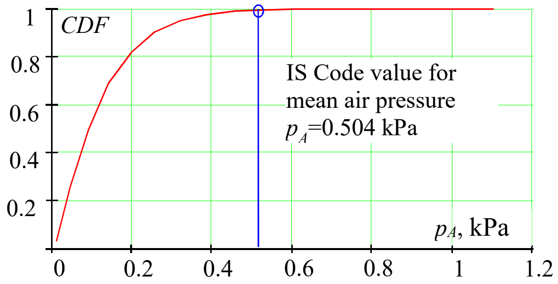

Figure 5: CDF for mean wind pressure

Fig. 5 shows the pressure value of 0.504 kPa that is used in the weather criterion in section 2.3 of the 2008 IS Code. The CDF for this value is interesting because it is actually quite high 0.993, when using the scatter diagram from IACS Recommendation 34, so that the safety level is only 0.007.

The setting the safety level for the level 1 criterion will define both the wave steepness and the wind pressure. Beyond these, there are no more random parameters involved in the level 1 criterion. Now, if the standard for level 2 criterion is established above the safety level for the level 1 criterion, the criteria always will be consistent between the two levels.

Physical Consistency

The second reason for the inconsistency between the level of the pure loss vulnerability criteria is actually the oversimplification of the level 1 criteria. The reason is that GM alone does not well characterize stability at large heel angles (a well known fact among naval architects). Thus, the level 1 criteria should include enough information to characterize stability at large heel angles. At the same time, it should be more conservative while perhaps less accurate than the level 2 criterion.

This idea can be implemented by formulating the level 1 criterion for the GZ curve in the worst possible position of ship on a wave (which is not necessarily when the midship section is located at exactly at the wave crest). Then, the level 2 criteria can be defined based on the stability variation throughout a complete wave pass (see Fig. 6). The conservatism of the level 1 criterion is then ensured by the simple fact that the worst GZ curve does not last too long during a wave pass.

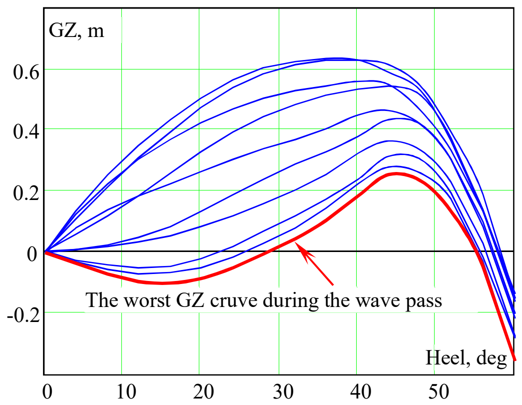

Figure 6: GZ Curve During Wave Pass, C11-class containership, wave steepness 0.012, KG=19.92 (IS Code critical)

Indeed, in this consideration, the level 1 criterion becomes more complex compared to a GM based-formulation that has been in consideration since 2011, including as currently contained in Annex 3 of SDC 6/WP.6 (Peters, *et al.* 2011). The new level 1 criterion proposal requires computation of GZ curve over the wave pass; these calculations do require a computer program with software suited for this purpose. This approach, however, seems to be inconsistent with the original intention (Peters *et al.* 2011) to limit level 1 efforts to spreadsheet-type calculations. However:

- GZ curves in longitudinal waves can be computed with most standard ship hydrostatic software. The level 1 criterion without any simplification can still be applied using a spreadsheet if the worst-case GZ curve during wave pass can be produced by the standard ship hydrostatic software;
- It may be possible to approximate the worst GZ curve during pass with the worst GM during the wave pass. If this will be found possible, the level of complexity of the proposed level 1 criterion will be on the same level as originally envisioned.

Consistent Criteria

Following the concept of the weather criterion, we consider a dynamic angle as a level 1 criterion. The GZ curve is selected as the worst GZ curve during the wave pass (see Fig. 3). The GZ curves in waves are computed for the effective wave height, corresponding to the agreed safety level that must be below the standard accepted for the level 2 criterion. Currently, the value of the level 2 standard equals to 0.06 per paragraph 1.3.1 of Annex 3 of SDC 6/WP.6.

If the safety level for the level 1 criterion is taken as 0.02, the steepness of the effective wave for a 260 m long ship is 0.0328, which is slightly lower than the 0.0334 proposed in Annex 3 of SDC 6/WP.6.

The mean wind pressure, corresponding to the safety level of 0.02 is $p_A = 0.407$ kPa (see Fig.2 and subsection 3.1). A few more assumptions are needed to compute the heeling lever:

The pure loss of stability failure mode occurs in stern quartering and following waves in which it will be too conservative to consider beam wind: it is assumed that the wave has a $\beta = 20$ degrees angle with ship heading .

Little roll motion is expected in following and stern quartering seas and, in this case, the roll back angle may be assumed to be zero.

No developed wind drift is assumed because the relative wind angle is small (20°), which means that the hydrodynamic resistance to wind drift is also small. This has the effect of making the lever of the wind force as the distance from the waterline to the center of wind pressure, which, of course, is different from the assumption made in the weather criterion.

Following the weather criterion assumption (see paragraph 2.3.2 of the 2008 IS Code), the sudden increase of the wind force (i.e., the sustained gust) above the mean value is taken as 1.5.

As a result of these assumptions, the lever of the heeling moment in the considered loading condition is computed as follows:

$$l_w = 1.5 \cdot \frac{p_A \cdot A \cdot Z}{g \cdot \Delta} \cdot \sin(\beta) \qquad (11)$$

where A is the projected lateral area of the ship and deck cargo above the waterline, Z vertical distance from the center of A to the waterline, Δ is mass displacement in metric tonnes, and g is the gravitational acceleration.

The level 1 criterion can be formulated as follows

$$\phi_d \leq R_{PL2} \qquad (12)$$

where ϕ_d is a dynamic angle of heel calculated by equalizing area a and area b, as shown in Fig. 7. R_{PL2} = 15 degrees for passenger vessels and 25 degrees otherwise.

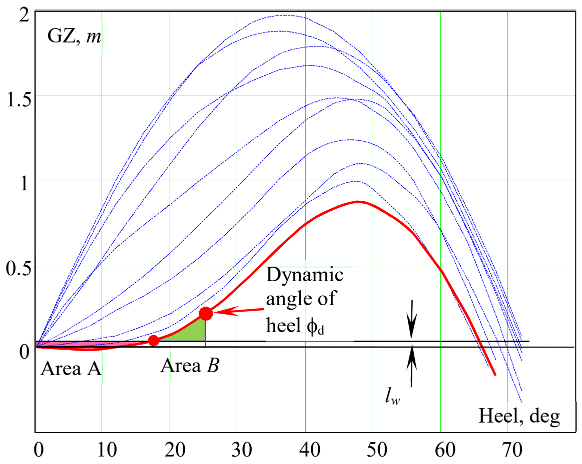

Figure 7: GZ Curve During Wave Pass, C11-class containership, KG=18.55 wave steepness 0.0328

To be consistent, the level 2 criterion is formulated for the same scenario, but takes into account time, i.e. that the GZ curve changes during the wave pass and does not remain at the worst case throughout the wave pass. Computation of the dynamic angle is carried out by numerical integration of the equations of motions, describing surging *x* and rolling ϕ:

$$\begin{cases} (\Delta + A_{11})\ddot{x} + R_x(\dot{x}) - T(\dot{x}, n) = F_x(x,t) \\ (I_x + A_{44})\ddot{\phi} + R_\phi(\dot{\phi}) + \Delta g GZ(\phi, x) = \Delta g l_w \end{cases}$$

where, I_x is the moment of inertia in roll; A_{11} and A_{44} are the added mass in surge and roll, respectively; R_x is the ship resistance in calm water; *T* is the ship thrust, achieved with commanded number of propeller revolutions, *n*; F_x is the Froude-Krylov wave force in direction of surge and R_ϕ is the roll damping.

The GZ curve in waves is precomputed and then is interpolated for the particular values of roll angle and position on the wave – see also paragraphs 3.3.2.4 of Annex 19 of SDC5/INF.4/Add.1, while the description of the calculation of the Froude-Krylov force can be found in (Belenky, *et al.* 2019)

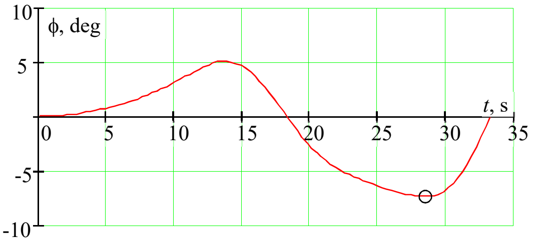

Figure 8: Roll during the Wave Pass; C11-class containership, KG=18.55 m wave steepness 0.034

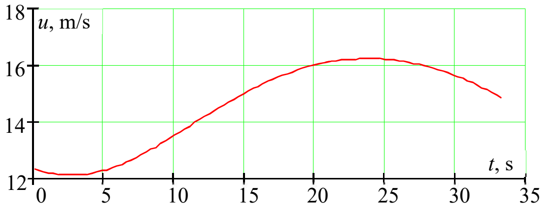

Figure 9: Surging Velocity during the Wave Pass; C11-class containership, KG=18.55 m wave steepness 0.034

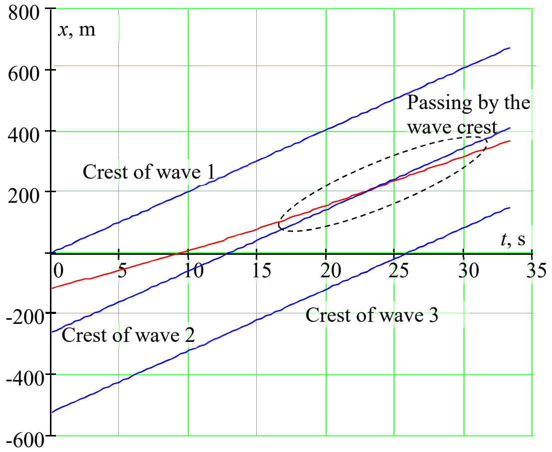

Figure 10: Distance travelled during the wave pass; C11-class containership, KG=18.55 m wave steepness 0.034

A numerical integration is performed for the duration of one wave pass and largest encountered roll angle for that one wave pass is recorded, see the example in Fig. 8-10.

Sample Calculations: Consistency

The numerical demonstration of consistency of the considered criteria is presented in Table 1. Calculations were performed for a RoPax ship, for which the particulars are presented in Table 2.

Table 1 is configured in order to test and compare the consistency of the four criteria, which are presented in four numbered columns. The base loading condition is the maximum KG for which the criteria of the 2008 IS Code are satisfied (column 1) – termed the "limiting 2008 IS Code critical condition". Column 2 shows the level 1 criterion as proposed in Annex 2 IMO SDC 6/WP.6 (column 2: "simplified GM"); column 3 shows the previously proposed level 1 criteria that involved the direct calculation of GM in a longitudinal wave; and column 4 that presents the dynamic angle criterion considered above in 3.3 for level 1.

Table 1: Considered Criteria for Sample RoPax Ship

Criteria →		2008 IS Code	Simpl. GM	Direct calc. for GM in waves	Considered dynamic angle criteria
Column →		1	2	3	4
ΔKG, m		0	-1.33	-0.147	-0.692
Level 1	Simpl. GM, m	-1.28	0.05	-1.134	-0.589
	Direct calc. for GM in waves, m	-0.097	1.23	0.05	0.596
	Considered criteria	44.3°	6.3°	37.6°	15.0°
Level 2	CR1	0	0	0	0
	CR2	0.537	$2\ 10^{-4}$	0.366	0.055
	Considered criteria	0.173	0	0.142	$8.28\ 10^{-3}$

Table 2: Principal Particulars for a Sample RoPax Ship

Length BP, m	140.4
Breadth molded, m	20.27
Draft amidships, m	5.77
KG (critical 2008 IS Code), m	9.622
GM (critical 2008 IS Code), m	0.702
Speed, kt	19
Windage area, A, m^2	2,739
Center of pressure above WL, h, m	9.92

The second line shows the required change of KG relative to the 2008 IS Code critical condition KG. This value also shows how conservative the criteria are relative to each other by indicating the amount of a decrease in KG needed to satisfy the other criteria in columns 2 through 4. As expected, the ”simplified GM” criterion is the most conservative, while the ”direct GM” is the least conservative. The considered dynamic angle criteria is about half way between columns 2 and 3.

Inconsistency can be observed in column 3. Here, the level 1 criterion is a critical condition: GM = 0.05m, while the level 2 criterion indicates vulnerability with a significant margin $CR_2 = 0.366$.

On the contrary, column 4 shows consistency for the dynamic angle criteria. The level 1 criterion is shown to be critical: a dynamic angle equal to 15 degrees, while the level 2 criterion is shown to pass with significant margin: $0.0083 < 0.06$.

The currently proposed criterion in column 2 of Table 1, “the simplified GM”, is also consistent, but the required KG must be reduced about 0.6 m from that shown for the considered criteria in column 4.

Sample Calculations: Separation Capability

To test the separation capability of the considered criteria, we consider the C11 container carrier (see Table 3) as a typical representative of the “old” post-panamax container ship. Built in the early 1990s, this class is known, *inter alia*, for significant variation of the GZ curve in waves leading to parametric roll (France, *et al.* 2003). We are not aware of any potential issues of pure loss of stability of any ship in this class, while they have been in service for about 30 years. Results of the calculations are presented in Table 4.

On the other hand, the observed vulnerability to pure loss of stability for a RoPax carrier may be well justified; as this ship is similar to a ship that suffered from a stability accident that may be attributed to pure loss of stability (Maritime New Zealand, 2007).

Table 3: Principle Particulars for a C11 Class Containership

Length BP, m	262
Breadth molded, m	40
Draft amidships, m	11.5
KG (critical 2008 IS Code), m	19.93
GM (critical 2008 IS Code),m	0.38
Speed, kt	24
Windage area, A , m2	7,887
Center of pressure above WL,h, m	14.73

The ability to differentiate the C11-class containership with the RoPax carrier is a good “stress-test” for the vulnerability criteria for pure loss of stability. To complete this test, the critical ΔKG values are also computed for the proposed level 2 criteria (as described in Annex 3 of SDC 6/WP.6) and the level 2 criteria, considered in this paper, see Table 5.

Both sample ships were found to be vulnerable to pure loss of stability by both the criteria in 2008 IS Code KG-critical condition, see column 1 in Tables 1 and 4.

Table 4: Considered Criteria for a C11 Class Containership

Criteria →		2008 IS Code	Simpl. GM	Direct calc. for GM in waves	Considered criteria
Column →		1	2	3	4
ΔKG, m		0	-3.69	-1.578	-1.374
Level 1	Simpl. GM, m	-3.643	0.05	-2.065	-2.269
	Direct calc. for GM in waves, m	-1.528	2.165	0.05	-0.153
	Considered criteria	-	1.7°	18.1°	25°
Level 2	CR1	0.057	0.057	0.057	0.057
	CR2	0.849	0	0.086	0.0128
	Considered criteria	0.18	0	$6.05\ 10^{-4}$	$6.58\ 10^{-5}$

Table 5: Critical KG for Level 2 Criteria

	Ropax R_{PL2}= 15°	C11 w/o weathertight volume R_{PL2}= 25°
Proposed Level 2 Criteria (Annex 3 of SDC 6/WP.6)	-0.39	-0.81
Considered Level 2 Criterion (this paper)	-0.41	-0.22

However, the minimum operational GM for C11-class containership is about 1 m (likely due to damage stability criteria requirements). The value of 0.9 m is the smallest GM mentioned by France, *et al.* (2003). As seen in the Table 5, the level-2 criterion from Annex 3 of SDC 6/WP.6 suggests that the GM for the C11 should be 1.19 m in order to avoid pure loss of stability failure.

The proposed level 2 criterion requires only GM = 0.6 m, which includes the entire operational range of GM, which indicates that the C11 is not vulnerable to pure loss of stability, which does not contradict existing operational experience and shows some separation capability of the proposed criterion.

4. SUMMARY AND CONCLUSIONS

The consistency of vulnerability assessments between levels 1 and 2 of the dead ship condition and pure loss of stability failure modes have been considered.

The level 2 vulnerability criterion for the dead ship condition is a probabilistic long-term criterion, which assesses dynamic stability in waves with an upcrossing rate or probability of upcrossing during a given exposure time. The level 1 vulnerability criterion replicates the weather criterion with an extended table for the natural roll period. Following other studies, it was found that consistency between the two levels cannot be guaranteed and that a certain probability of inconsistency has to be accepted.

As currently formulated, the level 2 criterion does not provide the roll back angle for the weather criterion, thus it cannot be used to extend applicability of the weather criterion within the current stability regulatory framework. However, it can be used for independent assessment of the safety level in dead ship conditions.

The consistency of vulnerability assessments between levels 1 and 2 for the pure loss of stability failure mode can be achieved by satisfying two conditions:

- Level 1 and 2 criteria use same mathematical model (like a dynamical angle of heel) or mathematical level for level 2 is less conservative compare to level 1 (e.g. level 1 is a dynamical angle computed with for the worst GZ curve during the wave pass, while level 2 accounts for variation of the GZ curve during the wave pass);
- Safety level for the deterministic level 1 criterion is set below the standard for the probabilistic level-2 criterion.

The possibility of considering consistent vulnerability criteria for pure loss of stability is suggested as a possible alternative for the future refinement of the second generation intact stability criteria.

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