Application of 2nd Generation Intact Stability Criteria on Naval Ships

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ABSTRACT

The second generation intact stability criteria are currently under finalization and validation at the IMO. These criteria are organized in five stability failure modes and three levels of vulnerability assessment in each failure mode. Although this new regulation will not apply to naval ships, it is interesting to investigate the behavior of this vessel typology as well, due to their geometry and typical Froude number. This paper deals with of the pure loss of stability and parametric roll phenomena. Level one and level two vulnerability criteria for three naval ships of different size (helicopter carrier, destroyer, offshore patrol vessel) are applied. Results show an overall satisfactory behavior of the three ships investigated by the new regulation, for both failure stability modes.

Keywords: *Parametric Roll, Pure Loss of Stability, 2nd Generation Intact Stability Criteria, Naval Ship*

1. INTRODUCTION

The second generation intact stability criteria are currently being finalized and validated at the IMO. These new criteria are organized in five stability failure modes: parametric roll, pure loss of stability, dead ship condition, surf-riding/broaching and excessive acceleration. In each failure mode, three levels of assessment are defined. The first vulnerability level criterion is set in order to require simple and approximate evaluations and entailing therefore a larger "safety margin". The second level in general is based on more accurate computations associated with a statistical averaging of the phenomena. Safety margins are accordingly tuned. The third level should consist of a direct assessment using robust and comprehensive numerical simulations and presumably allowing more awareness about safety margins. This paper deals with the criteria version for Pure Loss (PL) of stability and Parametric Roll (PR) defined during the second and third sessions of Sub-Committee on Ship Design and Construction of the IMO (SDC 2/WP.4 and SDC 3/WP.5). These new criteria assess in particular the wave profile effect of ship stability. Wave cases to be considered are based on a wave scatter diagram. For unrestricted sailing area, the new regulation imposes the one included in the IACS Recommendation No 34 (2001) corresponding to the Northern Atlantic. The new regulation allows the use of another wave scatter table if the ship is sailing in a restricted area.

Accidents caused by these failure modes may be fatal (Kaufmann, 2009) or may cause significant financial loss (France, *et al.* 2001) but they are fortunately rare. The number of naval ships in service is significantly smaller than the number of merchant vessels (and their time at sea is smaller too), therefore, form the risk point of view, it could be less interesting to address such kind of problems. However it cannot be excluded in principle that naval ships are not vulnerable to such stability failures. Although the new regulations are not intended for naval ships, it seems interesting to assess the outcome of their applications. In fact the hull geometry and the speed of naval ship typology are in principle a remarkable combination worthy of attention.

The goal of this study is to determine the vulnerability of three representative naval ships to the pure loss of stability and parametric roll failure modes as assessed by the new level one and level two vulnerability assessment criteria. The ships are chosen for their variety of typology and size: a helicopter carrier, a destroyer and an offshore patrol vessel. The principle consists in comparing the KG_{max} curves and the relevant GM_{min} associated with the new criteria to those associated with the current IMO criteria (IS Code 2.2 and 2.3, IMO, 2009) and French military criteria (DGA, 1999). Methods used to compute the new criteria and the associated KG_{max} curves are described by Grinnaert, *et al.* (2016).

2. PRESENTATION OF SHIPS

The main particulars of the three naval ships are listed in Table 1.

The first ship is the well-known former French Helicopter Carrier *Jeanne d'Arc*. She is known as non-vulnerable to heavy seas after serving for over 45 years as trainee ship on all seas around the World. Her data have been provided by the French Historic Service of Defense (SHD, 1957). Her numerical model is shown in Figure 1.

The second ship is the David Taylor Model Basin hull number 5415. She is presented by Moelgaard (2000). Imaginary superstructures inspired by those of the DDG-51 *Arleigh Burke* are added to her model to allow the computation of weather criteria of current IMO and military regulations. The data of this ship are available on the www.simman2008.dk website. Her hull is shown in Figure 2

The third ship is representative of a 1500-ton (full load) Offshore Patrol Vessel. Her hull is shown in Figure 3.

			Jeanne d'Arc	DTMB 5415	OPV
Length BP	L_{PP}	m	172	142	80.6
Breadth	B	m	24	19.06	9.6
Draft	d	m	6.5	6.15	3.37
Displacement	Δ	t	11768	8634	1250
Froude number	F_n	-	0.338	0.413	0.457
Bilge keels length	L_{bk}	m	55.7	35.7	24.0
Bilge keels breadth	B_{bk}	m	1.2	0.55	0.30
Metacentric height	GM	m	1.5	1.5	1.15

Table 1: Main particulars of ships

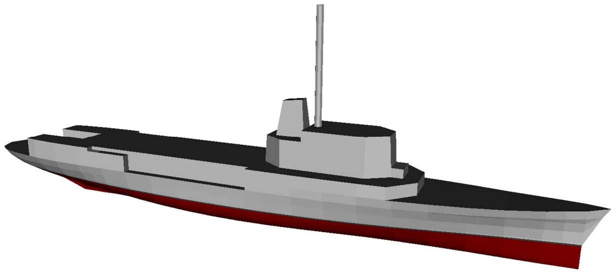

Figure 1: Numerical model of the Helicopter Carrier *Jeanne d'Arc*.

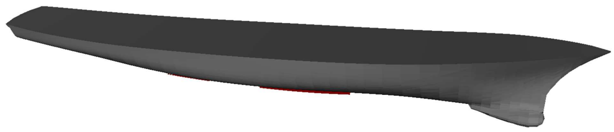

Figure 2: Hull of the DTMB-5415.

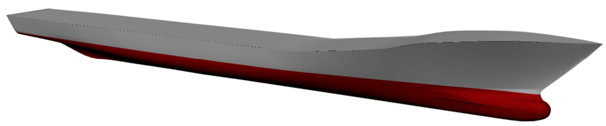

Figure 3: Hull of the Offshore Patrol Vessel.

3. PURE LOSS OF STABILITY

Physical Background

When a ship is sailing in head or following waves, the immersed volume distribution changes due to the wave profile This causes variations of restoring moment which may be significant if the wave length is comparable to the ship length and if the wave steepness is high. In turn this might imply large heel angle or capsize if GZ curve weakness lasts for a long time. Thus, ships sailing at high speed in following waves may be vulnerable to this failure mode.

Presentation of Criteria

The pure loss of stability criteria apply to the ships having a Froude number larger than 0.24. All the three naval ships studied in this paper are well over this threshold.

The level one criterion requires that the minimum metacentric height in waves is larger than 0.05 m. Two methods are proposed to calculate its value. The first method considers a parallel waterplane at lower draft. It may be implemented with the hydrostatic table. The second method considers the minimum GM for 10 positions of wave crest along the ship; the wavelength λ is the ship's length and wave height is 0.0334λ.The level two criterion consists of a statistical approach aimed to weight each wave scenario on the basis of a wave scatter table. For each wave derived from the table, the criterion considers the angle of vanishing stability and the angle of stable equilibrium under a steady heeling lever which value depends on both the wave and ship speed. In all these calculations the wave length is assumed equal to the ship length.

For more details, please refer to the new regulation (SDC 2/WP.4 and SDC 3/WP.5).

Results

The KG_{max} curves associated with level one and level two criteria of pure loss of stability for the three naval ships are shown in Figure 4 to Figure 6. The curves associated with the level one criterion are drawn in blue (first method) and red (second method). The curves associated with the second level are drawn in green. The grey curves indicate the KG_{max} associated with the current IMO IS Code regulation (dot line) and the current DGA French military regulation (dash line). The light blue curves give the height of the transverse metacenter and can be interpreted as zero-GM curves. We can observe following facts:

1) The two possible versions of level one give significantly different results for all ships. This point is also observed on merchant ships (Grinnaert, *et al.*, 2016).

2) The first method of level one is extremely conservative and require a large metacentric height which may conflict with the excessive acceleration criteria. The end-of-life loading condition of the FS *Jeanne d'Arc* (12,000 tons, GM=1.5m) and the representative loading condition of the Offshore Patrol Vessel do not fulfill the condition.

3) The level two is more conservative than the second method of level one. This point, which is unexpected and undesirable in the regulation, is observed also for some merchant ships (Grinnaert, *et al.*, 2016).

4) Since the level one curve (red curve, level one-second method) associated with pure loss of stability criteria is located above the curve associated with the military regulation, all the assessed ships can be deemed in principle as non-vulnerable to this stability failure mode by the new regulation. In case of the Destroyer and the Patrol Vessel this is true also with a rather considerable margin.

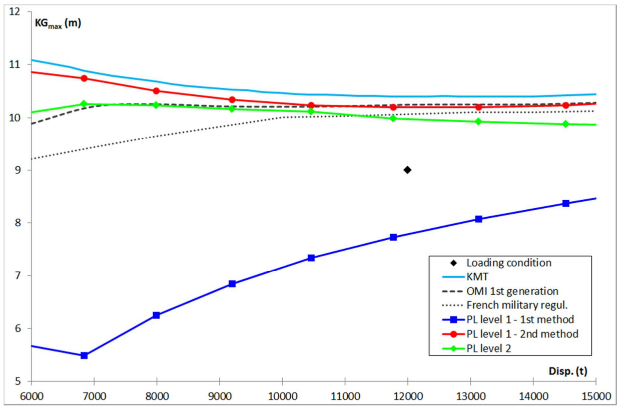

Figure 4: KG_{max} curves associated with the pure loss of stability criteria for the Helicopter Carrier *Jeanne d'Arc*.

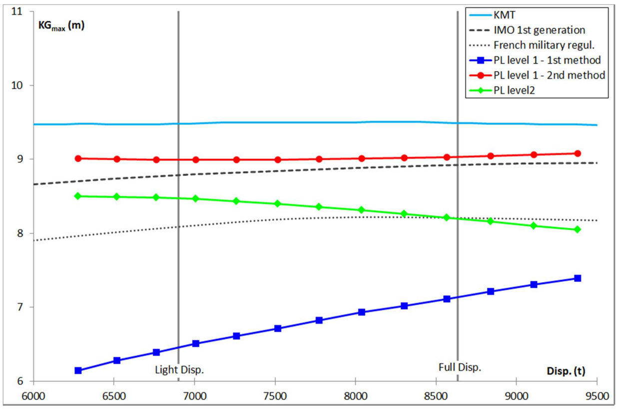

Figure 5: KG_{max} curves associated with the pure loss of stability criteria for the DTMB-5415.

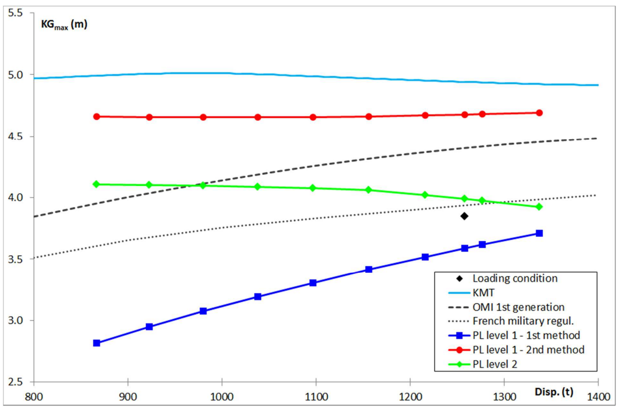

Figure 6: KG_{max} curves associated with the pure loss of stability criteria for the Offshore Patrol Vessel.

4. PARAMETRIC ROLL

Physical Background

Parametric roll is due to the repetition in time of variation of ship restoring moment in waves. It occurs when the wave encounter frequency is approximatively twice the ship's roll natural frequency. This failure mode is mostly observed on container ships (France, et al., 2001) because the classical hull shape of these ships may generate a large restoring moment variation. Increasing roll damping by providing large bilge keels is an efficient way to prevent parametric roll.

Presentation of Criteria

The level one criterion requires that the non-dimensional GM variation in waves (ΔGM/GM) is lower than a coefficient R_{PR} witch value is between 0.17 and 1.87, largely depending on bilge keels area. Two methods are proposed to calculate the value of ΔGM. The first method considers parallel waterplanes at higher and lower drafts. The second method considers 10 positions of wave crest along the ship, the wavelength λ is the ship's length and wave height is 0.0167λ. ΔGM is half the difference between the maximum and the minimum metacentric heights.

The level two criterion is made of two checks. The first check (C1) considers the GM variation in waves and the reference speed corresponding to the parametric resonance using a weighted average approach based on a table of 16 waves defined in terms of length, height and weight. The second check (C2) considers the maximum roll angle in waves and each wave scenario is weighted from the Wave Scatter Diagram; the final result is a combination for 7 different ship speeds corresponding to head and following seas. The maximum roll angle is computed by solving the one-degree-of-freedom differential equation of parametric roll.

For more details, please refer to the new regulation (SDC 2/WP.4 and SDC 3/WP.5).

Results

The KG_{max} curves associated with level one and level two criteria of parametric roll for the three naval ships are shown in Figure 7 to Figure 9. The curves associated with the level one criterion are drawn in blue (first method) and red (second method). The curves associated with the second level are drawn in green (C1 in plain line, C2 in dash line). The grey curves indicate the KG_{max} associated with the current OMI regulation (dot line) and French military regulation (dash line). The light blue curves give the KMT or zero-GM. We can observe following facts, some of which are similar to those observed in pure loss of stability:

1) The two possible versions of level one yields significantly different results for all ships.

2) The first method of level one is extremely conservative and requires a large metacentric height which may conflict with the excessive acceleration criteria. The end-of-life loading condition of the FS *Jeanne d'Arc* does not fulfill the condition. The representative loading condition for the Patrol Vessel is compliant but practically positioned on the curve.

3) The KG_{max} curves associated with the second level of vulnerability assessment, in the C2 check version, is coincident with the KMT curve for the Helicopter Carrier. This means that parametric roll never occurred during the one-DOF simulation.

4) The curves associated with the level one second method and both checks of level two are located above the curve associated with the current military regulation. Thus, all assessed ships can be deemed as non-vulnerable to the parametric roll by the new regulation.

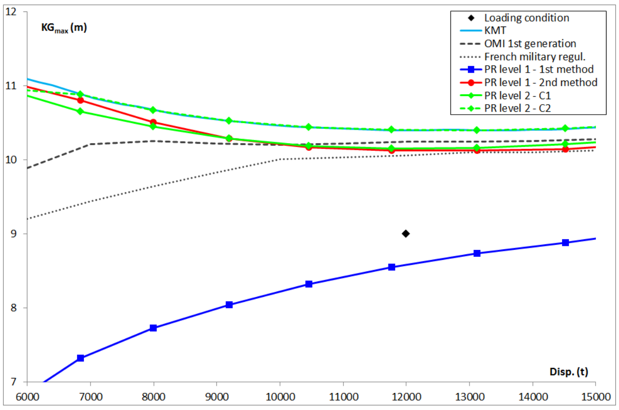

Figure 7: KG_{max} curves associated with the parametric roll criteria for the Helicopter Carrier *Jeanne d'Arc*.

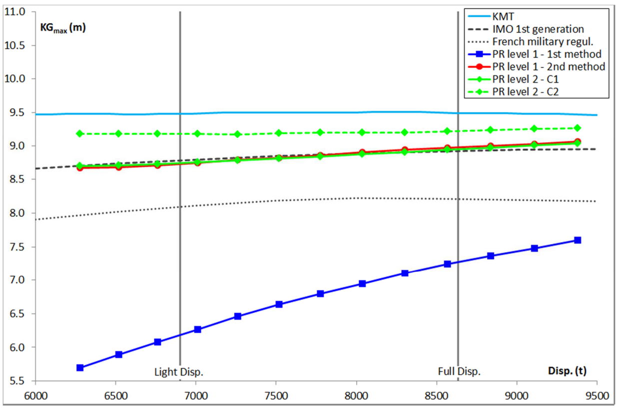

Figure 8: KG_{max} curves associated with the parametric roll criteria for the DTMB-5415.

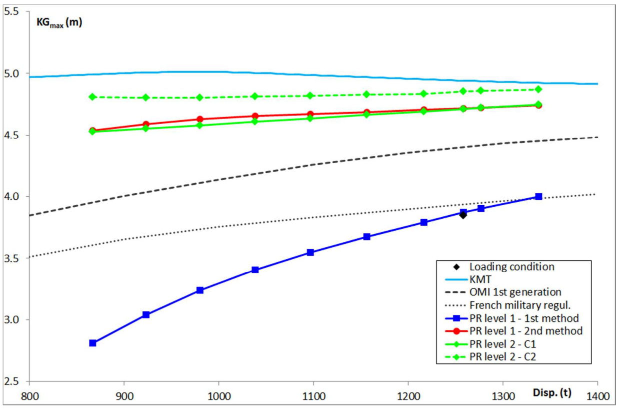

Figure 9: KG_{max} curves associated with the parametric roll criteria for the Offshore Patrol Vessel.

5. CONCLUSION

The computation of KG_{max} curves associated with level one and level two criteria of pure loss of stability and parametric roll for three different naval ships shows that these ships are not vulnerable to these failure modes according to the new regulation. Thus, the application of this regulation during the design of these vessels should not have improved their safety during sailing in waves. It also shows what has been already evidenced for merchant ships i.e. that the first method of level one (which considers parallel waterplanes) implies extremely large metacentric height which may conflict with the future excessive acceleration criteria.

It has been interesting to practically quantify for each ship the different level of safety provided by the IS code and the military set of rules: as expected, the navy rules are more severe and in the investigated cases it seems exactly of the appropriate amount in order to avoid ships appear vulnerable to the pure loss and parametric roll failures.

The three ships chosen in this study have relatively classical “military hull shape”. Thus, it is logical to find similar results. However, some other military vessels have significantly different hull shape (aircraft carrier, amphibious and assault vessels, military tankers, scientific vessels …) and may be worthy of assessment.

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