An integration of present navy ships intact stability criteria in the perspective of ship performance assessment in a seaway

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ABSTRACT

In the paper a possible integration of the present intact stability criteria for navy ships is proposed with the aim to include ship stability performance assessment in a seaway. In this view, IMO Second Generation Intact Stability Criteria (SGISC) are considered, as an interesting source of inspiration. In the background,the innovative approach formulated within the Naval Ship Code is described, as a possible framework where the above mentioned integration can take place. In order to get practical feasibility test, applications are carried out on three navy ship typologies, characterized by different sizes and operational profiles in order to compare the level of severity of the present intact stability navy criteria with the one implied by the first vulnerability level criteria of the SGISC. As a furthere step, then the second vulnerability level criterion for the dead ship stability failure mode is applied to the same set of shipsThe criterion in fact can be a possible supplement of investigation, beside the usual beam winds combined with rolling criterion, in order to better frame ship behavior in a seaway.

Keywords: *Intact Stability, Naval Ships, Wind and Waves.*

1. INTRODUCTION

The importance to assess stability performance of naval ships in extreme seas is well known, together with the implied challenges:for example the large amplitude motions reliable prediction and the identification of suitable performance–based criteria (Reed, 2009). Naval ships in principles share with merchant ships the same general issues relevant to stability failures but the safety rules framework to comply with is different, since Navies are not under IMO regulations. Another important difference is that naval vessel, due to their operational profile, often cannot avoid dangerous weather conditions when fulfilling their missions, while a commercial vessel often can choose an alternative route.

The attention to ship stability in waves is in parallel with an increasing interest in the development of risk based stability criteria. The trend is to frame the discussion about ship performance within a risk assessment procedure, dealing with the risk of capsizing (Peters, 2010; Tellet 2011).

At the beginning of the 21st century, NATO initiated an effort to develop the Naval Ship Code i.e. a goal-based standard for naval vessels that could guide navies and classification societies in the development of rules for naval vessels. The intent was to develop regulations for naval vessels that paralleled the IMO regulations for commercial vessels. A brief overview about the Naval Ship Code is going to be developed in the following.

The present Navy stability standard, from one side are recognized as a valuable reference in order to design appropriately safe ships. On the other side it is doubtful that they are able to truly capture the dynamic behavior of ships in extreme conditions. (Perrault et al. 2010).

It is recognized that the hydrostatics-based standards have attempted to incorporate some consideration of dynamic issues through the so called “beam winds combined with rolling criterion” i.e. the effect of beam wind and seas on ship behavior that in the IMO context is named weather criterion.

Nevertheless, it is recognized as well that the a possible way to overcome the limitations of the present standard seems to be the calculation of the probability of capsize as directly related to the probability of exceeding a critical roll angle, due to the environmental conditions. The methodology employed in determining the probability of exceeding a critical roll angle is described most of the times using time domain simulations combined with probabilistic input data for the wave conditions and heading and speed (Beaupuy et al. 2012).

In parallel with what above, the vulnerability criteria developed by IMO, in particular the second level vulnerability criteria, have been already indicated as reasonable tool, for example in an early design stage (Alman, 2010), in order to assess the ship behavior in waves.

Within the multilayered framework of the SGISC, the third and upper level of assessment is in line with the probability of capsizing prediction coupled with a suitable ship motion computational tool, which in principle, shoul be able to capture all the non-linear phenomena necessary for capsizing prediction. In the SGISC terminology this is named Direct Assessment (DA). With this is mind, the assessment tools developed as second level vulnerability criteria have been developed in order to be a good compromise between accuracy of results and computational engagement.

In this paper, in relation with the dead ship condition stability failure, the second vulnerability criteria is applied to a naval ship in order to investigate the applicability to this ship category and to compare results with the present intact stability standards for naval ships. In particular, the second vulnerability level performs a more extensive assessment, because of the wider scenario of environmental condition to be considered and the modelling of roll motion of the vessel by means of a one-degree of freedom (1-DOF).

Moreover, a wider comparison is made between such standards and the SGISC, in terms of all the first level vulnerability criteria for the whole set of stability failure modes addressed by IMO. Three different naval ship typologies have been considered i.e. and helicopter carrier, a destroyer and a patrol vessel.

2. PRESENT NAVY SHIPS INTACT CRITERIA

For the purpose of this paper, as brief overview of selected navy intact stability criteria has been carried out.

United States Navy (NAVSEA, 2016), United Kingdom MOD (2000), France MOD (1999) and Italy MOD (1980) rule texts have been considered and a very similar structure in terms of criteria and standard values habeen identified as expected. In fact, at a different extent, all of them are related with approach and criteria developed by Sarching and Goldberg (1962) .

Looking for a a general outline among them, indeed it is possible to spot the attention paid to the righting arm standing alone and moreover under the effect of different inclining moments i.e. turning at speed, the crowding of people on one side and the lifting of heavy load on one side. The influence of ice is also to be taken into consideration. What above with reference to specified loading conditions

As far as sea-state effects, the assessment beam winds influence together with rolling (fixed angle of 25 degrees for all the investigated rule texts) is requested.

The wind speed is actually a differentiated value, varying from 40 kn to 100 kn, in relation with the Administration and the naval ship typology.

The action of environmental conditions is very relevant form the safety point of view and in order to possibly improve or better validate the criteria, some investigations about the wind modeling in the beam winds combined with ship rolling has been carried out, with the support also of experimental tests (Luquet et al. 2015, Ariffin et al. 2016).

As a general remark, as it is well known, the set of rules to be applied for naval ships is unquestionably more severe if compared with the IMO Intact Stability Code (IMO, 2008) and this is coherent with the more severe operational profile warships have to fulfill with. For the same reason usually a thorough investigation of the seakeeping performances are carried out for this ship category, both on short term and/or long term perspective, with attention to specific issues like for example accelerations, slamming events or to more comprehensive parameters like operational indexes.

As already mentioned, the stability assessment in a seaway at the more exhaustive extent in principle is a seakeeping problem, with the need to capture all the necessary dynamic phenomena up to capsizing, often characterized by challenging nonlinearities. This process, beside to be expensive and time consuming, requires the appropriate numerical tool for the ship dynamic behavior prediction.

In line with a more thorough assessment of ship performance in waves, but as an intermediate phase between the present intact stability criteria and a challenging seakeeping prediction at large angles, the application of SGISC are assumed to be interesting also for navy ships.

3. THE SECOND GENERATION IS CRITERIA

The Maritime Safety Committee (MSC of the International Maritime Organization (IMO) approved and issued the Intact stability code in 2008 (IS Code) (IMO, 2008). Within IS Code is pointed out that new approaches to assess ship stability are required, with specific reference to the ship behavior in a seaway.

Therefore, a working group was established by IMO to select and to develop the so called second generation intact stability criteria. The working group has identified different stability failure modes related to the following phenomena:

- Variation of righting arm in waves;
- Dead ship condition;
- Maneuvering-related failures.

For a more accurate description on the physics of the phenomena see (Belenky et al, 2008) and (Belenky et al, 2011).

The ship compliance is assessed by a multi-tired approach structured in three levels, with increasing accuracy of formulation: in case the ship is not able to comply with the 1st level criterion (L1), she has to be assessed according to 2nd level criteria (L2). As already mentioned, a direct assessment (DA), for instance by means of a suitable numerical tool, should be carried out in case some vulnerability is evidenced also at the 2nd level criterion.. An Operational Guidance (OG) is to be adopted and approved by the Flag Administration, if the issue cannot be settled in the design phase. Along the years, an intense research and development activity for each mode of failure has been carried out by the IMO Working Group and by the international scientific community. An important and significant part of the literature to this regard is collected in the proceedings of the International Conference on Stability of Ship Ocean Vehicles (STAB) and the International Ship Stability Workshop (ISSW) of the latest years.

In 2015, at the 2nd meeting of the SDC (it is the IMO Ship Design and Construction Sub-Committee), the rule texts of criteria for Parametric Roll (PR), Pure Loss of Stability (PLS) and Surf-Riding/Broaching (SR) have been finalized (IMO, 2015). While the complete criteria of Dead Ship condition (DS) and Excessive Acceleration (EA) failures have been delivered at the end of the 3rd SDC session (IMO, 2016).

Dead Ship condition criteria – 2nd Level

This criterion analyses the ship vulnerability in the dead ship scenario. To do that, a long-term and a short-term probability indexes are evaluated. A ship is considered vulnerable to the dead ship condition failure mode when:

$$C < R_{DS0} \tag{1}$$

where R_{DS0} is the risk threshold, to be chosen among 0.04 and 0.06. C is the long-term probability index that measures the vulnerability of the ship. This index is based on the probability of occurrence of short-term environmental condition.

$$C = \sum_{i=1}^{N} W_i \cdot C_{S_i} \tag{2}$$

W_i is a short-term weighting factor for the specific environmental condition. The short-term dead ship stability failure index, C_{S_i}, for the relevant short-term environmental condition under consideration, is a measure of the probability that the ship will exceed specified heel angles at least once in the exposure time considered (1 hour), taking into account an effective relative angle between the vessel and the waves. To evaluate the short-term index, a heeling lever due to wind effects is calculated. The wind and beam seas are derived by means of the analysis of the sea and gust spectra. Waves are characterized, in the short-term, by a significant wave height H_S and a zero crossing period T_Z. The spectrum of wave elevation is of the Bretschneider/Two parameters Pierson-Moskowitz type. The mean wind speed U_W is determined solely from the significant wave height H_S. The wind is assumed to fluctuate around the mean wind velocity. The total wind speed is given by the sum of the mean wind speed and the gust fluctuation speed. The spectrum of the gust is of the Davenport type, and it depends on the mean wind speed. The long-term characterization of the standard environmental conditions is given by means of a given wave scatter diagram. More details about the procedure are given in the Explanatory Notes (IMO, 2016-ANNEX 6).

4. THE NAVAL SHIP CODE

The concept of the formal risk assessment, or design for safety approach, is already implemented by IMO within its rulemaking activity.

NATO has followed a similar attitude in adopting Goal Based Standards (GBS) as a basis for the "Naval Ship Code" ANEP-77 (NATO, 2014). GBS are a powerful tool able to establish a framework for integrating stability into a risk based design process (Alman, 2011). Within a goal based standards, a goal or 'safety objective' is defined through a series of tiers or a framework for verification through design construction and operation.

In ANEP-77, the goal based standards approach is structured on five tiers as follows:

- Tier 0 - Aim (Philosophies and Principles)
- Tier 1 – Goal
- Tier 2 – Functional Areas
- Tier 3 – Performance Requirements
- Tier 4 – Verification Methods
- Tier 5 – Justification

Performance requirements are defined in relation with ship operational profile and verified using appropriate criteria. As already mentioned the basic principle of a goal based approach is that the goals should represent the top tiers of the framework, against which ship is verified both at design and construction stages, and during ship operation. This approach has several advantages over more traditional prescriptive standards even though the Naval Ship Code can become prescriptive if appropriate. Alternatively, it can remain at a high level applying other standards and relevant assurance processes. In this way GBS approach permits innovation by allowing alternative arrangements to be justified as complying with the higher level requirements.

The Naval Ship Code is recalled as significant in this paper because it can represent the background framework where application of SGISC to naval ships can find a possible rational collocation.

Moreover, in the introduction chapter of the Naval Ship Code, it is stated that the overall aim of the Code is to provide a standard for naval surface ship safety based on and benchmarked against IMO conventions and resolutions.

In this sense a continuous attention to IMO safety rules and their development is considered as an appropriate attitude.

In chapter III Buoyancy, Stability and Controllability, the main goals for such safety issues are identified. The buoyancy, freeboard, main sub-division compartment and stability characteristics of the ship shall be designed, constructed and maintained to:

- Provide an adequate reserve of buoyancy in all foreseeable intact and damaged conditions, in the environment for which the ship is to operate;
- Provide adequate stability to avoid capsizing in all foreseeable intact and damaged conditions, in the environment for which the ship is to operate, under the precepts of good seamanship;
- Permit embarked persons to carry out their duties as safely as reasonably practical;
- Protect the embarked persons and essential safety functions in the event of foreseeable accidents and emergencies at least until the persons have reached a place of safety or the threat has receded including preventing the malfunction of the life-saving systems and equipment.

An important reference is made to environmental condition.

Verification that the ship complies with this high level aims shall be by the Naval Administration. Provision of evidence to support verification shall be by the owner.

5. THE APPLICATION CASES

In order to obtain an immediate flavor on the real feasibility about consistent integration between present navy intact stability rules and IMO SGISC, some investigations are carried out.

The application of such IMO criteria to navy ships has already been studied in the latest years with interesting results (Tomaszeck and Bassler, 2015; Grinnaert et al. 2016).

The selected ships are a destroyer unit, a helicopter carrier and a patrol vessel.

Main ships data are given in Table 1.

Table 1 – Main Data of investigated vessels

			Destroyer	Heli-Carrier	Patrol Vessel
Length BP	L_{BP}	(m)	142	172	80.6
Breadth	B	(m)	19.1	24	9.6
Draught	T	(m)	6.15	6.50	3.37
Displacement	Δ	(t)	8634	11768	1250
Froude number	F_n	-	0.413	0.338	0.457

Due to the importance of the areas exposed to wind, special attention is given to the shape and dimensions of ship's windage areas that for each ship are appropriately designed on the basis of similar existing units.

First vulnerability level assessments –All stability failure modes

At first, the three ships are investigated calculating the max KG curves derived from the compliance with the SGISC first vulnerability level criteria for all the stability failure modes..

Results, for each vessel described above, are shown in Figure 1, 2 and 3. In the same figures, it is possible to put in evidence the max KG curves (indicated with "Navy") that derive from the compliance with a set of criteria representative of the present intact stability requirements for navy ships.

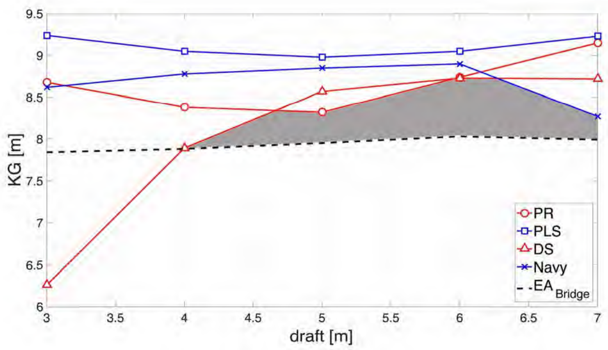

Figure 1 – KG_{max} curves for Destroyer

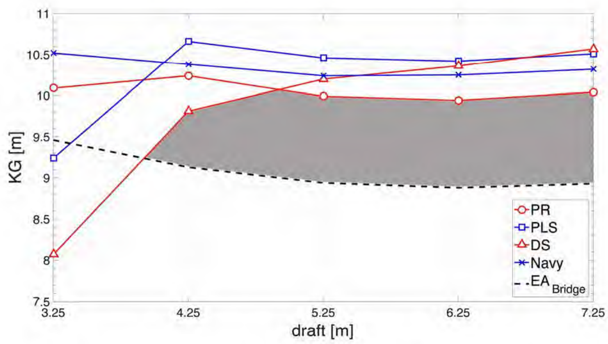

Figure 2 – KG_{max} curves for Helicopter carrier

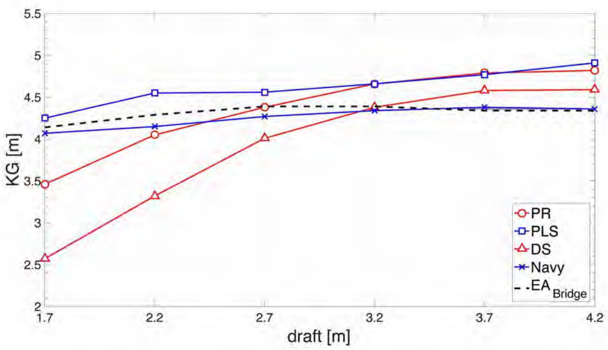

Figure 3 – KG_{max} curves for Patrol Vessel

In order to better understand the results, it is worthwhile to remind that for the case of Excessive Accelerations the curve should be named as the curve of the min KG i.e. it is required that the KG value is higher with reference to that curve. It is immediately evident how the "design space" (indicated with a grey area) is limited for the Helicopter carrier and the Destroyer; the same "design space" is totally non existing for the Patrol Vessel.

Since the set of criteria that have been applied are first level vulnerability criteria, it is definitely advisable to proceed to the second level in order to be able in case to design the ship.

It is interesting to point out that the present intact stability standard for navy ships are well positioned in between the other curves, denoting a comparable and equivalent level of safety with SGISC-firsr vulnerability level.

Second vulnerability level assessment - Dead ship condition

The further investigation, raising to the higher second vulnerability level, is specifically limited to the dead ship condition stability failure.

As already mentioned, the Naval Ship Code is based on goal based approach i.e. a performance assessment perspective. In this sense it is not so easy to find a suitable methodology to carry out the performance assessment. The second vulnerability level criteria developed by IMO can be considered as a possible option, worth to be investigated. The second level criteria are defined to be a wide-ranging tool able to better frame the ship behavior than first level ones and, even though not expressly meant, they are in principle suitable to be applied also to navy ship category. The beam winds combined with ship rolling criterion, as already described in its traditional present formulationwithin the Naval Ship Code,, is applied for a wind speed of 100 kn. The derived max KG curves are shown in Figure 4, 5 and 6, where also results derived from the application of second vulnerability level criterion are reported.

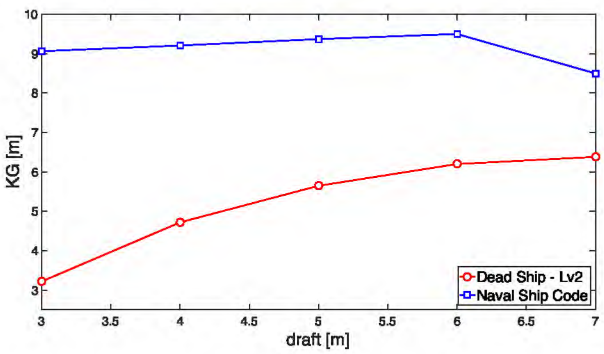

Figure 4 – KG_{max} curves for Destroyer

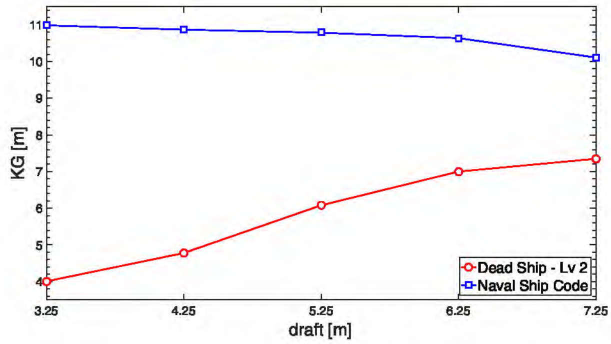

Figure 5 – KG_{max} curves for Helicopter carrier

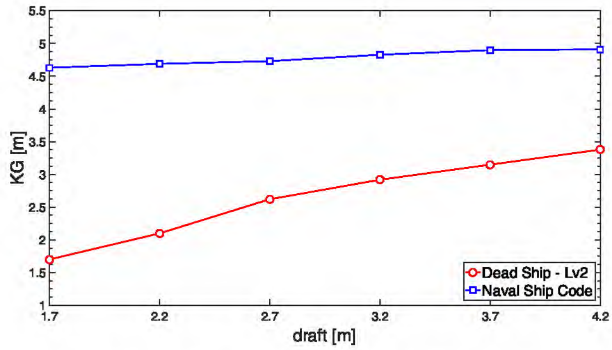

Figure 6 – KG_{max} curves for Patrol Vessel

The max KG curves derived from SGISC second vulnerability level are significantly more severe than the present wind+ship roll criterion, for all the three investigated ships.

Moreover, results are not in line with what expected: the beam winds combined with ship rolling criterion, applied with 100 kn wind speed, was expected to be in principle more severe than the second vulnerability level approach. This one in fact is more extensive in terms of sea state conditions investigated, including less severe environment conditions..

6. CONCLUSIONS

Due to the need to find efficient tools to investigate ship dynamic stability in waves, the SGISC are applied to a set of naval ship category i.e. a helicopter carrier, a destroyer and a patrol vessel. A special attention is paid to the ship performance assessment for beam winds combined with ship rolling, since naval ships cannot limit in principle their operational profile in case of of weather and sea state adverse conditions.

The application of the first vulnerability level criteria, for all the stability failure modes, to the three ships has evidenced the nearly equivalent level of safety of the present intact stability rules for naval ships when compared with the SGISC curves/first vulnerability level.

A critical issue is that the max KG curve for the excessive acceleration failure mode, when combined with other curves, practically limits the "design space" to a very narrow area, especially for the patrol vessel.

As regards the application of the second level vulnerability criterion for the dead ship condition stability failure, results give evidence about the higher severity of the criterion when compared with the one applied by the Naval Ship Code and practically equivalent to the beam winds combined with ship rolling already applied by Navies.

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