A SGISC-Based Study about operational Profiles of Navy Vessels

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ABSTRACT

In this paper, for selected navy vessels, a study of operational profiles in terms of intact stability performance in waves has been carried out. As an assessment tool, operational measures formulated within the Second Generation Intact Stability Criteria (SGISc) have been considered suitable for the analysis, as further detailed in the relevant guidelines. An application to different naval vessel typologies has been undertaken for the different stability failure modes. Results are analysed also in the view to evaluate how decisions in terms of ship speed may affect also ship stability besides range.

Keywords: *Stability in waves, Surf-Riding, Excessive Acceleration, Operational Guidance, Navy Vessel, Operative profile.*

1. INTRODUCTION

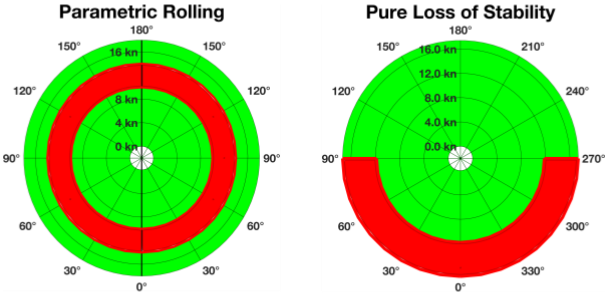
The need to evaluate naval vessels performance in extreme seaway condition is well known, as well as the resulting challenges, e.g., the large amplitude motions implied together with relevant non-linearities and the identification of suitable performance-based criteria (Reed, 2009). Due to the complexity of the phenomena acting on a ship, it is not always possible to fully understand the behaviour of the ship in a seaway during the design phase. Measures and guidance may be needed to safe handle the ship (Liwång, 2019), especially in harsh weather condition. In fact, due to their operational profile, naval vessel often cannot avoid extreme environmental conditions when fulfilling their mission.

For these reasons, operational profiles of naval vessels are often subject of studies aiming to the definition of operational guidance relying on different criteria. In the work of Thompson (2022), decision support has been defined taking into account the fatigue of structure for naval vessel. A similar analysis can be found also in (Magoga, 2020). The capsize risk in heavy weather conditions has been tackled instead by Peters (2019). The aspect of helicopter landing on board in non-ideal condition has been addressed by Colwell (2002) as well. Also the issues of reduction of the fuel consumption and pollutant emission (Vasilikis, 2022) have been addressed. Regardless the aspects which have been focused on, the ship safety represent the common topic of interest related to the naval vessel behaviour in waves.

As described in the section above, operational guidance for naval unit can be formulated according to several criteria relying on different aspects characterising ship performance that in turn can range in the diverse topics of the naval architecture and marine engineering. In this work, safety of the naval vessels has been considered in terms of stability in a seaway condition. Embracing the philosophy of the goal-based approach, tools and criteria deemed appropriate can be used to assess the sufficient level of safety (NATO, 2014; Hoppe, 2005). In light of this, it has been decided to take into account the so-called Second Generation Intact Stability criteria (SGISc). These criteria, recently finalized at IMO, have been developed according to physic-based approach. With this premise, SGISc can be applied in principle to every ship, regardless its typology, hence to naval vessels as well. Although SGISc are developed for commercial ships, relevant applications to naval vessels can be found in literature (Petacco, 2017; Boccadamo, 2019; Rinauro, 2020).

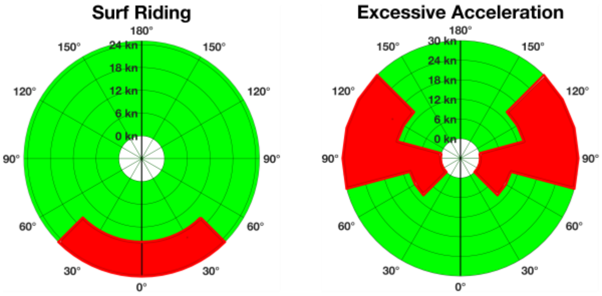
In the SGISc framework, three different typologies of operational guidance (OG) have been defined: probabilistic OG, deterministic OG and simplified OG. The first two typologies require an advanced numerical tool able to compute a non-linear time-domain simulation considering at least 4 degrees of freedom. The last typology relies on a simplified version of the stability criteria defined in (IMO, 2020; 2022). Four different stability failures have been considered in this work: parametric rolling (PR), pure loss of stability (PL), surf-riding (SR) and excessive acceleration (EA).

- For the PR failure it is suggested to avoid forward speed not compliant with second check of Level 2 regardless the wave direction (Figure 1a).
- For PL failure it is suggested to avoid forward speed greater than $0.752 \cdot \sqrt{\mathrm{L_{PP}}}$ [m/sec] in following to beam wave headings whether Level 2 is not met (Figure 1b).
- For SR failure two types of OG exist. In this paper, it has been adopted the version which suggests to avoid forward speeds greater than $0.94 \cdot \sqrt{\mathrm{L_{PP}}}$ [m/sec] in those sea states having $H_S \geq 0.04 \cdot L_{PP}$ and $\lambda \geq 0.8 \cdot L_{PP}$ for quartering seas, i.e., ±45° (Figure 1c).
- For EA failure is suggested to avoid those sailing conditions (i.e., combination of heading, speed and sea state) where the short term criterion of Level 2 $C_S(\mu, V_S, H_S, T_Z) > 10^{-6}$ (Figure 1d). Level 2 of EA should be properly modified to take into account heading and wave encounter frequency.



(a) Simplified OG for the Parametric Rolling failure mode

(b) Simplified OG for the Pure Loss of Stability failure mode



(c) Simplified OG for the Surf-Riding failure mode

(d) Simplified OG for the Excessive Acceleration failure mode

Figure 1: Generic examples of suggested measures according to the simplified OG.

2. APPLICATION CASE

In this work the simplified OG for the parametric rolling, excessive acceleration and surf-riding stability failures have been applied.

In the analysis, three typologies of naval vessel have been considered: a destroyer unit, an amphibious transport dock (also called as Landing Platform Dock, LPD) and an offshore patrol vessel (OPV). The considered units differ in terms of size and operational profile. In Table 1 their main dimensions are reported.

Table 1: Main dimensions of the analysed vessels.

Main characteristics		Destroyer	LPD	OPV
Length at WL	[m]	150.10	173.37	75.80
Beam at WL	[m]	19.00	28.16	9.60
Design Draft	[m]	6.00	6.90	3.37
Volume	[m^3]	8 128.0	20 896.0	1 226.2
Vertical CoG	[m]	7.75	10.50	3.85
Block coeff.	[-]	0.501	0.620	0.472
Natural roll period	[sec]	10.93	11.61	7.49
Service speed V_S	[kt]	20.0	18.0	14.0
Maximum speed	[kt]	30.0	25.0	25.0
Endurance @V_S	[nm]	4400	7000	3500

The assessment of lateral acceleration phenomenon requires the definition of the highest position where crew may be present. Since the excessive accelerations highest values are related also to the longitudinal position, it may happen that largest lateral acceleration occurs at the extremities of the vessel, even if is not the highest point. Thus, it has been deemed appropriate to identify the points to be assessed based on the deckhouse length. The deckhouse has been divided in three zones based on the position along the ship length, as defined in (1).

$$X_{dh} \leq x < X_{dh} + \frac{L_{dh}}{3} \tag{1a}$$

$$X_{dh} + \frac{1}{3} L_{dh} \leq x < X_{dh} + \frac{2}{3} \cdot L_{dh} \tag{1b}$$

$$X_{dh} + \frac{2}{3} \cdot L_{dh} \leq x \tag{1c}$$

where X_{dh} is the longitudinal position of the beginning of the deckhouse and L_{dh} is the deckhouse overall length. Bearing in mind this, the points shown Figure 2 and reported in Table 2 have been assessed in terms of excessive acceleration by means of criterion Level 2.

Table 2: Coordinates of the points for each deckhouse zone in the excessive acceleration assessment.

Deckhouse Zone		Aft Zone	Mid Zone	Fore Zone
Destroyer	*x [m]*	48.7	82.3	103.0
	z [m]	21.6	26.7	26.5
LPD	*x [m]*	62.2	96.2	135.2
	z [m]	34.5	40.2	33.1
OPV	*x [m]*	23.4	35.6	44.7
	z [m]	13.0	13.4	15.9

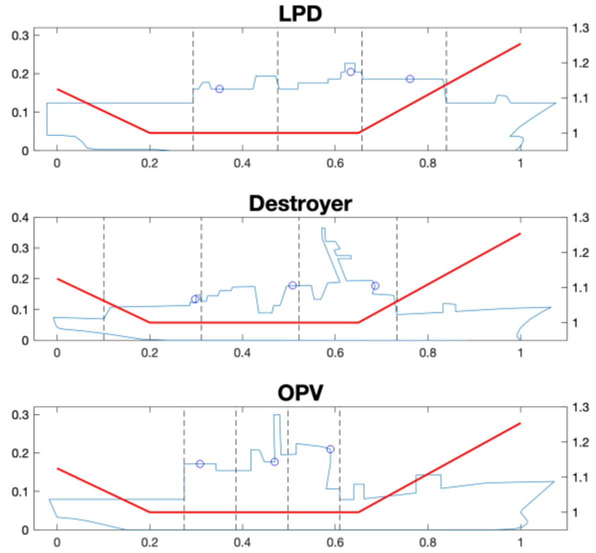


Figure 2: Comparison of the longitudinal profiles of the assessed units and k_L coefficient.

Once the worst position has been identified by the largest criterion value (i.e., when the ship is deemed more vulnerable), it is possible to continue the application of the OG for this stability failure mode.

All OGs have been evaluated for a selection of sea states. The sea state code defined by NATO (2000) has been adopted to identify the significant wave height H_S; in particular, three different sea states have been selected as reported in Table 3.

Table 3: Relationship between the Sea state code and significant wave height as defined in (NATO, 2000).

Sea state code	Significant wave height range [m]	Significant wave height considered [m]
4	1.25 – 2.5	1.50
6	4.0 – 6.0	5.50
8	9.0 – 14.0	11.50

The zero-crossing period T_Z for each sea state has been identified by means of the wave scatter table of the North Atlantic Ocean (IACS, 2001). Considering the selected significant wave height, the two T_Z having the highest occurrence have been considered in the analysis. In Table 4, the considered T_Z for each sea state are reported.

Table 4: Selection of the two T_Z having the largest occurrence for each considered sea state.

Sea state code	Considered H_S [m]	Selected T_Z [sec] I°	II°
4	1.50	7.5	8.5
6	5.50	9.5	10.5
8	11.50	11.5	10.5

According to all outcomes of each stability failure mode, a comprehensive polar diagram is provided as a function of wave encounter angle, ship speed and sea state parameters. The total OG polar diagram is obtained by the superposition of polar diagram for each stability failure and the areas deemed dangerous are highlighted in red.

3. RESULTS

Results are presented in terms of polar diagram, measuring the heading and the ship speed along the radius. Heading from 0° (following wave) to 180° (heading wave) with step of 30° have been considered. Ship speed from 0 kn to the maximum ship speed V_{Max} with a step of 2 kn have been analysed. Each combination of heading and speed identifies a sector of ±15° and ±1 kn. Sectors deemed vulnerable by the simplified OG, thus, to be avoided during the navigation, have been highlighted in red. Each polar plot reports the ship service speed V_S (dashed circle) and the maximum ship speed V_{Max} (dash-dot circle). Thanks to the symmetry of the results, polar diagrams have been split and represented from 0° to 180°. On the right side are reported the results for the most likely T_Z, while on the left side results for the second most likely T_Z are shown. For the EA failure mode, the worst location selected for the following analysis are within the fore zone for the OPV and LPD and in the mid zone for the destroyer. Application of OG for the EA stability failure points out that caution in the navigation is needed in sea state 8 for all vessels and in sea state 6 for the OPV. Due to their structure, simplified OG for PR, PL and SR (if applicable) are represented by a fixed scheme which can be repeated regardless the vessel and sea state, as shown in Figure 1. A summary of the cases where OG are needed is reported in Table 5.

Table 5: Outcomes summary of the application of simplified OG.

Vessel	Stability failure	Sea State code		
		4	6	8
Destroyer	*PR*	-	-	-
	PL	-	-	-
	EA	-	-	Y
	SR	-	-	Y
LPD	*PR*	-	-	-
	PL	-	-	-
	EA	-	Y	Y
	SR	-	-	Y
OPV	*PR*	-	-	-
	PL	-	-	-
	EA	-	Y	Y
	SR	-	Y	Y

Y = Operational Guidance is needed.

According to the results, polar diagrams have been superimposed for each sea state, and a comprehensive representation of the OG has been obtained (Figure 3 to Figure 5).

4. COMMENTS & CONCLUSIONS

In this work, an overview on how safety aspect during navigation of naval vessel may be affected by the operational profile is given. In particular, safety in terms of stability has been considered. The operational guidance of the SGISc framework have been described and analysed. Although the SGISc are not meant for naval vessels, the simplified guidance has been applied to evaluate how safety aspects may affect the vessel operability.

In particular, all stability failure modes except for the dead ship condition, have been applied and results have been presented in terms of polar diagram. The analysis has been limited to a selection of sea states, in accordance with the nomenclature adopted by the navies. Outcomes point out that all vessels do not need any operational guidance for the PR and PL stability failure mode, regardless the considered sea state. As concern the EA and SR phenomena, warnings to the master are required when sailing in sea state 6 and sea state 8.

As expected, the EA guidance affects mainly the beam encounter angles, suggesting to completely avoid beam waves regardless ship speed. Bow waves (120° and 150°) set an upper limit to the ship speed, while quartering waves set a minimum sailing speed. It seems reasonable that this behaviour is to be associated at the encounter frequency as a function of the heading and speed. It is worth noting that in the EA assessment, the point which has the largest acceleration according to the criterion is not always the highest one. Two out of three vessels show the forward heading case as worst in terms of acceleration location.

Regarding the SR phenomenon, it seems that only in heaviest weather condition (i.e., sea state 8) operational measures are needed in following seas (i.e., ±45°). The sailing condition to be avoided set a maximum speed that in any case is always higher than the service speed. It is worth noting that the guidance for SR has a very simplified structure; therefore, a more accurate tool is preferable, especially for the largest vessels.

From the comprehensive overview of the OG, it appears that the outcomes suggest significant limitations or at least hints for considerations relevant to the actual operational profile. Both in term of available heading and in term of allowed speed.

For sake of completeness, it is pointed out that some relevant aspects in heavy seaway conditions have been not considered in the assessment undertaken. It should be highlighted that some sailing conditions may be considered safe by OG but they may result to be unattainable because of limits in the propulsion and steering system or other undesirable problems, such as slamming or excessive vertical motion. Nevertheless, the analysis carried out can be considered as a starting point to address the relation among operative profile, safety, and eco-friendly aspects in the navy framework. In future works, the wave added resistance can be addressed and an estimation of the actual speed loss and pollutant emissions taken into consideration.

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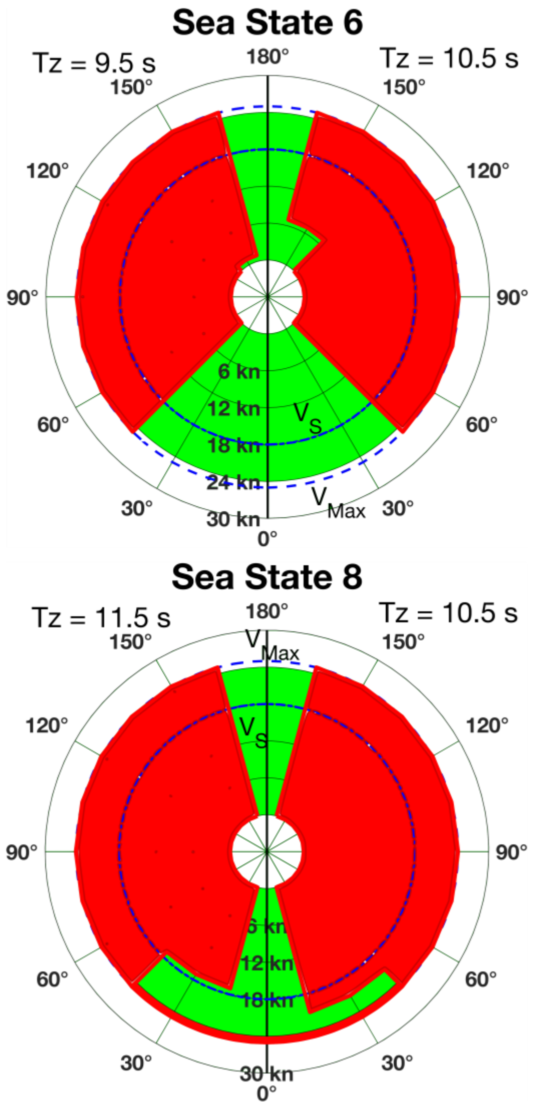

Figure 3: Polar diagram of the comprehensive OG for the LPD unit. Sea state 4 does not need any operative measures.

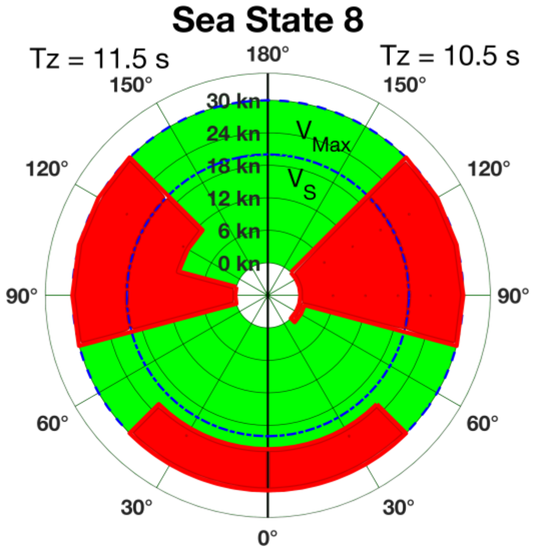

Figure 4: Polar diagram of the comprehensive OG for the Destroyer unit. Sea state 4 and sea state do not need any operative measures.

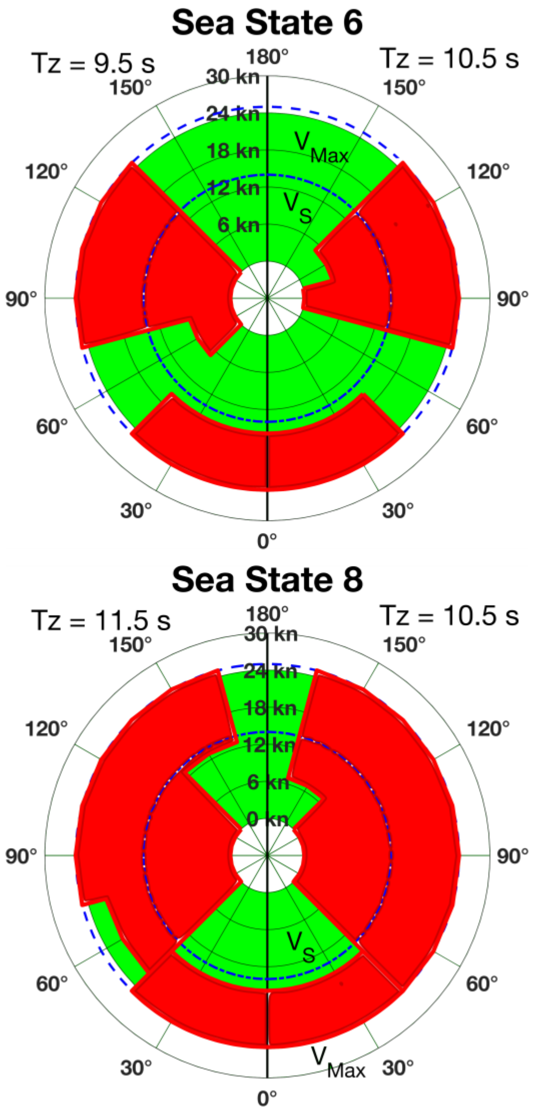

Figure 5: Polar diagram of the comprehensive OG for the OPV unit. Sea state 4 does not need any operative measures.