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An overview about operational measures in the framework of Second Generation Intact Stability criteria

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ABSTRACT

The Second Generation Intact Stability criteria (SGISc) addresses ship stability in waves, focusing on specific dynamic-based phenomena, i.e. parametric roll, pure loss of stability, dead ship condition, surf-riding and excessive accelerations. Their application is encouraged by IMO to assess their consistency and validity. Three assessment levels are defined to evaluate ship vulnerability during design stage, with the possibility to complement them by operational measures. After an introduction to SGISc operational measures, application cases are carried out for mega-yacht and a RO-RO passenger ship: the vulnerability levels (i.e. Level 1 and Level 2) and operational measures (i.e. operational limitation and operational guidance) are investigated and discussed.

Keywords: *Stability in waves, Operational Limitations, Operational Guidance, Ro-Ro ferry, Mega-yacht.*

1. INTRODUCTION

With the MSC Circular 1627 (2020) the International Maritime Organization (IMO) has recently issued the Second Generation Intact Stability criteria (SGISc): at present their application is not mandatory, but IMO strongly recommends their application in order to collect feedbacks and gain experience for a possible further improvement and enhancement. In the intact stability rules framework, the SGISc may represent a disruptive step forward toward the probabilistic and performance-based approach. The criteria tackle the ship stability performance in a seaway condition, which requires a wide knowledge, not only on typical ship stability aspects, but also on seakeeping and manoeuvrability features. The perspective selected during the criteria development process, in fact has been to study and make reference to the physics at the base of the specific ship dynamic phenomenon. Namely, the five stability failures modes considered in SGISc are: dead ship condition, excessive acceleration, parametric rolling, pure loss of stability and surf-riding/broaching-to.

A physics-based criterion is definitely demanding but it is in principle very versatile and can be applied to a wide spectrum of ship typology. At the same time, during the early design phase, it is not always possible to undertake a thorough and comprehensive analysis about the ship performance: in fact specific details about the ship and the relevant loading condition are not completely defined, at this stage. In order to overcome this burden, the SGISc have been structured on different levels with an increasing accuracy and complexity, the so-called multi-layered approach (Figure 1). It is made up of two *vulnerability levels* (Level 1 and Level 2), that together with the *direct stability assessment* (DSA), are named *design assessments*. Level 1 is the simplest vulnerability criterion, it can be carried out just knowing some basics about ship stability such as geometry and a few loading condition data. Level 2 represents a step toward the complete analysis carried out in the DSA. It entails the concept of short and long term analysis, as well as some ship stability fundamentals, treated in a more advanced manner than the first level, e.g. the use of response amplitude operator or uncoupled time domain model. An in-depth description of *vulnerability levels* can be found in several sources (IMO, 2020; Petacco, 2019; U.S. Coast Guard, 2019). Finally, as last assessment level, the DSA represents the most advanced tool to analyse the ship vulnerability to the five stability failure modes considered in the SGISc framework. It evaluates the ship stability performance in a seaway condition combining a simulation model, with at least four degrees of freedom, and a probabilistic approach to determine the failure rate over a year. Due to the complexity of the investigated phenomenon, its formulation and implementation can be demanding. Nevertheless, in the latest years, significant steps forward have been made with encouraging results (Shigunov et al., 2019; Kuroda et al., 2019).

Notwithstanding the multi-level approach structure, there is no hierarchy between levels. Therefore, when applying the SGISc, it is possible to select any assessment level regardless its complexity or conservativeness. For instance, a ship can be evaluated directly with the DSA and if the outcome points out a vulnerability, it is still possible to select another level to assess the ship. This approach has been adopted in order to overcome some limited inconsistencies that may appear between level application (Tompuri et al. 2017; Peters & Belenky, 2019). With regard to the SGISc framework, an inconsistency occurs when a more accurate approach defines the ship vulnerable contradicting the result of a more conservative (made on purpose because it is less accurate) lower level. Nevertheless, it is expected that a sequential application of the criteria, from the simplest to the complex tool direction is the most effective approach, which ensures the lowest burden in terms of time and cost.

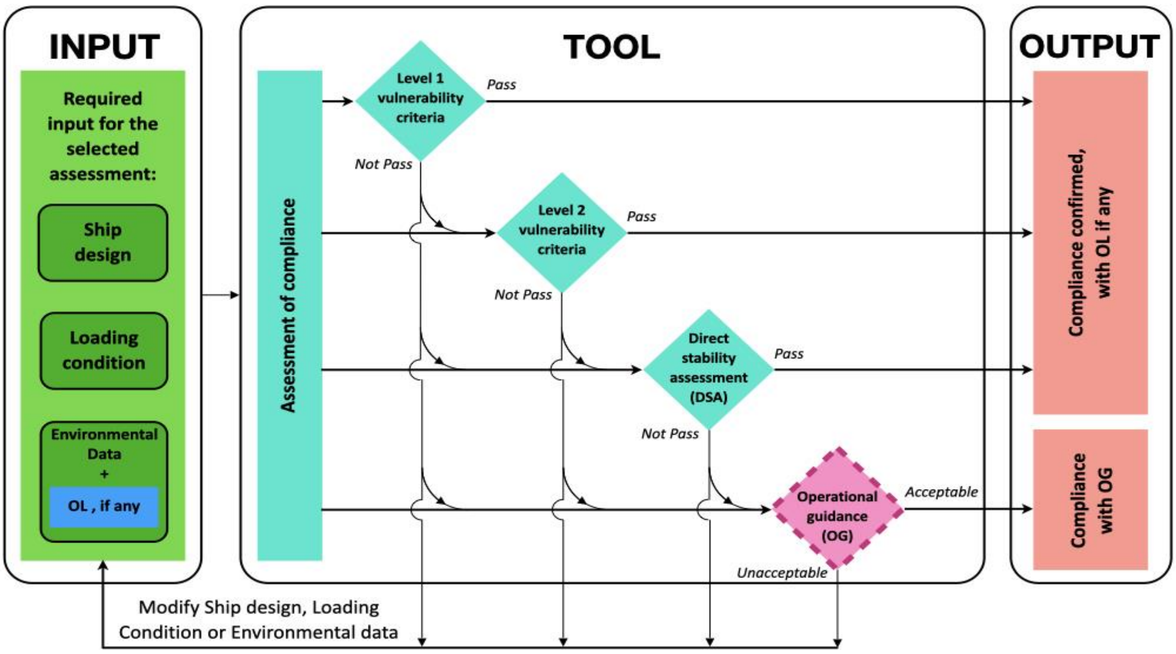

Figure 1: Schematic representation of the multi-layered approach.

A specific attention to the ship operational aspects during the navigation is another innovation introduced by SGISc compared to the first-generation criteria, i.e. the Intact Stability code (IS code) (2008). In fact, as a further possible option, Operational Guidance (OG) or Operational Limitation (OL) are introduced. It is not always possible to ensure a safer ship performance focusing only on the design aspect (Liwång, 2019; Bačkalov et al., 2016); therefore, it may be convenient to provide some operational indications to the master. They are required as a complementary tool to fully address the safety performance of a vessel.

Clearly, these can be applied only to those phenomena where navigational decisions play an active role on the scenario, namely all the failure mode addressed by SGISc except for the dead ship condition. It is worth mentioning that it is not deemed acceptable a loading condition requiring an intensive application of operational measures, i.e. both the operational guidance and limitations.

In the next paragraph, an overview focused on the operational measures contained in the SGISc will be given. Moreover, after the *vulnerability levels* application to selected representative vessels, also the OG and the OL have been applied. Finally, considerations and comments about the outcomes will be discussed in the later part of this paper.

2. OPERATIONAL LIMITATIONS

The first category of operational measures addressed hereinafter is the OL. It affects the environment where the vessel is sailing. OL set a restriction to the navigation and loading condition in terms of geographical area or allowed sea state. OL can be distinguished in two typologies, namely those related to areas, routes or season and those related to maximum significant wave height.

The latter allow to evaluate the vulnerability of the vessel selecting the worst wave height scenario the ship may happen to face. It means that the stability failure risk for the considered loading condition is deemed acceptable when the ship navigate in conditions up to the maximum identified wave height. The wave scatter table is consistently modified neglecting all the sea state having a significant wave height higher than the identified threshold. The modified wave scatter table is than named *limited scatter table*. Applications of this typology can be found in literature (Rudaković & Bačkalov, 2019). Eventually, when an OL related to the maximum wave height is applied to make the ship compliant to SGISc, it is required that detailed weather forecasts are provided to the master. This is necessary to modify the route in order to avoid dangerous sea state deemed not to be sufficiently safe.

The other typology of OL can be applied to identify an operative scenario in terms of geographical area, season and route where the navigation is deemed not acceptable because of the significant risk of stability failure. OL related to areas, routes and season can be introduced within the calculation of each SGISc directly acting on the selection of the wave scatter table. It is sufficient to identify the proper scatter table related to the environmental condition selected for the ship assessment. OL navigation constraints are not dependant on the actual daily weather forecast.

Therefore, OL may be considered at all intents an external tool acting on the input data of a methodology defined in the SGISc framework. In particular, the only data affected by these restrictions are those related to the environmental condition therefore not depending on the loading condition and ship characteristics. These modifications can be done without any complexity, thanks to the modularity structure of SGISc. The criteria have been developed with the capability to replace certain formulations or boundary conditions, as in the case of OL. In Figure 2, it is proposed an interpretation of the logical application scheme for the OL.

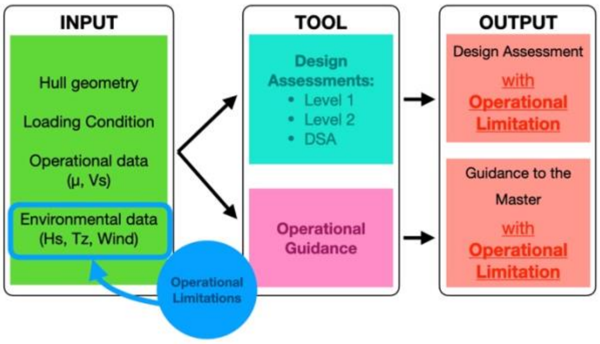

Figure 2 : Logical scheme of Operational Limitations in the SGISc framework.

3. OPERATIONAL GUIDANCE

The OG is the second typology of operational measures, it directly tackles the operative ship features. The OG provides a set of information to the master about safe ship handling in the most likelihood environmental condition. It suggests all the operational actions able to reduce the failure probability such as a reduction of speed or an indication about which routes should be avoided for certain sea states.

Although OG strongly depends on the actual environmental conditions, it is not practicable to compute the calculation in real-time. Hence, it should be prepared during the design process or at least just before the vessel voyage. Therefore, the OG should include all the most probable situations (i.e. the combination of speed, route and sea state information) that might be encountered during the ship life or voyages. In this perspective, the OG becomes usable only when detailed sea state and wind forecast data are available on board. Having these data, the master is able to plan the best sailing condition (i.e. the ship speed V_s and the mean wave encounter direction μ) according to the OG.

OG can be treated as an independent tool able to point out which situations should be avoided to ensure a sufficient safety level in terms of stability in a seaway condition. The term situation, even if *assumed situation* is more appropriate, means a combination of the sea state characteristics (e.g. significant wave height H_s , zero-crossing wave period T_z , wind direction and gust properties) and the sailing condition (i.e. V_s and μ). In Figure 3, a graphical representation of the OG placement in the SGISc context is proposed

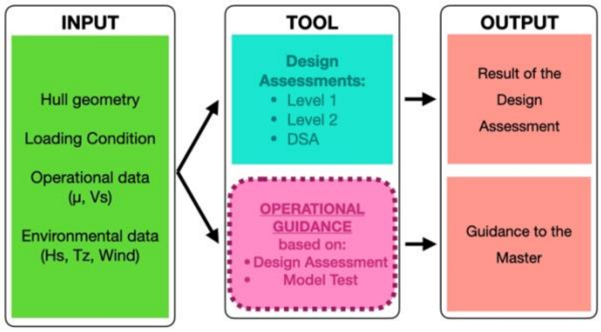

Figure 3 : Graphical representation of Operational Guidance in the SGISc framework.

According to the MSC Circular 1627 (2020), three equivalent methodologies to determine the OG have been proposed:

- *Probabilistic operational guidance;*
- *Deterministic operational guidance;*
- *Simplified operational guidance.*

The probabilistic and deterministic approaches differ in terms of methodology used in the post-processing of the outcomes, but these two typologies share the same numerical prediction tool i.e. the one also adopted for the DSA. It should be able to reproduce as accurately as possible the ship motions in a seaway condition. Moreover, it should detect the occurrence of failure events, which are defined as the exceedance of a lateral acceleration or heel angle. The numerical tool is to be developed in the time domain with at least three coupled degrees of freedom, depending on the stability failure. Technical requirements and validation data for the numerical tool are given in MSC Circular 1627 (2020). It should be noted that the development of such numerical code is challenging for the researchers and experts; nevertheless, promising results can be found in literature (Shigunov et al., 2019; Kuroda et al., 2019; Yang, 2020).

Finally, the simplified operational guidance does not require any complex computational code. It can rely on the same methodology adopted by the vulnerability levels (i.e., first and second assessment levels); nevertheless, some modifications are requested in order to introduce operative aspects, such as wave encounter angle or relative ship speed. As a result, these simplifications lead to a relevant level of conservativeness, represented by a severe standard threshold or an enlargement of the forbidden operative domain. The SGISc leave the designer the possibility to develop an appropriate methodology to carry out the simplified OG analysis when deemed practicable. Although, a superior level of safety compared to the design assessments must be ensured. Besides, the SGISc provide some examples developed on the basis of the vulnerability levels. A detailed description will be given in the next paragraphs.

4. APPLICATION CASE

In this paper, vulnerability levels have been applied to two different ship typologies. In light of the results, it has been decided to cope with the identified vulnerability by means the application of operational measures. All the stability failure modes have been considered, except for the dead ship condition and surf-riding. The first one has been disregarded because it does not allow to develop OG. The surf-riding failure has not been analysed since sufficient detail were not available for the selected unit.

Both the typologies of OL have been applied. Firstly, reasoning about possible routes for the considered units, it has been decided to limit the sailing area to the Mediterranean Sea, the Red Sea and part of Atlantic Ocean in front of Iberian coast. In Figure 4, the considered sailing area for calculations is shown. In light of this choice, the maximum wave height required by the second typology of OL has been selected, for a comparison. In particular, the maximum wave height recorded in above considered area, i.e. $H_{s,max} = 11{,}5\,[m]$, has been selected as limiting wave height.

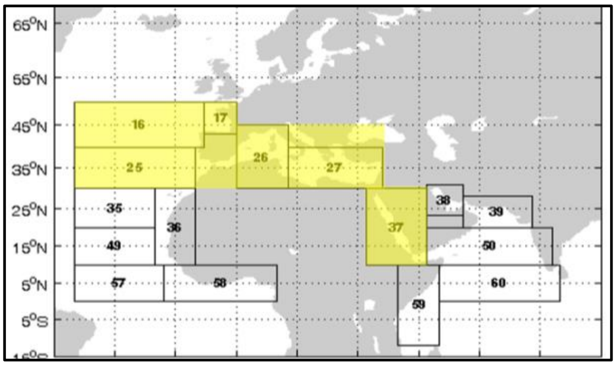

Figure 4 : Geographical area considered for the operational limitations.

As concern the OG, the simplified approach as proposed in the MSC Circular 1627 (2020) has been applied. A description of the guidance for each failure mode is given below. In the simplified guidance for the PL failure mode, all the sea states resulting in a short-term criterion equal to one, are deemed dangerous and a relevant restriction on the ship speed is introduced. Namely, the short-term criterion is evaluated by means the same methodology of the second vulnerability level. As expected, the introduced restriction is very severe and it requires to not exceed a threshold forward speed, calculated as $V_{limit} = 0.752 \cdot \sqrt{L}$, in following to beam wave directions. A similar approach is suggested for the PR failure mode. In this case, a vessel should completely avoid a speed in all those sea states resulting in a short criterion, evaluated with the second check of second level, that is equal to 1, regardless wave directions. The simplified OG for the EA failure mode requires a modification of the second vulnerability level. In order to account for the wave directions, the absolute value of the wave encounter angle sine function should be added to the transfer function for the lateral acceleration. Moreover, in the whole calculation, the wave encounter frequency ω_e replaces the wave frequency ω_w. Finally, two different simplified guidance for the surf-riding failure mode has been suggested. The simplest methodology adopts a similar structure of the first vulnerability level, in fact, the direction and sea states to be avoided are determined on the basis of the ship main dimensions. Wave direction angle less than 45° (i.e., following seas) are deemed dangerous for those sea states having a significant wave height greater than 4% of the ship length L and a wavelength longer than 80% of L . The second version of simplified guidance is directly based on the short-term criterion formulation of second vulnerability level. As a difference, the diffraction component should be taken into account in the wave force calculation. Hence, the ship should avoid following to beam wave directions for all those sea state resulting in a $C_{ST} > 0.005$, where C_{ST} is the short term criterion as defined in the second vulnerability level of surf-riding.

2.1 The vessels under investigation

The vulnerability levels and, subsequently, the operational measures have been applied to two different typologies of vessel. The first one is a mega-yacht about 70 meters long. It represents a common unit sailing in the Mediterranean and adjacent seas. The main data and loading condition information are reported in Table 1. This unit has been subject of an extensive campaign of applications (Petacco et al., 2020; Petacco & Gualeni, 2018) pointing out that some stability failures comply with the corresponding criteria, hence no OL nor OG are required in principle. Therefore, in order to identify a more challenging situation for this unit, it has been deemed reasonable investigate it at the end of its life: a raising of the centre of gravity of about 10% and an increase of about 5% of the displacement have been considered. The updated loading information are given in Table 2.

Table 1. Main data about the mega-yacht unit

Main data and loading condition		
L_{PP}	64,94	[m]
B	13,20	[m]
D	7,50	[m]
d	3,30	[m]
Δ	1,629 x10^4	[t]
V_S	17,4	[kn]
VCG	5,50	[m]
LCG	31,74	[m]
GM	1,91	[m]
T_{roll}	8,35	[sec]
C_B	0,562	[-]

Table 2. Modified loading condition considering the vessel at the end of its life

Modified Loading condition		
d	3,47	[m]
Δ	1,721 x10^4	[t]
VCG	6,05	[m]
GM	1,01	[m]
T_{roll}	11,39	[sec]

The second typology of vessel analysed in this investigation is a representative RO-RO ferry. In Table 3 hull data and information about loading conditions are given. In this case, in order to identify vulnerabilities, a reduction of three meter of the ship breadth has been adopted.

Table 3. Main data about Ro-Ro pax ferry

Main data and loading condition		
L_{PP}	200,55	[m]
B	29,00	[m]
D	21,00	[m]
d	7,00	[m]
Δ	2,29 x10^4	[t]
V_S	28,00	[kn]
VCG	13,50	[m]
LCG	85,33	[m]
GM	2.04	[m]
T_{roll}	15.52	[sec]
C_B	0.548	[-]

5. RESULTS

The results obtained by the applications described in the previous paragraph are presented below. In Figure 5, the maximum and minimum limiting KG are shown for the mega-yacht unit. Along the horizontal axis there is the draft, while on the vertical axis the limiting KG values are reported. The dashed lines represent the maximum KG limit evaluated for each stability failures. The continuous bold line shows the envelop of the dashed lines. The continuous line marked with triangle represents the minimum KG limit obtained by the application of the EA failure. The grey shaded area, between the minimum and maximum KG curves, shows the area compliant with all the stability failures at the same time. Finally, the black cross indicates the actual loading condition considered for this unit.

The same representation has been adopted also for the application to the RO-RO ferry, as shown in Figure 6. The outcomes point out that, for the considered loading conditions, both the vessels are not compliant with the vulnerability levels.

Considering this, if case a ship design modification is not viable, according to SGISc, two options are feasible: apply the more precise and time consuming DSA (a positive result cannot be given for granted however) or introduce some restrictions to the navigation by means of the operational measures. As first attempt, it has been decided to apply the OL related to geographical area. In particular, it has been deemed appropriate for the typologies of vessel analysed to consider a navigation limited to the Mediterranean Sea, the Red Sea and part of the Atlantic Ocean close to the Iberian coast (Figure 4). Outcomes of the application to the mega-yacht and the ferry are reported respectively in Figure 7 e Figure 8.

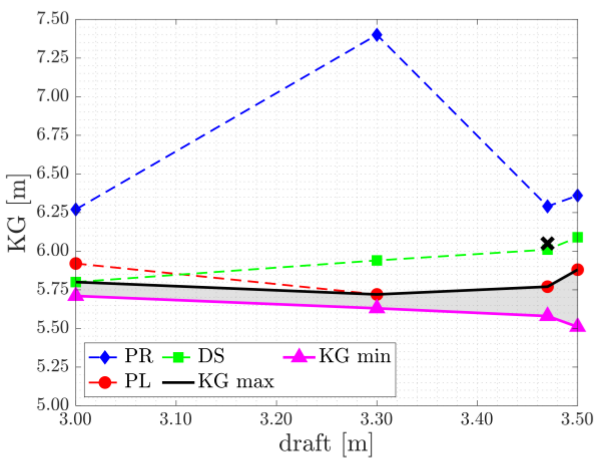

Figure 5: Limiting KG curves for the Mega-yacht unit.

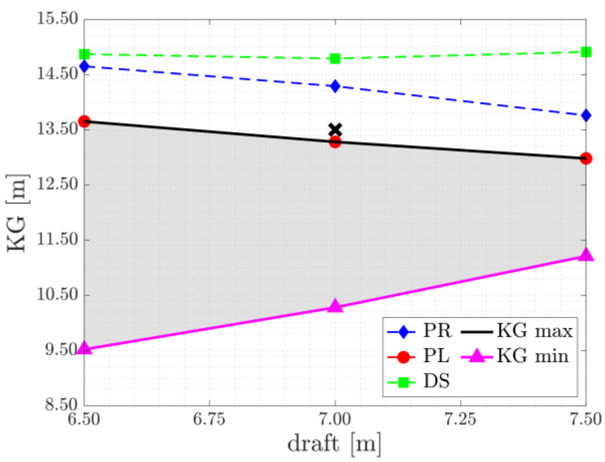

Figure 6: Limiting KG curves for the RO-RO ferry.

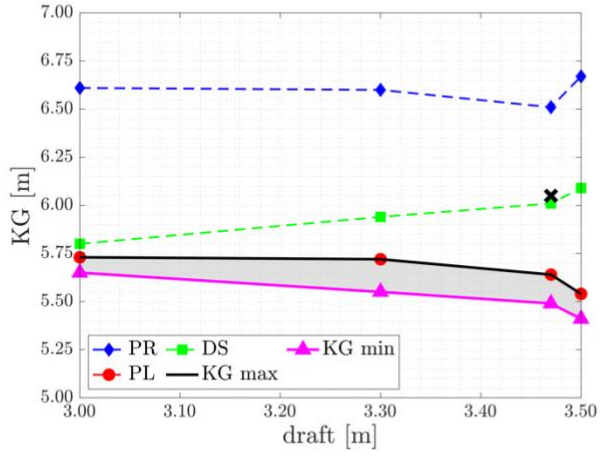

Figure 7: Limiting KG curves for the megayacht unit evaluated introducing the OL related to the geographical area.

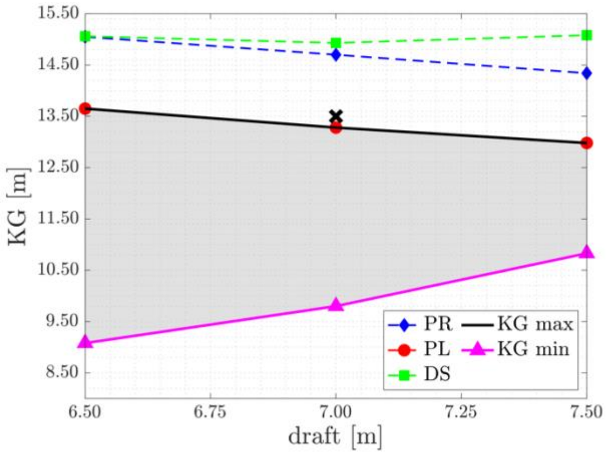

Figure 8: Limiting KG curves for the RO-RO ferry evaluated introducing the OL related to the geographical area.

As concerns the mega-yacht unit, it appears that there is a slight increase of the design space, even if this area has been shifted downward becoming more demanding in terms of maximum KG. Nevertheless, the unit continues to be not compliant with the SGISc. With reference to the RO-RO ferry, the upper limiting curve is unchanged while the minimum KG curve has been slightly lowered, resulting in a small increase of the design space. Also in this case, the vessel is still considered not compliant to all the addressed stability failures at the same time.

Table 4. Limiting KG values computed with and without the application of OL for the mega-yacht unit.

Maximum KG values – [m]				
Draft [m]	3,00	3,30	3,47	3,70
Without OL	5,80	5,72	5,77	5,88
With OL related to geo. area	5,80	5,73	5,64	5,54
With OL related to maximum H_s	5,80	5,72	5,77	5,88
Minimum KG values – [m]				
Draft [m]	3,00	3,30	3,47	3,70
Without OL	5,71	5,63	5,58	5,51
With OL related to geo. area	5,65	5,55	5,49	5,41
With OL related to maximum H_s	5,69	5,62	5,57	5,50

Table 5. Limiting KG values computed with and without the application of OL for the RO-RO ferry.

Draft [m]	6,50	7,00	7,50
Without OL	13,65	13,28	12,98
With OL related to geo. area	13,65	13,28	12,98
With OL related to maximum H_s	13,65	13,28	12,98
Draft [m]	6,50	7,00	7,50
Without OL	9,52	10,28	11,21
With OL related to geo. area	9,08	9,80	10,83
With OL related to maximum H_s	9,44	10,24	11,18

As second analysis, the application of OL related to a maximum significant wave height has been carried out. The outcomes point out that there is no modification in the limiting KG curves for the assessed units. The very same results obtained for the plain application of SGISc have been obtained, except for a few drafts where the negligible difference is about a few centimetres. The limiting KGs have been summarized in Table 4 and Table 5, respectively for the mega-yacht and the RO-RO ferry.

Despite the introduction of OL, it appears that the assessed vessels still continue to be vulnerable according to the SGISc. In this condition, the multi-layered approach allow to draw up the OG to be made available to the master. As indicted in the above paragraph, the simplified OG have been selected for this work. Regarding the PR stability failure, due to the strong simplifications introduced by this methodology, the OG suggest avoiding all wave directions for those speed deemed vulnerable. A general application to the mega-yacht unit is shown in Figure 9. In the polar diagram, the ship speed is reported along the radius while the angle indicates the wave heading; following sea is represented with heading of 180°. Also for the PL failure mode strong simplifications have been introduced, thus when a sea state is deemed unsafe waves approaching from beam to following seas must be avoided, for a speed higher than 12 [kn] when observing Figure 10. Although simplified OG have been applied for the EA failure mode, there are enough information to develop an adequate diagram. In Figure 11, on the same polar diagram, the guidance for the mega-yacht unit is reported, referring to a sea state having a zero-crossing period comparable to the natural roll period (T_{roll}). The polar diagram has been split in two parts, the left side refers to a sea state with a $H_s = 10.5\ [m]$, while the right

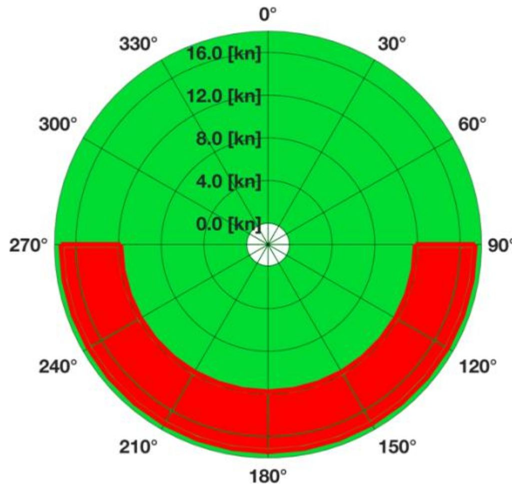

Figure 10: Generic example of simplified OG for the PL failure mode for those sea state considered as unsafe.

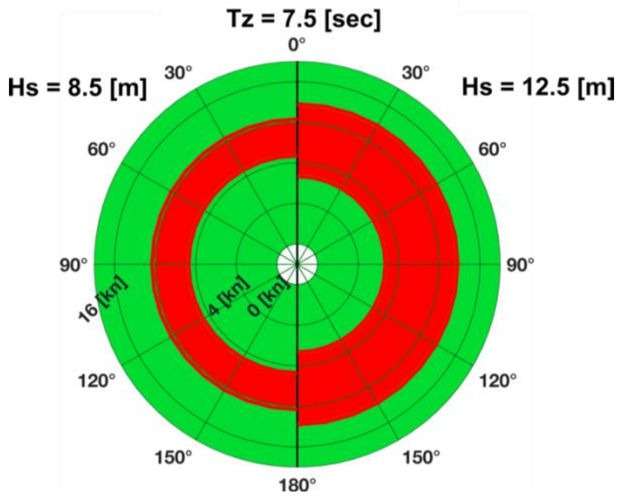

Figure 9: Example of simplified OG of PR for the mega-yacht unit referred to a sea state having a $T_z = 7.5\ [sec]$. The plot on the left side is evaluated for a $H_s = 8.5\ [m]$, the plot on the right side is referring to a $H_s = 12.5\ [m]$.

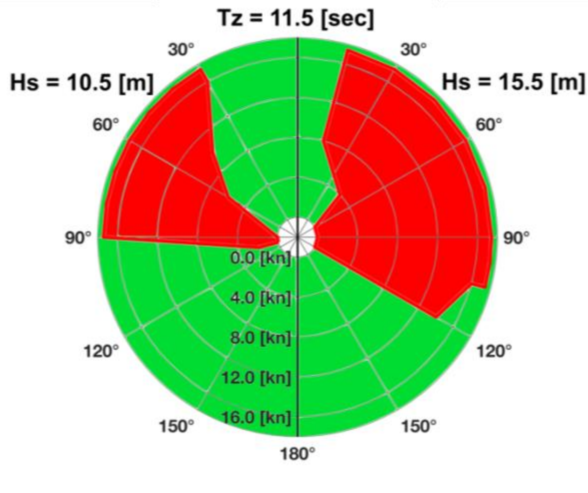

Figure 11: Example of simplified OG of EA for the mega-yacht unit referred to a sea state having a $T_z = 11.5\ [sec]$. The plot on the left side is evaluated for a $H_s = 10.5\ [m]$, the plot on the right side is referring to a $H_s = 15.5\ [m]$.

side refers to a $H_s = 15.5\,[m]$. The results point out that there is no need to develop any OG for the RO-RO as concern the EA failure mode. These seems acceptable since both the ferry and the mega-yacht are considered not vulnerable to this stability failure mode.

In Figure 12 and Figure 13 (see Appendix 1) those sea states that require an OG have been highlighted, respectively for the mega-yacht and the RO-RO. In particular, the cells of the wave scatter table for the North Atlantic Ocean have been evidenced in red color to show the sea states deemed unsafe; the grey color indicates those sea state having a statistical probability equal to zero. In both figures, a colored table is shown for each assessed stability failure, i.e., pure loss of stability, parametric roll and excessive acceleration. The fourth table is obtained by merging the above tables; it reports which sea state requires at least an OG referred to one of the considered stability failure mode.

According to the MSC Circular 1627 (2020), the loading condition of a vessel implementing the OG is considered as not acceptable if the ratio between the total duration of assumed situations which should be avoided to the total operational time is greater than 20%. The duration of a single situation (i.e., the combination of sea state and sailing condition) is evaluated taking into account the sea state probability, according to the wave scatter table, and the probabilities of each headings and speeds, which are considered uniformly distributed. In (1), it has been summarized the explicit formula of this ratio:

$$p_{OG_{h,t,\mu,v}} = f_s(H_s,T_z)f_\mu(\mu)f_v(v)\cdot \Delta H_s \Delta T_z \Delta\mu\Delta v$$

$$p_{TOT} = \sum_{h,t,\mu,v} \Delta Hs\Delta Tz\Delta\mu\Delta v \qquad (1)$$

$$K = \frac{\sum_{h,t,\mu,v}[p_{OG_{h},t,\mu,v}]}{p_{TOT}}$$

Where K is the above-mentioned ratio; $p_{OG_{h,t,\mu,v}}$ is the duration of a single assumed situation to be avoided; p_{TOT} is the total operational time; $f_s(H_S,T_Z)f_\mu(\mu)f_v(v)$ is the joint probability density function of sea state and sailing condition. The results of this application for the investigated vessels are reported in Table 6 and they are all well below the 20% value.

Table 6. Ratio between operational time affected by OG and total operational time

Operational Guidance acceptance			
K	PL	PR	EA
Mega-yacht	4.58 %	2.0 %	0.1 %
RO-RO	1.2 %	0.9 %	0.0 %

6. CONCLUSIONS

In this paper an overview about SGISc has been given, with a particular focus on the operational aspects. An interesting innovative aspect of these criteria is in fact the attention to operational measures about ship stability in a seaway condition, properly integrated in a larger multi-layered framework.

After a brief description of the criteria for the assessments during the design process (first and second vulnerability levels & direct stability assessment), the operational limitation and operational guidance have been defined in more details.

In particular, their relationship with the other tools defined in the SGISc framework has been pointed out. It can be stated that OG acts has an independent tool able to quantify ship vulnerability to a certain stability failure mode. On the contrary, the OL are more linked with the SGISc framework and need an assessment tool in order to be applied.

To enhance the qualitative insight on operational measures, a vulnerability analysis has been carried for two vessel typologies: a mega-yacht unit and a RO-RO ferry, that are assessed in conditions properly selected to put in evidence a certain level of vulnerability. After the application of first and second levels, which shown a vulnerability of both vessels, the operational measures have been applied.

As first limitation, it has been assumed a geographical restriction to the navigation. The outcomes of this limitation are not sufficient to consider the ship not vulnerable. Therefore, it seemed necessary to apply also the limitation related to maximum significant wave height. The wave height threshold has been selected in order to make comparable the outcomes; due to this assumption, the new results obtained are very similar to those of full application of vulnerability levels. In this application, it appears that the PL failure mode provides the most severe maximum allowed KG curve. It should be noted that no vulnerabilities have been noticed concerning the EA failure mode.

The analysis took into considerations also the OG, in their simplified version. Due to the large amount of sea state considered, only two examples of polar diagram are reported in this paper. The results point out a severe penalization for the ship activity, in fact strict constrains are to be applied at the navigation, e.g. certain sea state or following to beam waves must be avoided totally. This is directly related to the need to balance the simplifications introduced by the methodology and a sufficient level of safety. Thus it seems necessary to apply an enhanced version of guidance such as deterministic or probabilistic OG, which rely on a more accurate numerical simulation tool possibly enlarging the navigation domain. As concern guidance for EA, despite the simplifications, the results give sufficient information to reduce the vulnerability level keeping the navigation practicable.

Referring to an overview about the application of OG, it seems that the RO-RO ferry may bypass the vulnerability related to its design features by a few operational safeguards. In fact, the assumed situation to be avoided are always lower than 20% of total situation for all the stability failure. The same results are obtained for the mega-yacht unit; also in this case all the stability failure modes need guidance for an acceptable amount of assumed situation. This application demonstrates how the design and operational aspect may be combined to reach a sufficient level of safety. With particular reference to the investigated cases, this combination has been beneficial for the considered vessel. However, it is always preferable to fix stability in waves issues during the design process.

The IMO encourages the application of the SGISc in order to collect constructive feedbacks about their application. Moreover, a wide SGISc application increases the awareness of researchers and stakeholders involved in the ship design process, such as designer and shipbuilder. Through the outcomes of this work, it has been shown how the awareness about SGISc should also be spread among the on-board personnel. In fact, also proper action in the ship handling may significantly reduce the risk for the navigation.

7. REFERENCES

Bačkalov, I., Bulian, G., Rosén, A., Shigunov, V. and Themelis, N., 2016, "Improvement of ship stability and safety in intact condition through operational measures: challenges and opportunities", Ocean Engineering, pp. 353-361.

IMO, 2008, "Adoption of the International code on Intact Stability", MSC.Resolution 267(85) London, UK.

IMO, 2020, "Interim Guidelines on the Second Generation Intact Stability criteria", MSC.1/ Circular 1627, London, UK.

Kuroda, T., Hara, S., Houtani, H. and Ota, D., 2019, "Direct Stability Assessment for excessive acceleration failure mode and validation by model test" Ocean Engineering, Vol. 187.

Liwång, H., 2019, "Exposure, vulnerability and recoverability in relation to a ship's intact stability", Ocean Engineering, Vol. 187.

Petacco, N., 2019, "Second Generation Intact Stability Criteria: Analysis, Implementation and Applications to significant ship typologies", PhD Thesis, University of Genoa, Genoa, IT.

Petacco, N. and Gualeni, P., 2018, "A System Approach for Second Generation Intact Stability criteria compliance", Proceedings of 13rd International Conference on the Stability of Ships and Ocean Vehicles, pp. 261-270, Kobe, JP.

Petacco, N., Stio, G., and Gualeni, P., 2020, "Second Generation Intact Stability criteria: Application of operational limitations & guidance to a megayacht unit", MARTECH 2020 - Proceedings of the 5th International conference on Maritime Technology and Engineering, Lisbon, PT.

Peters, W. S. and Belenky, V., 2019, "On regulatory consistency of criteria for dead ship condition and pure loss of stability", Proceedings of the 17th International Ship Stability Workshop, pp. 71-80, Helsinki, FI.

Rudaković, S. and Bačkalov, I., 2019, "Operational limitations of a river-sea container vessel in the framework of the Second Generation Intact Stability Criteria", Ocean Engineering, Vol. 183, pp. 409-418

Shigunov, V., Themelis, N. and Spyrou, K., 2019, "Critical Wave Groups Versus Direct Monte-Carlo Simulations for Typical Stability Failure Modes of a Container Ship", Springer, Contemporary Ideas on Ship Stability, pp. 407-421, Cham, CH.

Tompuri, M., Ruponen, P. and Lindroth, D., 2017, "On the consistency of the level 1 and 2 vulnerability criteria in the Second Generation Intact Stability", Proceedings of the 16th International Ship Stability Workshop, pp. 3-8, Belgrade, RS.

U.S. Coast Guard, 2019, "Continued development of Second Generation Intact Stability criteria". Carderock Naval Architecture Division Report, USA.

Yang, S. H., 2020, "Study on the Parametric Rolling of Medium-Sized Containership Based on Nonlinear Time Domain Analysis" Proceeding of the ASME 2020 39th International conference on Offshore Mechanics and Arctic Engineering, Vol 6b:Ocean Engineering.

APPENDIX 1

Hereinafter the outcomes derived from OG application to the mega-yacht unit and to RO-RO ferry are shown. The cells in red show the unsafe sea states; the grey cells indicate those sea state having a statistical probability equal to zero. In both figures, a colored table is shown for each stability failure under investigation, i.e., pure loss of stability, parametric roll and excessive acceleration. The fourth table is obtained by merging the above tables; it reports which sea state requires at least an OG referred to the relevant stability failure mode.

Operational Guidance - Pure Loss of Stability

Significant wave height - Hs - [m]	Zero up-crossing period - Tz - [sec]															
	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5	11,5	12,5	13,5	14,5	15,5	16,5	17,5	18,5
0,5	0,13	13,37	86,56	118,60	63,42	18,63	3,69	0,56	0,07	0,01	0,00	0,00	0,00	0,00	0,00	0,00
1,5	0,00	2,93	98,60	497,60	773,80	556,97	237,57	70,35	16,07	3,05	0,51	0,08	0,01	0,00	0,00	0,00
2,5	0,00	0,22	19,75	215,88	623,00	744,95	486,04	206,60	64,45	16,02	3,37	0,63	0,11	0,02	0,00	0,00
3,5	0,00	0,02	3,49	69,55	322,65	567,50	509,91	283,80	111,41	33,77	8,43	1,82	0,35	0,06	0,01	0,00
4,5	0,00	0,00	0,60	19,61	135,43	328,85	385,75	268,55	127,52	45,51	13,09	3,19	0,69	0,13	0,02	0,00
5,5	0,00	0,00	0,10	5,10	49,84	160,29	237,27	200,83	112,60	46,36	15,09	4,10	0,97	0,21	0,04	0,01
6,5	0,00	0,00	0,02	1,26	16,70	69,03	125,79	126,86	82,59	38,68	14,08	4,22	1,09	0,25	0,05	0,01
7,5	0,00	0,00	0,00	0,30	5,21	27,01	59,44	70,32	52,49	27,67	11,17	3,67	1,02	0,25	0,06	0,01
8,5	0,00	0,00	0,00	0,07	1,54	9,79	25,59	35,06	29,69	17,46	7,76	2,77	0,84	0,22	0,05	0,01
9,5	0,00	0,00	0,00	0,02	0,43	3,32	10,19	15,99	15,22	9,92	4,83	1,87	0,61	0,17	0,04	0,01
10,5	0,00	0,00	0,00	0,00	0,12	1,07	3,79	6,75	7,17	5,15	2,73	1,14	0,40	0,12	0,03	0,01
11,5	0,00	0,00	0,00	0,00	0,03	0,33	1,33	2,66	3,14	2,47	1,42	0,64	0,24	0,07	0,02	0,01
12,5	0,00	0,00	0,00	0,00	0,01	0,10	0,44	0,99	1,28	1,10	0,68	0,33	0,13	0,04	0,01	0,00
13,5	0,00	0,00	0,00	0,00	0,00	0,03	0,14	0,35	0,50	0,46	0,31	0,16	0,07	0,02	0,01	0,00
14,5	0,00	0,00	0,00	0,00	0,00	0,01	0,04	0,12	0,18	0,18	0,13	0,07	0,03	0,01	0,00	0,00
15,5	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,04	0,06	0,07	0,05	0,03	0,01	0,01	0,00	0,00
16,5	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,02	0,02	0,02	0,01	0,01	0,00	0,00	0,00

Operational Guidance - Parametric Roll

Significant wave height - Hs - [m]	Zero up-crossing period - Tz - [sec]															
	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5	11,5	12,5	13,5	14,5	15,5	16,5	17,5	18,5
0,5	0,13	13,37	86,56	118,60	63,42	18,63	3,69	0,56	0,07	0,01	0,00	0,00	0,00	0,00	0,00	0,00
1,5	0,00	2,93	98,60	497,60	773,80	556,97	237,57	70,35	16,07	3,05	0,51	0,08	0,01	0,00	0,00	0,00
2,5	0,00	0,22	19,75	215,88	623,00	744,95	486,04	206,60	64,45	16,02	3,37	0,63	0,11	0,02	0,00	0,00
3,5	0,00	0,02	3,49	69,55	322,65	567,50	509,91	283,80	111,41	33,77	8,43	1,82	0,35	0,06	0,01	0,00
4,5	0,00	0,00	0,60	19,61	135,43	328,85	385,75	268,55	127,52	45,51	13,09	3,19	0,69	0,13	0,02	0,00
5,5	0,00	0,00	0,10	5,10	49,84	160,29	237,27	200,83	112,60	46,36	15,09	4,10	0,97	0,21	0,04	0,01
6,5	0,00	0,00	0,02	1,26	16,70	69,03	125,79	126,86	82,59	38,68	14,08	4,22	1,09	0,25	0,05	0,01
7,5	0,00	0,00	0,00	0,30	5,21	27,01	59,44	70,32	52,49	27,67	11,17	3,67	1,02	0,25	0,06	0,01
8,5	0,00	0,00	0,00	0,07	1,54	9,79	25,59	35,06	29,69	17,46	7,76	2,77	0,84	0,22	0,05	0,01
9,5	0,00	0,00	0,00	0,02	0,43	3,32	10,19	15,99	15,22	9,92	4,83	1,87	0,61	0,17	0,04	0,01
10,5	0,00	0,00	0,00	0,00	0,12	1,07	3,79	6,75	7,17	5,15	2,73	1,14	0,40	0,12	0,03	0,01
11,5	0,00	0,00	0,00	0,00	0,03	0,33	1,33	2,66	3,14	2,47	1,42	0,64	0,24	0,07	0,02	0,01
12,5	0,00	0,00	0,00	0,00	0,01	0,10	0,44	0,99	1,28	1,10	0,68	0,33	0,13	0,04	0,01	0,00
13,5	0,00	0,00	0,00	0,00	0,00	0,03	0,14	0,35	0,50	0,46	0,31	0,16	0,07	0,02	0,01	0,00
14,5	0,00	0,00	0,00	0,00	0,00	0,01	0,04	0,12	0,18	0,18	0,13	0,07	0,03	0,01	0,00	0,00
15,5	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,04	0,06	0,07	0,05	0,03	0,01	0,01	0,00	0,00
16,5	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,02	0,02	0,02	0,01	0,01	0,00	0,00	0,00

Operational Guidance - Excessive Acceleration

Significant wave height - Hs - [m]	Zero up-crossing period - Tz - [sec]															
	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5	11,5	12,5	13,5	14,5	15,5	16,5	17,5	18,5
0,5	0,13	13,37	86,56	118,60	63,42	18,63	3,69	0,56	0,07	0,01	0,00	0,00	0,00	0,00	0,00	0,00
1,5	0,00	2,93	98,60	497,60	773,80	556,97	237,57	70,35	16,07	3,05	0,51	0,08	0,01	0,00	0,00	0,00
2,5	0,00	0,22	19,75	215,88	623,00	744,95	486,04	206,60	64,45	16,02	3,37	0,63	0,11	0,02	0,00	0,00
3,5	0,00	0,02	3,49	69,55	322,65	567,50	509,91	283,80	111,41	33,77	8,43	1,82	0,35	0,06	0,01	0,00
4,5	0,00	0,00	0,60	19,61	135,43	328,85	385,75	268,55	127,52	45,51	13,09	3,19	0,69	0,13	0,02	0,00
5,5	0,00	0,00	0,10	5,10	49,84	160,29	237,27	200,83	112,60	46,36	15,09	4,10	0,97	0,21	0,04	0,01
6,5	0,00	0,00	0,02	1,26	16,70	69,03	125,79	126,86	82,59	38,68	14,08	4,22	1,09	0,25	0,05	0,01
7,5	0,00	0,00	0,00	0,30	5,21	27,01	59,44	70,32	52,49	27,67	11,17	3,67	1,02	0,25	0,06	0,01
8,5	0,00	0,00	0,00	0,07	1,54	9,79	25,59	35,06	29,69	17,46	7,76	2,77	0,84	0,22	0,05	0,01
9,5	0,00	0,00	0,00	0,02	0,43	3,32	10,19	15,99	15,22	9,92	4,83	1,87	0,61	0,17	0,04	0,01
10,5	0,00	0,00	0,00	0,00	0,12	1,07	3,79	6,75	7,17	5,15	2,73	1,14	0,40	0,12	0,03	0,01
11,5	0,00	0,00	0,00	0,00	0,03	0,33	1,33	2,66	3,14	2,47	1,42	0,64	0,24	0,07	0,02	0,01
12,5	0,00	0,00	0,00	0,00	0,01	0,10	0,44	0,99	1,28	1,10	0,68	0,33	0,13	0,04	0,01	0,00
13,5	0,00	0,00	0,00	0,00	0,00	0,03	0,14	0,35	0,50	0,46	0,31	0,16	0,07	0,02	0,01	0,00
14,5	0,00	0,00	0,00	0,00	0,00	0,01	0,04	0,12	0,18	0,18	0,13	0,07	0,03	0,01	0,00	0,00
15,5	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,04	0,06	0,07	0,05	0,03	0,01	0,01	0,00	0,00
16,5	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,02	0,02	0,02	0,01	0,01	0,00	0,00	0,00

Operational Guidance - Total

	Zero up-crossing period - Tz - [sec]															
	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5	11,5	12,5	13,5	14,5	15,5	16,5	17,5	18,5
0,5	0,13	13,37	86,56	118,60	63,42	18,63	3,69	0,56	0,07	0,01	0,00	0,00	0,00	0,00	0,00	0,00
1,5	0,00	2,93	98,60	497,60	773,80	556,97	237,57	70,35	16,07	3,05	0,51	0,08	0,01	0,00	0,00	0,00
2,5	0,00	0,22	19,75	215,88	623,00	744,95	486,04	206,60	64,45	16,02	3,37	0,63	0,11	0,02	0,00	0,00
3,5	0,00	0,02	3,49	69,55	322,65	567,50	509,91	283,80	111,41	33,77	8,43	1,82	0,35	0,06	0,01	0,00
4,5	0,00	0,00	0,60	19,61	135,43	328,85	385,75	268,55	127,52	45,51	13,09	3,19	0,69	0,13	0,02	0,00
5,5	0,00	0,00	0,10	5,10	49,84	160,29	237,27	200,83	112,60	46,36	15,09	4,10	0,97	0,21	0,04	0,01
6,5	0,00	0,00	0,02	1,26	16,70	69,03	125,79	126,86	82,59	38,68	14,08	4,22	1,09	0,25	0,05	0,01
7,5	0,00	0,00	0,00	0,30	5,21	27,01	59,44	70,32	52,49	27,67	11,17	3,67	1,02	0,25	0,06	0,01
8,5	0,00	0,00	0,00	0,07	1,54	9,79	25,59	35,06	29,69	17,46	7,76	2,77	0,84	0,22	0,05	0,01
9,5	0,00	0,00	0,00	0,02	0,43	3,32	10,19	15,99	15,22	9,92	4,83	1,87	0,61	0,17	0,04	0,01
10,5	0,00	0,00	0,00	0,00	0,12	1,07	3,79	6,75	7,17	5,15	2,73	1,14	0,40	0,12	0,03	0,01
11,5	0,00	0,00	0,00	0,00	0,03	0,33	1,33	2,66	3,14	2,47	1,42	0,64	0,24	0,07	0,02	0,01
12,5	0,00	0,00	0,00	0,00	0,01	0,10	0,44	0,99	1,28	1,10	0,68	0,33	0,13	0,04	0,01	0,00
13,5	0,00	0,00	0,00	0,00	0,00	0,03	0,14	0,35	0,50	0,46	0,31	0,16	0,07	0,02	0,01	0,00
14,5	0,00	0,00	0,00	0,00	0,00	0,01	0,04	0,12	0,18	0,18	0,13	0,07	0,03	0,01	0,00	0,00
15,5	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,04	0,06	0,07	0,05	0,03	0,01	0,01	0,00	0,00
16,5	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,02	0,02	0,02	0,01	0,01	0,00	0,00	0,00

Figure 12: Outcomes of OG application to the mega-yacht unit for pure loss of stability, parametric roll and excessive accelerations and the merge of all

Operational Guidance - Pure Loss of Stability

Significant wave height - Hs - [m]	Zero up-crossing period - Tz - [sec]															
	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5	11,5	12,5	13,5	14,5	15,5	16,5	17,5	18,5
0,5	0,13	13,37	86,56	118,60	63,42	18,63	3,69	0,56	0,07	0,01	0,00	0,00	0,00	0,00	0,00	0,00
1,5	0,00	2,93	98,60	497,60	773,80	556,97	237,57	70,35	16,07	3,05	0,51	0,08	0,01	0,00	0,00	0,00
2,5	0,00	0,22	19,75	215,88	623,00	744,95	486,04	206,60	64,45	16,02	3,37	0,63	0,11	0,02	0,00	0,00
3,5	0,00	0,02	3,49	69,55	322,65	567,50	509,91	283,80	111,41	33,77	8,43	1,82	0,35	0,06	0,01	0,00
4,5	0,00	0,00	0,60	19,61	135,43	328,85	385,75	268,55	127,52	45,51	13,09	3,19	0,69	0,13	0,02	0,00
5,5	0,00	0,00	0,10	5,10	49,84	160,29	237,27	200,83	112,60	46,36	15,09	4,10	0,97	0,21	0,04	0,01
6,5	0,00	0,00	0,02	1,26	16,70	69,03	125,79	126,86	82,59	38,68	14,08	4,22	1,09	0,25	0,05	0,01
7,5	0,00	0,00	0,00	0,30	5,21	27,01	59,44	70,32	52,49	27,67	11,17	3,67	1,02	0,25	0,06	0,01
8,5	0,00	0,00	0,00	0,07	1,54	9,79	25,59	35,06	29,69	17,46	7,76	2,77	0,84	0,22	0,05	0,01
9,5	0,00	0,00	0,00	0,02	0,43	3,32	10,19	15,99	15,22	9,92	4,83	1,87	0,61	0,17	0,04	0,01
10,5	0,00	0,00	0,00	0,00	0,12	1,07	3,79	6,75	7,17	5,15	2,73	1,14	0,40	0,12	0,03	0,01
11,5	0,00	0,00	0,00	0,00	0,03	0,33	1,33	2,66	3,14	2,47	1,42	0,64	0,24	0,07	0,02	0,01
12,5	0,00	0,00	0,00	0,00	0,01	0,10	0,44	0,99	1,28	1,10	0,68	0,33	0,13	0,04	0,01	0,00
13,5	0,00	0,00	0,00	0,00	0,00	0,03	0,14	0,35	0,50	0,46	0,31	0,16	0,07	0,02	0,01	0,00
14,5	0,00	0,00	0,00	0,00	0,00	0,01	0,04	0,12	0,18	0,18	0,13	0,07	0,03	0,01	0,00	0,00
15,5	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,04	0,06	0,07	0,05	0,03	0,01	0,01	0,00	0,00
16,5	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,02	0,02	0,02	0,01	0,01	0,00	0,00	0,00

Operational Guidance - Parametric Roll

Significant wave height - Hs - [m]	Zero up-crossing period - Tz - [sec]															
	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5	11,5	12,5	13,5	14,5	15,5	16,5	17,5	18,5
0,5	0,13	13,37	86,56	118,60	63,42	18,63	3,69	0,56	0,07	0,01	0,00	0,00	0,00	0,00	0,00	0,00
1,5	0,00	2,93	98,60	497,60	773,80	556,97	237,57	70,35	16,07	3,05	0,51	0,08	0,01	0,00	0,00	0,00
2,5	0,00	0,22	19,75	215,88	623,00	744,95	486,04	206,60	64,45	16,02	3,37	0,63	0,11	0,02	0,00	0,00
3,5	0,00	0,02	3,49	69,55	322,65	567,50	509,91	283,80	111,41	33,77	8,43	1,82	0,35	0,06	0,01	0,00
4,5	0,00	0,00	0,60	19,61	135,43	328,85	385,75	268,55	127,52	45,51	13,09	3,19	0,69	0,13	0,02	0,00
5,5	0,00	0,00	0,10	5,10	49,84	160,29	237,27	200,83	112,60	46,36	15,09	4,10	0,97	0,21	0,04	0,01
6,5	0,00	0,00	0,02	1,26	16,70	69,03	125,79	126,86	82,59	38,68	14,08	4,22	1,09	0,25	0,05	0,01
7,5	0,00	0,00	0,00	0,30	5,21	27,01	59,44	70,32	52,49	27,67	11,17	3,67	1,02	0,25	0,06	0,01
8,5	0,00	0,00	0,00	0,07	1,54	9,79	25,59	35,06	29,69	17,46	7,76	2,77	0,84	0,22	0,05	0,01
9,5	0,00	0,00	0,00	0,02	0,43	3,32	10,19	15,99	15,22	9,92	4,83	1,87	0,61	0,17	0,04	0,01
10,5	0,00	0,00	0,00	0,00	0,12	1,07	3,79	6,75	7,17	5,15	2,73	1,14	0,40	0,12	0,03	0,01
11,5	0,00	0,00	0,00	0,00	0,03	0,33	1,33	2,66	3,14	2,47	1,42	0,64	0,24	0,07	0,02	0,01
12,5	0,00	0,00	0,00	0,00	0,01	0,10	0,44	0,99	1,28	1,10	0,68	0,33	0,13	0,04	0,01	0,00
13,5	0,00	0,00	0,00	0,00	0,00	0,03	0,14	0,35	0,50	0,46	0,31	0,16	0,07	0,02	0,01	0,00
14,5	0,00	0,00	0,00	0,00	0,00	0,01	0,04	0,12	0,18	0,18	0,13	0,07	0,03	0,01	0,00	0,00
15,5	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,04	0,06	0,07	0,05	0,03	0,01	0,01	0,00	0,00
16,5	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,02	0,02	0,02	0,01	0,01	0,00	0,00	0,00

Operational Guidance - Excessive Acceleration

Significant wave height - Hs - [m]	Zero up-crossing period - Tz - [sec]															
	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5	11,5	12,5	13,5	14,5	15,5	16,5	17,5	18,5
0,5	0,13	13,37	86,56	118,60	63,42	18,63	3,69	0,56	0,07	0,01	0,00	0,00	0,00	0,00	0,00	0,00
1,5	0,00	2,93	98,60	497,60	773,80	556,97	237,57	70,35	16,07	3,05	0,51	0,08	0,01	0,00	0,00	0,00
2,5	0,00	0,22	19,75	215,88	623,00	744,95	486,04	206,60	64,45	16,02	3,37	0,63	0,11	0,02	0,00	0,00
3,5	0,00	0,02	3,49	69,55	322,65	567,50	509,91	283,80	111,41	33,77	8,43	1,82	0,35	0,06	0,01	0,00
4,5	0,00	0,00	0,60	19,61	135,43	328,85	385,75	268,55	127,52	45,51	13,09	3,19	0,69	0,13	0,02	0,00
5,5	0,00	0,00	0,10	5,10	49,84	160,29	237,27	200,83	112,60	46,36	15,09	4,10	0,97	0,21	0,04	0,01
6,5	0,00	0,00	0,02	1,26	16,70	69,03	125,79	126,86	82,59	38,68	14,08	4,22	1,09	0,25	0,05	0,01
7,5	0,00	0,00	0,00	0,30	5,21	27,01	59,44	70,32	52,49	27,67	11,17	3,67	1,02	0,25	0,06	0,01
8,5	0,00	0,00	0,00	0,07	1,54	9,79	25,59	35,06	29,69	17,46	7,76	2,77	0,84	0,22	0,05	0,01
9,5	0,00	0,00	0,00	0,02	0,43	3,32	10,19	15,99	15,22	9,92	4,83	1,87	0,61	0,17	0,04	0,01
10,5	0,00	0,00	0,00	0,00	0,12	1,07	3,79	6,75	7,17	5,15	2,73	1,14	0,40	0,12	0,03	0,01
11,5	0,00	0,00	0,00	0,00	0,03	0,33	1,33	2,66	3,14	2,47	1,42	0,64	0,24	0,07	0,02	0,01
12,5	0,00	0,00	0,00	0,00	0,01	0,10	0,44	0,99	1,28	1,10	0,68	0,33	0,13	0,04	0,01	0,00
13,5	0,00	0,00	0,00	0,00	0,00	0,03	0,14	0,35	0,50	0,46	0,31	0,16	0,07	0,02	0,01	0,00
14,5	0,00	0,00	0,00	0,00	0,00	0,01	0,04	0,12	0,18	0,18	0,13	0,07	0,03	0,01	0,00	0,00
15,5	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,04	0,06	0,07	0,05	0,03	0,01	0,01	0,00	0,00
16,5	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,02	0,02	0,02	0,01	0,01	0,00	0,00	0,00

Operational Guidance - Total

Significant wave height - Hs - [m]	Zero up-crossing period - Tz - [sec]															
	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5	11,5	12,5	13,5	14,5	15,5	16,5	17,5	18,5
0,5	0,13	13,37	86,56	118,60	63,42	18,63	3,69	0,56	0,07	0,01	0,00	0,00	0,00	0,00	0,00	0,00
1,5	0,00	2,93	98,60	497,60	773,80	556,97	237,57	70,35	16,07	3,05	0,51	0,08	0,01	0,00	0,00	0,00
2,5	0,00	0,22	19,75	215,88	623,00	744,95	486,04	206,60	64,45	16,02	3,37	0,63	0,11	0,02	0,00	0,00
3,5	0,00	0,02	3,49	69,55	322,65	567,50	509,91	283,80	111,41	33,77	8,43	1,82	0,35	0,06	0,01	0,00
4,5	0,00	0,00	0,60	19,61	135,43	328,85	385,75	268,55	127,52	45,51	13,09	3,19	0,69	0,13	0,02	0,00
5,5	0,00	0,00	0,10	5,10	49,84	160,29	237,27	200,83	112,60	46,36	15,09	4,10	0,97	0,21	0,04	0,01
6,5	0,00	0,00	0,02	1,26	16,70	69,03	125,79	126,86	82,59	38,68	14,08	4,22	1,09	0,25	0,05	0,01
7,5	0,00	0,00	0,00	0,30	5,21	27,01	59,44	70,32	52,49	27,67	11,17	3,67	1,02	0,25	0,06	0,01
8,5	0,00	0,00	0,00	0,07	1,54	9,79	25,59	35,06	29,69	17,46	7,76	2,77	0,84	0,22	0,05	0,01
9,5	0,00	0,00	0,00	0,02	0,43	3,32	10,19	15,99	15,22	9,92	4,83	1,87	0,61	0,17	0,04	0,01
10,5	0,00	0,00	0,00	0,00	0,12	1,07	3,79	6,75	7,17	5,15	2,73	1,14	0,40	0,12	0,03	0,01
11,5	0,00	0,00	0,00	0,00	0,03	0,33	1,33	2,66	3,14	2,47	1,42	0,64	0,24	0,07	0,02	0,01
12,5	0,00	0,00	0,00	0,00	0,01	0,10	0,44	0,99	1,28	1,10	0,68	0,33	0,13	0,04	0,01	0,00
13,5	0,00	0,00	0,00	0,00	0,00	0,03	0,14	0,35	0,50	0,46	0,31	0,16	0,07	0,02	0,01	0,00
14,5	0,00	0,00	0,00	0,00	0,00	0,01	0,04	0,12	0,18	0,18	0,13	0,07	0,03	0,01	0,00	0,00
15,5	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,04	0,06	0,07	0,05	0,03	0,01	0,01	0,00	0,00
16,5	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,02	0,02	0,02	0,01	0,01	0,00	0,00	0,00

Figure 13: Outcomes of OG application to a RO-RO ferry for pure loss of stability, parametric roll and excessive accelerations and the merge of all