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Article

Development and Comparison of Regional/Seasonal Wave Scatter Table using Hindcast Data for Simplified Operational Measures of Ships

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Abstract: The operational measure (OM) of the Second-Generation Intact Stability Criteria (SGISC) is the initial step toward the design of a performance-based dynamic stability assessment of the ship by considering both the vessel's operation, loading condition and weather parameters. The SGISC recommends the standard wave scatter table (WST) for the environmental data, an indefinite requirement for a simplified assessment pathway, which provides the probability of wave occurrence. The existing standard WST was developed based on the North Atlantic Ocean. This study aims to identify the discrepancy in the probability of wave occurrence in the IMO-recommended WST when compared with developed hindcast WST for smaller regions of the North Atlantic Ocean for the application of SGISC. The significant difference in the existing standard WST is identified when compared with hindcast data, especially across different seasons. A case study of OM on the C11 class post-Panamax container ship for excessive acceleration is provided to better represent the study. The identified limitation limits the use of standard WST in ship stability assessment. The study recommends using hindcast-based WST for SGISC applications that are region and season based. This recommendation is beneficial in improving the safety assessment by OM, given the data is reliable and available for the season and region-specific, and hence the accuracy of the ship stability can be improved while using for the SGISC OM assessment. Further, it makes the WST adhere to the actual framework of the SGISC, i.e., using existing environmental data for design assessment and improving the simplified stability analysis.

Keywords: Wave scatter table; operational measures; second generation intact stability criteria; hindcast wave scatter table; hindcast data;

1. Introduction

The Second-Generation Intact Stability Criteria (SCISC) is the dynamic design stability assessment of a ship, endorsed and adopted by the International Maritime Organisation (IMO), and finalised at the 7th session of the (IMO) sub-committee, which was held in February 2020(IMO, 2020). A final draft of the explanatory notes for evaluating the ship using the SGISC is a working process (IMO, 2021) and is delayed due to the COVID outbreak. In the SGISC, a three-tier assessment pathway is defined, with increased complexity on assessment down the pathway, namely Vulnerability Criteria ONE (VC1)[1], Vulnerability Criteria TWO (VC2)[2] and Direct Stability Assessment for five-ship dynamic failure modes. Each path in the SGISC is independent; thus, successful validation of the ships using any individual path is acceptable. The SGISC also addresses the operational aspect

[1] Vulnerability criteria one is the simplest stability assessment method available in SGISC.

[2] Vulnerability criteria two is the simplest probabilistic stability assessment pathway in SGISC.

through operational measures with the above pathways: Simplified operational measures using VC1 and VC2, Probabilistic and Deterministic operational measures using the direct stability assessment pathway. The operational measure encompasses operational limitation and operational guidance, where the former limits the conditions in which a ship can operate if it fails to meet the safety standard, while the latter recommends operating parameters for conditions limited by the former(IMO, 2020; Petacco & Gualeni, 2020).

All design assessment pathways in the SGISC require three input factors: the environmental factor, the ship's internal loading conditions and the ship's design parameters. The environmental condition is the most challenging among the considered input factors, especially when developing Operational Measures (OM). Accurate environmental data is required to identify operational limitations and operational guidance parameters. Meanwhile, simplified OM uses Wave Scatter Table (WST), which is historical wave data statistics. The SGISC provides no specific directions to incorporate real-time weather data while using WST for effective OM (Marlantes et al., 2022). The WST provides the probability of wave occurrence as a function of significant wave height and zero-crossing period. The SGISC recommends using the standard WST figure 1 to assess the dynamic behaviour of a ship.

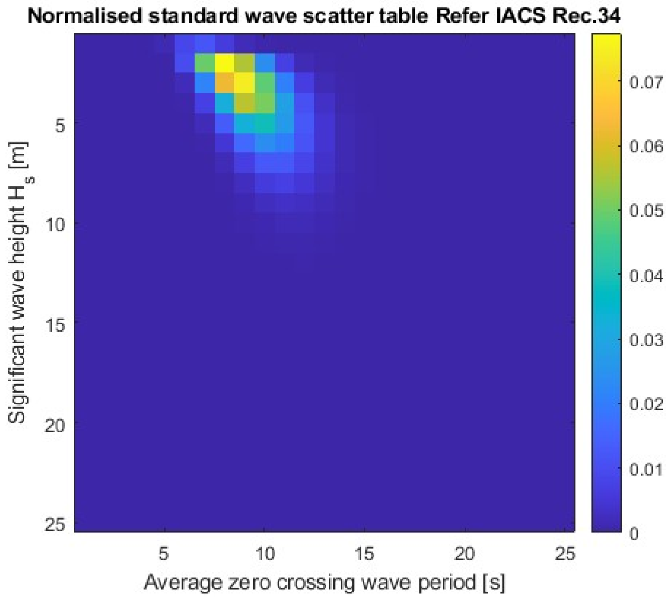

Figure 1:Existing Standard WST (Sea area 8, 9, 15 and 16)(IMO, 2020).

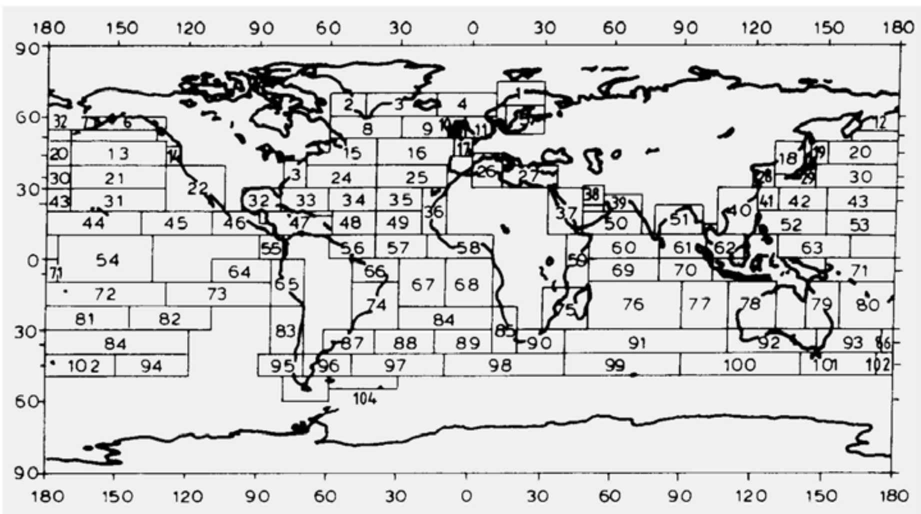

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Figure 2: Sea area nomenclature (IACS, 2001).

BMT UK provides the WST's for 104 sea areas, as shown in figure 2 (Hogben, 1986; IACS, 2001), including four seasons annually. However, the WSTs are not available for all seasons and all sea areas defined in the globe. The individual WST for the regions and seasons is an example of local WST. The WST is based on visual observations of the wave's relative motion with respect to the ship's direction, which is reported to the Main Marine Databank of the UK Meteorological Office from ships operating in specific regions. The data is collected randomly at different conditions by different observers over the years. It is worth mentioning that standard WST only covers sea areas 8, 9, 15, and 16 as defined in (BMT, 2011). The stored wave data is quality controlled and enhanced by the well-validated NMIMET method. NMIMET method takes into account swell, but the wave period estimates are expected to be less reliable in areas where the swell is a major component of the climate (such as in tropical region)(BMT, 2011). Also, the data do not reflect on areas prone to Typhoons or Hurricanes as it is unlikely to have a visual observation of this region because ships are operated to avoid regions of rough sea. These limitations are barriers to estimating a reasonably acceptable ship's dynamic behaviour using the simplified SGISC. The following paragraph outlines the application of the standard and the modified WST on the simplified OM assessment of the SGISC.

The pathway to estimate ship stability using vulnerability criteria and simplified operational measures is addressed in (IMO, 2020; Marlantes et al., 2022) and (Petacco & Gualeni, 2020), respectively. For a ship to have unrestricted operation, the ship must pass the threshold criteria laid out in the SGISC. The ship which fails to meet the threshold criteria with the standard WST can use a modified WST, limiting the operation to the modified WST's location, route, or season. Further, the operational limitations could be defined at specific significant wave height for standard WST or modified WST based on a given SGISC assessment. This process limits the operation of the ship to a defined significant wave height across the globe if assessed against standard WST or restricted to modified WST's region, route, or season. However, failure to achieve a successful combination with operational limitations, the ship can operate with the operational guidance based on the modified or the standard WST if the design assessment is accepted. This allows the ship to operate with the operational parameters advised. The above combination of operational limitation and operation guidance is only accepted if the ship's total operation failure time to the total ship operation time estimated based on the standard or modified WST is less than 0.2 for the considered operation limitation and operation guidance (IMO, 2020; Petacco & Gualeni, 2020).

Therefore, the operational time for a ship considering individual wave is important to estimate acceptance criteria and is defined by the magnitude of the probability of occurrence of the wave in the WST. The total operational time is the summation of individual operating time in encountering each wave case with non-zero probability in the WST. The change in the WST will result in a change in the probability distribution of wave occurrence and hence the operating time. Thus, the individual operating time of the ship in encountering each wave varies with different WST. On the other hand, changing the WST according to region, season, and route gives a more accurate reading of wave probability with respect to time and location(González et al., 2015; Marlantes et al., 2022). By doing so, the OM will be defined based on the actual operating condition, i.e., the region and seasonal circumstance; thus, using modified WST improves the accuracy of weather data and further the accuracy of design assessment. Therefore, it is vital to verify the representation of the wave and its probability of occurrence in the WST used for the SCISC assessment. This paper investigates the existing standard WST representation of the wave profile when compared to individual sea areas. The investigation compares the quality and representativeness of waves in the recommended standard WST with hindcast data WST and compares OM outcomes for both region and season. The novelty of this paper appears in investigating the need for regional and seasonal WST over the standard WST.

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The use of real-time weather data is a different approach compared to intact stability regulations given in the 2008 IS Code(IMO, 2008). It allows for achieving real-time operational stability using SGISC. Two factors are considered important; real-time weather data and ship operation status to achieve the required assessment. The forecasted WST can be used for the ship operation guidance if data is available for number of days. Therefore, real-time ship stability analysis during operation will emerge as a systematic, regulated and recognised approach(Bačkalov et al., 2016).

A significant amount of research is in progress to regulate the practical application of simplified operational measures, some of which include studies addressing operational limitations (Tompuri et al., 2016) based on standard WST or modified WST. Also, some research focuses on variation in stability estimation when the different weather data source is used (Bulian & Orlandi, 2022). Meanwhile, other studies (Hashimoto et al., 2017) used a numerical approach by incorporating operational limitations and route navigation simulations to assess the failure modes and using ship traffic-based AIS data (Hashimoto & Furusho, 2022). However, the limits on recommended standard WST are not assessed, given that successful validation with the same will achieve ships with unrestricted operation. Therefore, it is important to assess recommended standard WST's safety limit that holds valid for major seasons and regions. However, such a study is not available and is carried out in this paper using hindcast data. The study allows to identify the existing limitation of standard WST.

The following paper is outlined as follows. Section 2 discusses the methodology used for the study, Section 3 briefly describes the ship used for the case study, and section 4 covers the discussion and the result.

2. Methodology

In this section, the methodology is discussed by looking at the technique used for developing the local/modified WST, followed by the comparative study of the WSTs. The discussion extend to analysing the excessive acceleration operational limitation.

2.1. Developing Hindcast WST

Australian meteorological hindcast data is used to develop standard and local/seasonal WST for sea areas under consideration, i.e., North Atlantic Sea, given hindcast data is the most reliable source for historical weather data analysis. Bureau of Meteorology (BoM), Australia and CSIRO have developed a hindcast model called Centre for Australian Weather and Climate Research Wave Hindcast (CAWCR), which uses WAVEWATCH III, a numerical model, to provide higher resolution global meteorological data. The model has been well-validated and updated over the years (Durrant et al., 2014). It has undergone two updates in the past, and since June 2013, no significant configuration change has been made to the model. The data available has 0.4-degree spatial and hourly temporal resolution for the global data. The spatial resolution is higher for the region around Australia. For this study, the data from June 2013 to March 2022 with a spatial resolution of 0.4 degrees is used. The CSIRO provides free access to the hindcast model through the CISRO data server. The server is populated monthly with the previous month's hindcast file(Smith et al., 2021).

Table 1: Developed WST hindcast file parameters.

Wave Parameter	netCDF Variable Name	Reference Table Name
Significant wave height	hs	Mean sea WST (WSTM)
Mean period of first frequency moment	t01	
Significant wave height of wind sea	phs0	Wind sea WST (WSTW)
Peak period wind sea	ptp0	
Significant wave height of primary swell	phs1	Swell sea WST (WSTS)
Peak period of primary swell	ptp1	

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The monthly files (netCDF file format) required for the study are downloaded to the local system and striped for parameters shown in *Table 1* for the North Atlantic Sea. The temporal data of the North Atlantic Sea area are saved under individual sea area numbers, i.e., 8, 9, 15 and 16, to reduce the size of individual files. To further reduce the size of the file and for fast processing, each monthly sea area file is reduced to monthly WST for wind, swell and mean sea using an in-house developed algorithm. The algorithm is capable of developing WST for customised sea regions, including customised time for wind, swell and mean sea. The individual monthly WST is a 25 by 25 matrix and is stored in a structured format to m.files which is used for further analysis in this study. The data set developed is a simple way of looking into the sea state contribution of swell, wind and mean sea.

The monthly data are sorted as a function of wave height and zero-crossing wave period, and the occurrence of each state is counted to the respective matrix (mean, wind and swell). The matrix has unit meter and unit period resolution. The following data points are considered for generating a WST; significant wave height (hs) and mean period of first frequency moment (t01), significant wave height of wind sea (phs0) and peak period of wind sea (ptp0), significant wave height of primary swell (phs1) and peak period of primary swell (ptp1). The combinations make the mean sea WST, the wind sea WST, and the swell sea given in WST *Table 1*. *Eq 1* and *Eq 2* are used to estimate the zero-crossing wave period since it is not directly available from the peak and mean wave period. The CAWCR wave model uses the JONSWAP wave model to develop the hindcast wave model (Smith et al., 2021). The developed matric is called the local hindcast WST.

$$\frac{T_z}{T_P} = 0.6673 + 0.05037\gamma - 0.006230\gamma^2 + 0.0003341\gamma^3 \tag{1}$$

$$\frac{T_1}{T_P} = 0.7303 + 0.04936\gamma - 0.006556\gamma^2 + 0.0003610\gamma^3 \tag{2}$$

where T_z is zero-crossing period, T_1 is mean period, T_p is peak period, and γ is the peak shape parameter.

Table 2: File names.

Filename	Seasons/Period
Annual	Whole year (12 months)
Season 1	Mar to May (3 months)
Season 2	Jun to Aug (3 months)
Season 3	Sep to Nov (3 months)
Season 4	Dec to Feb (3 months)

From the monthly local hindcast WST, the annual and seasonal WST is developed by summing the monthly WST for respective months. The seasonal and annual WST is then summed up to consecutive 2, 5 and 10-year WST to investigate the sea state variation over the years. The sample size of the wave in each WST is different due to differences in the size of each sea area and also the temporal sampling length for each developed WST. Subsequently, the annual and seasonal WST are normalised such that the cumulative probability of occurrence of each table is one for better comparison study shown in Table 2. In this study, the 10-year data set is used, which is more appropriate for research that requires regional and seasonal WST.

2.2. WST Comparison

For the comparison study of the WST, the probability of wave occurrence is summed with respect to wave height to plot the probability density function (pdf) vs wave height for each WST. In order to carry out quick comparison of WST over regional and seasonal

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WST, each WST's pdf corresponding to the Rayleigh pdf function is mapped, and the Rayleigh shape parameter (α)is compared to identify the variation in WST. To carry out the mapping of the Rayleigh pdf to match the hindcast WST's pdf, the following three techniques were used: i) least square error method (LSE), ii) least area error method (LAE) and iii) least square error method for the peak of the curve (LSEP). The peak of the curve is the region above the mean probability of exceedance (MPoE) calculated using Eq 3. The smaller Rayleigh shape parameter means the spread is narrow with a sharp peak located closer to the lower wave height, while the larger shape parameter means the pdf is broad and flat and the peak of pdf is towards the higher wave height.

$$\text{MPoE}=\frac{1}{Maximum\ wave\ height\ with\ non\ zero\ probability\ of\ occurance} \tag{3}$$

2.3. Excessive acceleration vulnerability assessment and operational limitation

In this study, Excessive acceleration VC1 (IMO, 2020) is used to estimate the acceleration of C11 class post-Panamax container ship against each WST considered for this study which is seasonal and regional WST of sea areas 8, 9, 15 and 16. This study also incorporates the operational limitation methodology proposed by Bulian & Francescutto (Bulian & Francescutto, 2021) for dead ship VC1. In the Bulian's study, the wave steepness table is updated based on the WST to introduce operational limitations to the level one dead ship condition. The same methodology is used for level one excessive acceleration estimation. The details of Bulian's methodology are available from the reference paper, but the outline of the methodology used for this study is provided below.

Table 3: Standard wave steepness table(Bulian & Francescutto, 2021).

Wave age at natural roll period, β_r	**Wave steepness factor, s**
$\leq$0.360	0.100
0.420	0.098
0.480	0.093
0.721	0.065
0.841	0.053
0.961	0.044
1.081	0.038
1.201	0.032
1.321	0.028
1.441	0.025
1.561	0.023
1.681	0.021
$\geq$1.802	0.020

Excessive acceleration VC1 operational limitation.

1. Define the respective WST.
2. Estimate the mean wind speed for the WST at the probability of exceedance =1.2%. For IMO's recommended standard WST, the wave height and mean wind speed (V_w) at 1.2% probability of exceedance is 8.9m and 26 m/s, respectively.
3. Determine the modified wave steepness using table 3 and Eq 4 (Bulian & Francescutto, 2021).
4. Apply excessive acceleration vulnerability criteria one with the modified wave steepness table.

Using the modified wave steepness table, excessive acceleration for the C11 containership is estimated for comparison. The results of level one excessive acceleration operational limitation is compared with the example provided in appendix 2 of the IMO SGISC draft explanatory notes (IMO, 2021).

$$T_r = \frac{2\beta_r \pi V_w}{g} \tag{4}$$

where β_r is wave age at natural roll period, V_w is mean wind speed, and T_r is natural roll period

3. Sample Ship

The C11 class post-Panamax container ship is used for this study. The inputted data is from information available on the IMO example case study and hence appropriate to compare the algorithm developed in this study. The following table provides information required for the VC1 excessive acceleration estimation table 4.

Table 4: C11 class post-Panamax Container ship characteristics.

h_k, Height of the navigation deck above the keel, m	48.72
x, Longitudinal distance of the location where passenger or crew may be present from the aft perpendicular, m	177.41
Length, bp, m	262
Beam, m	40
Draft amidships, m	11.5
GM, m	1.4
KG, m	12.75
Block coefficient	0.56
Midship section coefficient	0.959
Bilge keel length ratio(l_{BK}/Lbp)	0.2921
Bilge keel height ratio(h_{BK}/B)	0.010

4. Results and Discussion

The discussion of the results in the following section is outlined in two folds. The first section validates and compares the hindcast data with the BMT global statistic data to provides insight into the outcome of the WST comparison. The second section discusses the outcome of the operational limitations using VC1 excessive acceleration.

4.1. WST Comparison

There are two sets of data used in this study. The BMT global statistic WST (hear after BGW) (Hogben, 1986) and WST developed from the Australian hindcast model (hear after AHD). Also, we have the standard WST recommended in the SGISC interim guidelines, which is similar to BGW data as it originated from BGW(IACS, 2001). Figure 1 shows the standard WST recommended by SGISC. Figure 3, 4 and 5 show the WST developed with hindcast mean, wind, and swell sea data for standard WST region (Sea area, 8, 9, 15, 16) (hereafter sea area S). All WST images are normalised for comparison.

Figure 6 shows the pdf of Standard WST provided in SGISC along with the associated Rayleigh pdf and Figure 7 shows the same for standard WST area using AHD mean sea state. It is evident from Figures 6 and 7 that AHD mean sea pdf and BGW pdfs are almost similar for the sea area S. Additionally, the Rayleigh shape parameter for individual sea areas and the standard WST sea area estimated using BGW data, AHD mean sea, AHD wind sea and swell sea are provided for comparison in Table 5. The statistical comparison of Table 5 is provided in Table 6. It is clear that the BGW has the highest mean shape parameter followed by AHD mean, AHD wind and AHD swell Table 6. This shows the assessed sea areas are wind dominant rather than swell, and the trend of sea state across all sea areas is the same, as the standard deviation is small. Hence evaluation of SGISC with standard WST is acceptable for all regions considered. Figure 8 shows the AHD swell sea state pdf, an example of a lower Rayleigh shape parameter.

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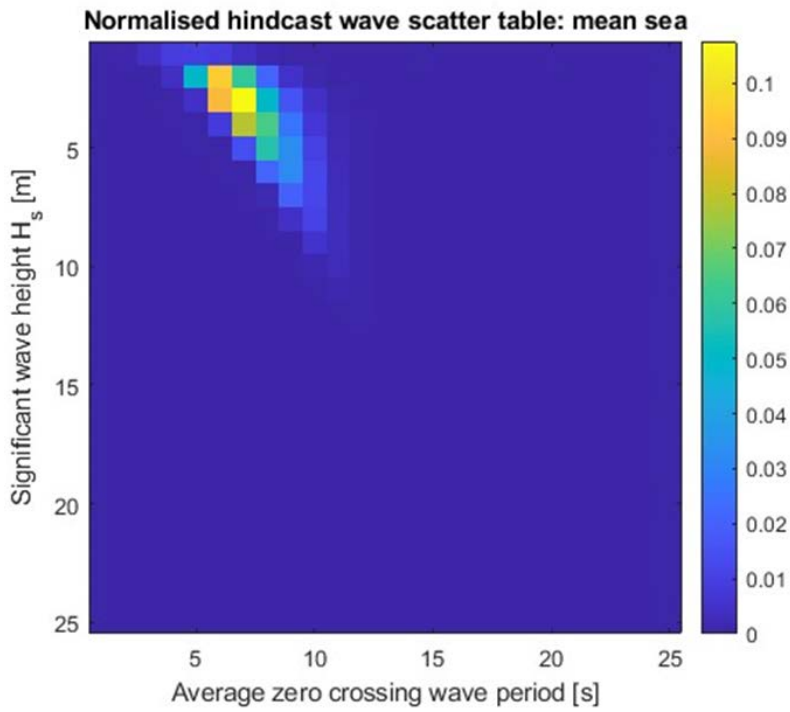

Figure 3: Hindcast WST for mean sea (sea area S- full year).

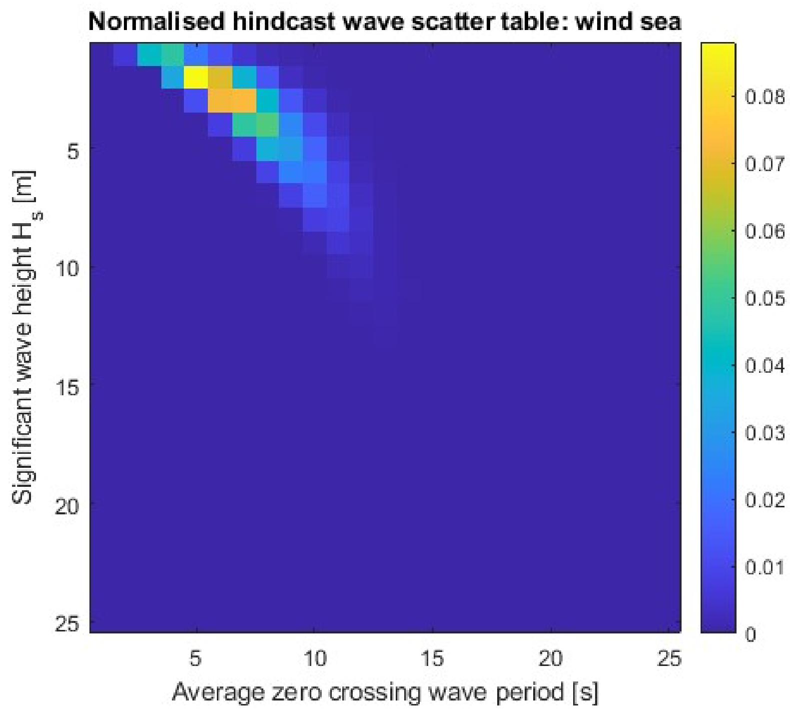

Figure 4:Hindcast WST for wind sea (sea area S- full year).

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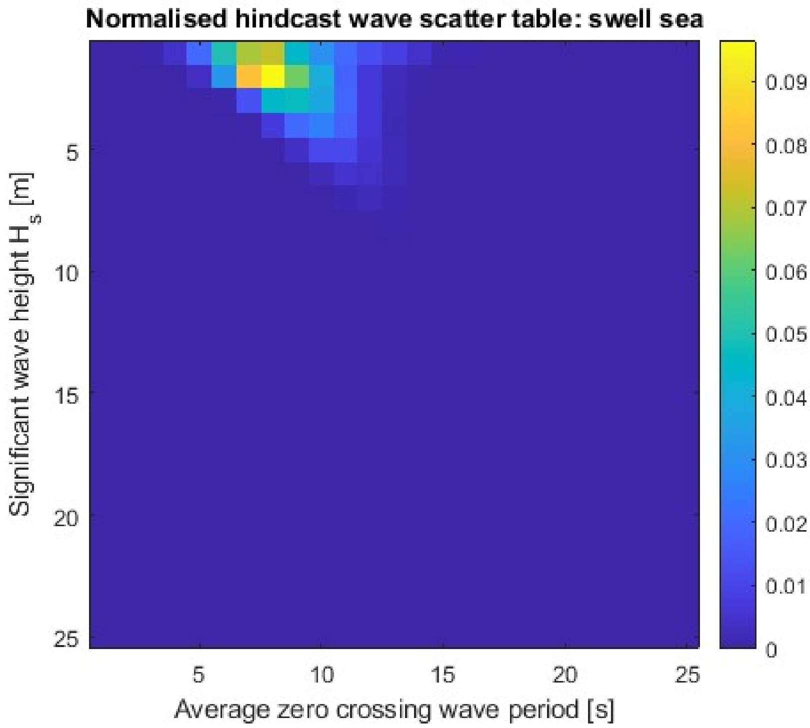

Figure 5: Hindcast WST for swell sea (sea area S- full year).

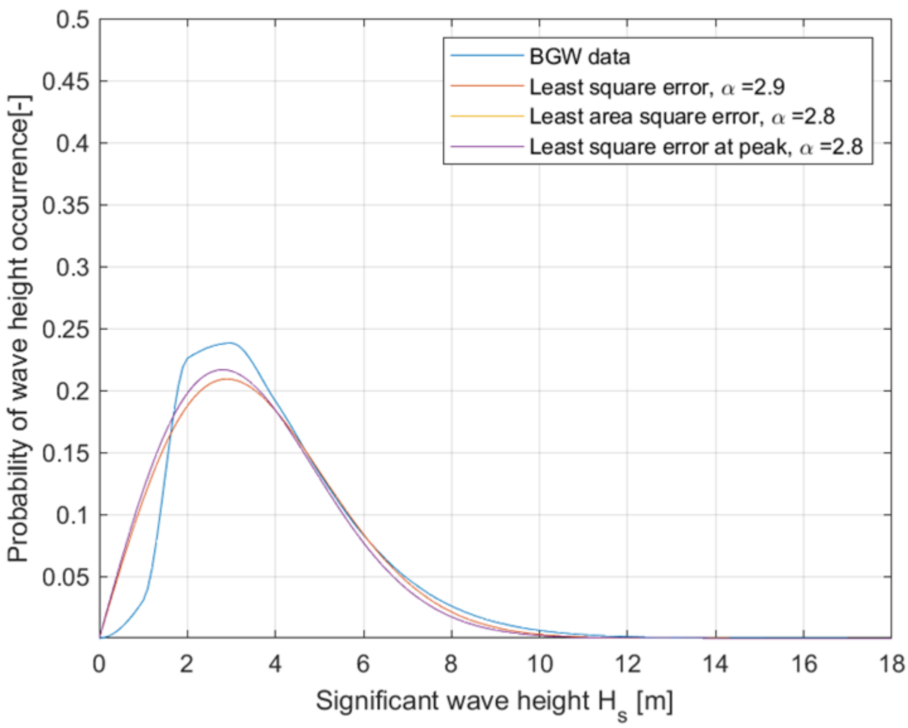

Figure 6: Plots of Standard WST pdf.

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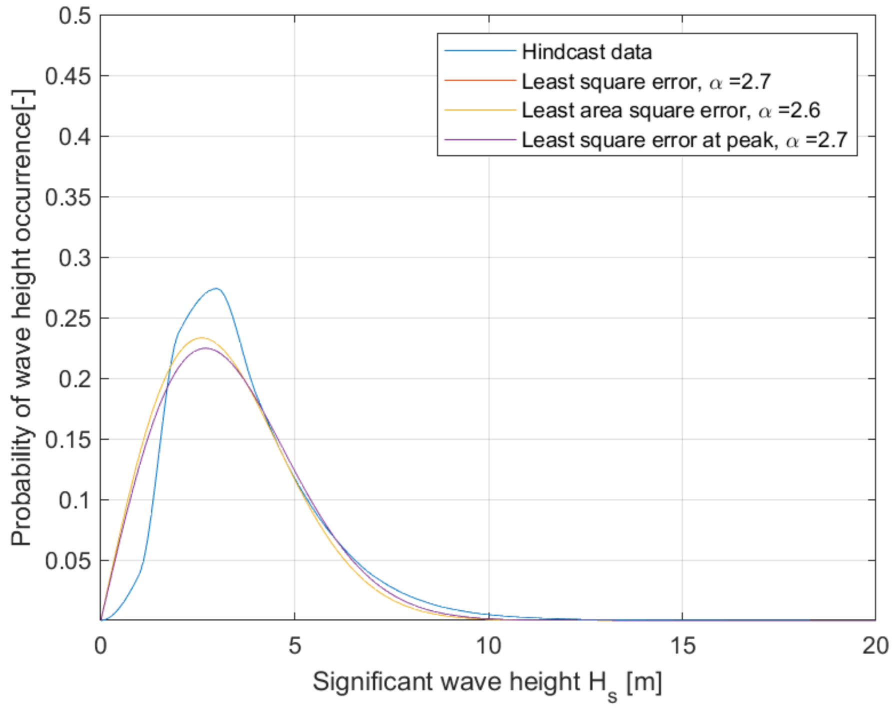

Figure 7: Plots of Standard WST mean sea pdf (sea area S- full year).

Table 5: Rayleigh shape parameter for full year.

Data / Sea area	LES				LAE				LSEP			
	BGW	AHD mean	AHD wind	AHD Swell	BGW	AHD mean	AHD wind	AHD Swell	BGW	AHD mean	AHD wind	AHD Swell
Sea area S	2.9	2.7	2.5	1.6	2.8	2.6	2.5	1.6	2.8	2.7	2.5	1.6
Sea area 8	3	2.8	2.6	1.5	2.9	2.7	2.6	1.6	2.9	2.7	2.6	1.5
Sea area 9	2.9	3	2.8	1.6	2.8	2.9	2.8	1.7	2.8	2.9	2.8	1.6
Sea area 15	2.6	2.4	2.1	1.3	2.5	2.3	2.1	1.3	2.5	2.3	2.1	1.3
Sea area 16	2.8	2.8	2.6	1.7	2.7	2.7	2.5	1.7	2.7	2.7	2.5	1.7

Table 6:Statistical comparison of Rayleigh shape parameter for mean, wind and swell sea pdf (sea area S-full year).

	BGW	AHD Mean Sea	AHD Wind Sea	AHD Swell Sea
Mean	2.773	2.68	2.50667	1.553
Standard deviation	0.148645	0.2077	0.237447	0.1457

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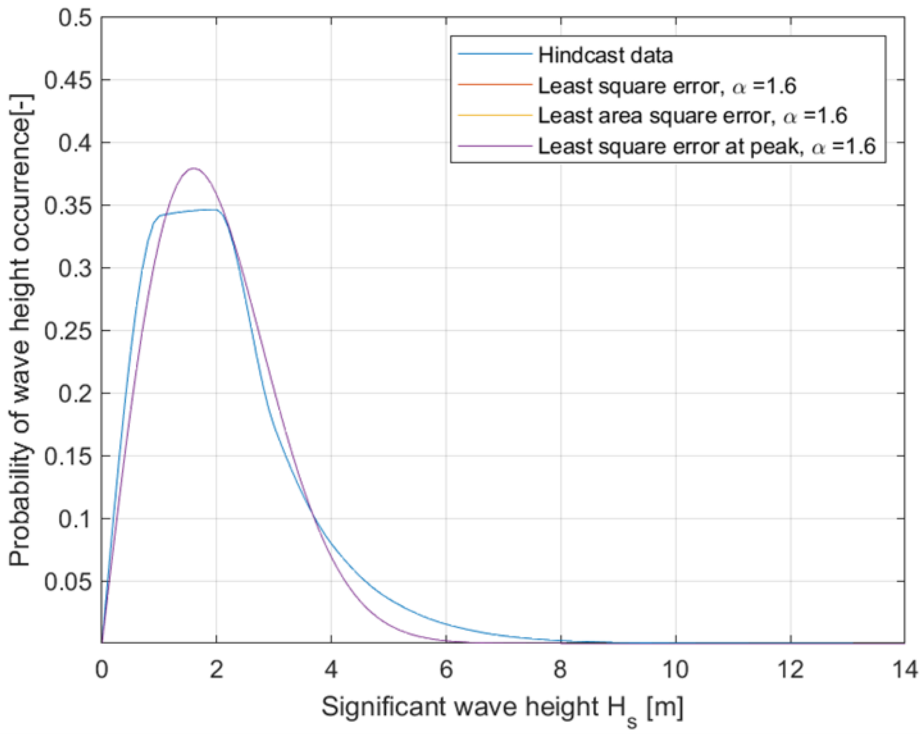

Figure 8: Plots of Standard WST swell sea pdf (sea area S- full year).

Similarly, for all sea areas, the seasonal WST is compared using the same technique. For this discussion, the AHD mean sea data is considered. Table 7 shows the Rayleigh shape factor comparison of WST for seasons 1 to 4. The statistical comparison of table 7 is provided in table 8, which shows the mean Rayleigh shape factor varies over the seasons, with the highest value in season 4 and the lowest in season 2. The average percentage change in shape factor, compared with the standard WST recommended by IMO, is provided in Table 8. The highest shape factor in the sea area is observed in sea area 9, which is 48% higher than standard WST (table 7). The percentage change shows the deviation of the shape parameter for seasonal WST from the annual shape parameter estimated in Table 6. This shows the sea area S go through different wave profile during each season. The effect would be much greater if the analysis carried out on monthly intervals than being seasonal. The higher shape factor for season 4 indicates that the WST of season 4 has a higher probability of occurrence for larger wave heights compared to other WST, and the highest is observed in season 4 in sea area 9 (figure 9). It is clear that in figure 9, the peak of pdf has increased, and the peak significant wave height moved to 5 m, from 3m given in (Figures 6 and 9). This illustrates a significant difference among seasonal WST; hence, merging seasonal and regional sea areas will result in an inaccurate depiction of the sea profile for SGISC application. Thus, the SGISC estimation using seasonal WST must be carried out to understand the significance of the probability of wave occurrence in seasonal WST. The following section is the case study of using seasonal WST for excessive acceleration estimation. Since the standard WST is modified to seasonal WST, the following is an example of seasonal and regional operational limitation estimates for the excessive acceleration.

Table 7: Rayleigh shape parameter for AHD data (mean sea).

	LES				LAE				LSEP			
Data / Sea area	Season 1	Season 2	Season 3	Season 4	Season 1	Season 2	Season 3	Season 4	Season 1	Season 2	Season 3	Season 4

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Sea area S	2.8	1.9	2.8	3.8	2.7	1.9	2.7	3.7	2.7	1.9	2.7	3.7
Sea area 8	2.9	2	3	3.8	2.8	2	2.9	3.7	2.9	1.9	2.8	3.8
Sea area 9	3	2.1	3.1	4.3	2.9	2.1	3	4.2	2.9	2	3	4.2
Sea area 15	2.5	1.8	2.4	3.1	2.4	1.8	2.3	3.1	2.5	1.8	2.4	3.1
Sea area 16	2.9	2	2.8	3.9	2.8	2	2.7	3.8	2.7	1.8	2.6	3.7

Table 8:Statistical comparison of Rayleigh shape parameter for season 1, 2, 3, 4.

	Season 1	Season 2	Season 3	Season 4
Mean	2.76	1.9133	2.746	3.7267
Standard deviation	0.1764	0.091548	0.2416	0.3788
S%	3.5%	28.2%	3%	39.7%
S%: Percentage change in shape parameter with respect to IMO recommended standard WST				

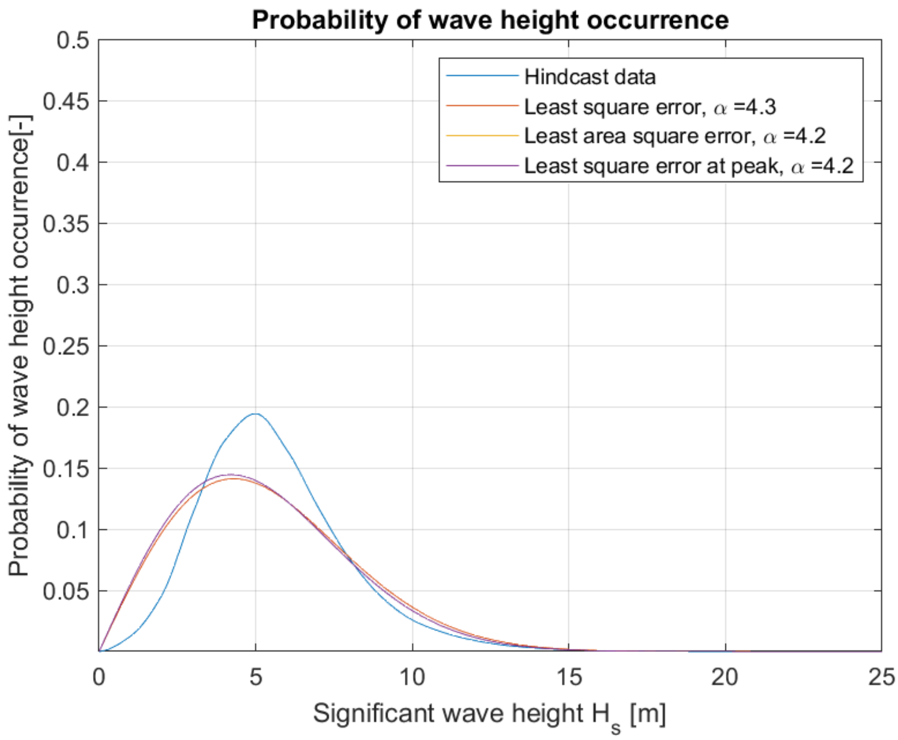

Figure 9: Plots of WST mean sea pdf (sea area 9- season4).

4.2. Excessive acceleration level one operational limitation

To this end, it is clear that WST varies significantly over the season for the considered sea area, hence the probability of wave occurrence. Therefore, this variation could negatively affect the estimation of simplified OM, given that modification of environmental factors is possible in achieving OM using VC1 and VC2. In this study, Bulian methodology, as discussed in section 2.3, is used to introduce operational limitations for evaluating excessive acceleration level one for C11 container ships. In the following discussion, only mean sea AHD data is considered, and a similar comparison could be made with AHD wind data. Tables 9 and 10 show the estimated wave height and wind speed for developed WST based on Bulian's method. The standard WST's wave height and wind speeds are 8.9 m and 26 m/s (green font). The value of the same parameters for the AHD estimate, which are higher than standard WST, is highlighted in red. Based on the developed table (Tables 9 and 10) the wave steepness table was developed for each WST to introduce seasonal and regional operational limitations. The wave steepness table for standard WST recommended by IMO (Table 11), mean AHD data sea area S full year (Table 12) and mean AHD data sea area S season 4 (Table 13) are given in tables. It is clear the wave steepness stable has changed significantly. With the modified WST and wave steepness table, the excessive acceleration of C11 is estimated using the VC1 equation outlined in section 2.3.1 of IMO, 2020.

Table 9: Significant wave height [m] at Probability of exceedance 1.2%.

Data	BGW	AHD				
WST	Annual	Annual	Season 1	Season 2	Season 3	Season 4
Sea area S	8.9	8.7	8	4.8	8	10.3
Sea area 8	8.8	8.7	8.1	4.9	8.3	11.8
Sea area 9	8.9	9.8	8.5	5.3	8.6	11.8
Sea area 15	8.2	7.3	7.3	4.1	6.7	8.4
Sea area 16	8.7	8.5	7.7	4.7	7.7	9.9

Table 10: Mean wind speed [m/s] corresponding to significant wave height estimated in table 13.

Data	BGW	AHD				
WST	Annual	Annual	Season 1	Season 2	Season 3	Season 4
Sea area S	25.9902	25.5994	24.2071	17.2204	24.2071	28.6489
Sea area 8	25.795	25.5994	24.4084	17.4588	24.8086	28.0899
Sea area 9	25.9902	27.7141	25.2055	18.3964	25.4028	31.3669
Sea area 15	24.6089	22.7736	22.7736	15.5026	21.508	25.0074
Sea area 16	25.5994	25.2055	23.5981	16.9804	23.5981	27.9023

Table 11: Standard wave steepness table standard WST(IMO, 2020).

Natural roll period, T_r	Wave steepness factor, s
$\leq$6.0	0.100
7.0	0.098
8.0	0.093
12.0	0.065
14.0	0.053
16.0	0.044
18.0	0.038
20.0	0.032
22.0	0.028
24.0	0.025
26.0	0.023
28.0	0.021
$\geq$30.0	0.020

Table 12:Standard wave steepness table AHD data (full year).

Natural roll period, T_r	Wave steepness factor, s
$\leq$5.9	0.100
6.9	0.098
7.9	0.093
11.8	0.065
13.8	0.053
15.7	0.044
17.7	0.038
19.7	0.032
21.7	0.028

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23.6	0.025
25.6	0.023
27.6	0.021
≥29.5	0.020

Table 13: Standard wave steepness table AHD data (Season 4).

Natural roll period, T_r	Wave steepness factor, s
≤6.6	0.100
7.7	0.098
8.8	0.093
13.2	0.065
15.4	0.053
17.6	0.044
19.8	0.038
22.0	0.032
24.2	0.028
26.4	0.025
28.6	0.023
30.8	0.021
≥33.0	0.020

To quantify the difference in using individual WST, the estimated excessive acceleration is compared to the example provided in IMO, 2021. Table 14 shows the estimated acceleration for the C11 container ship. It is apparent that the acceleration estimated by standard WST is less compared to season 4 results. The excessive acceleration provided in IMO 2021 is highlighted in green. In all WST cases considered in table 14, the ship is vulnerable to excessive acceleration since the estimated value is above the maximum limit of 4.64m/s². Let's assume 8.1m/s² is the cut-off for excessive acceleration for the following discussion. The ship assessed using standard WST will successfully pass the level one assessment and be allowed to operate unrestricted. But the same ship which is allowed to operate in all sea areas and seasons failed the season 4 for sea area 9 assessment, which contradicts the stability results estimated with Standard WST. This demonstrates the necessity of using local and regional WST than universal WST for SGISC stability assessment to avoid misinterpretation of stability estimations while improving safety.

Table 14: Excessive acceleration [m/s²] of C11 class container ship with modified WST.

Data	BGW	AHD				
WST	Annual	Annual	Season 1	Season 2	Season 3	Season 4
Sea area S	8.0099	7.9109	7.5485	4.9814	7.5485	8.6104
Sea area 8	7.9412	7.9109	7.59	5.0493	7.6997	9.1549
Sea area 9	8.0099	8.4068	7.8068	5.4341	7.8405	9.1549
Sea area 15	7.6622	7.0663	7.0663	4.257	6.6088	7.7345
Sea area 16	7.9109	7.8068	7.3522	4.8456	7.3522	8.4707

5. Conclusion

The Second-Generation Intact Stability Criteria opened doors for operation-based intact stability assessment, and the operational measure is the initial step toward the design of a performance-based dynamic stability assessment. The SGISC recommends the standard wave scatter table (WST) for the environmental data, an indefinite requirement for a simplified assessment pathway, which provides the probability of wave occurrence. To improve the assessment mechanism introduced by SGISC, the differences in regional and seasonal WST are investigated and compared with standard WST. The Rayleigh pdf shape factor was utilised for comparison with the corresponding IMO recommended standard

WST. The result shows the Rayleigh shape factor variation by almost 40% for seasons 2 and 4, with the maximum variation of 48% for wind sea in season 4. The paper also compares the results of VC1 excessive acceleration for C11 container ship. Although, the results match the case study provided in the explanatory notes; however, the ship's excessive acceleration varies for each region and season, and the estimates are higher in season 4 compared to the full year and standard WST. It is clear from the study that outcome achieved using Standard WST does not hold the safety margin for the region within the standard WST especially in season 4. It is therefore recommended to evaluate the acceptance of ship operation for all seas and seasons by individual seasonal and sea area than standard WST. In conclusion, the study recommends the use of regional and seasonal hindcast data for simplified operational measures to improve the safety of operations.

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