MARITIME SAFETY COMMITTEE
108th session
Agenda item 19

MSC 108/19
22 December 2023
Original: ENGLISH
Pre-session public release: ☒

## ANY OTHER BUSINESS

### Comments on the review of the North Atlantic wave data

### Submitted by ICS, INTERTANKO, INTERCARGO and RINA


**SUMMARY**

| | |
|---|---|
| *Executive summary:* | As a result of an IMO Goal Based Standards audit, IACS has revised and adopted new wave data for the North Atlantic (Recommendation No. 34). This data is the basis for the development of the Common Structural Rules for Bulk Carriers and Oil Tankers, and indeed, is the basis for many other IACS class society rules. The co-sponsors have several concerns relating to this new data and, noting it's critical importance for the reliability of ship structures and safety, the co-sponsors invite a more detailed consideration of this revised data by the Committee. The co-sponsors' concerns include the methodology used to calculate the revised wave data, the substantially less onerous data that has resulted from the review, and the potential relaxation of ship construction standards that the new data could enable. |
| *Strategic direction, if applicable:* | 7 |
| *Output:* | 7.24 |
| *Action to be taken:* | Paragraph 39 |
| *Related documents:* | MSC 96/5 and MSC 107/INF.10 |


## Introduction

1 The Common Structural Rules for Bulk Carriers and Oil Tankers (CSR) form a core part of class societies' rules, given that all IMO GBS-conformant class societies have incorporated the CSR, which are subject to IMO's goal-based ship construction standards for bulk carriers and oil tankers (GBS) and are thus periodically audited by IMO.

2 Document MSC 107/INF.10 (IACS) includes the following GBS audit observation which relates to the North Atlantic wave data[1] utilized to determine the CSR:

> "Modern data show both an increase in mean significant wave height for the North Atlantic and that more extreme weather is being experienced in recent years, including the existence of rogue waves and the possible effect of climate change. However, IACS' Rec. No.34, that is based on old wave statistics, was last revised in 2000/2001 and there is no evidence of monitoring since its adoption. While the TB report notes that significant discrepancies are observed between predictions by different databases, no studies have been submitted to show how new data have been assessed to conclude that none of the new databases could be used, nor has any sensitivity study been provided to assess the potential effect of the new data on motions and loads. [paragraphs omitted]
>
> The audit has not found sufficient justification that the wave data used in the rules properly represent North Atlantic conditions."

3 Document MSC 107/INF.10 also confirms that, in response to the auditors request to review the wave data, IACS has completed its review of the old data (IACS Rec.34 Standard Wave Data – Rev.1 Corr.1) and in January 2023 published amended wave data to their website (IACS Rec 34. Standard Wave Data – Rev.2). For brevity, these two sets of wave data are hereafter referred to as Rev.1 and Rev.2 respectively.

4 The co-sponsors would like to thank IACS for the diligent work they have done on this review, and the co-sponsors acknowledge and respect the extensive engineering and metocean expertise within the IACS classification societies. However, the co-sponsors have several concerns relating to the new Rev.2 data. The co-sponsors also note that although other IACS class rules relating to ship structure are not subject to IMO goal-based standards (and therefore not subject to IMO audit), many also utilize the same IACS Rec.34 wave data. Therefore, although for the IMO auditors this matter is restricted to the CSR, changes to the IACS Rec.34 wave data have potentially far-reaching implications, possibly affecting the structural reliability of a significant proportion of the world fleet for decades to come. This, coupled with the uncertain impact of global warming on future sea states, highlights the vital importance of this data. The co-sponsors therefore suggest it is an appropriate topic for the detailed consideration of this Committee.

5 The following sections articulate the co-sponsors' concerns.

**Methodology**

***Use of hindcast AIS tracks for weather-routed ships***

6 The co-sponsors are aware that the previous Rev.1 wave data was based upon BMT's Global Wave Statistics (BMT, 1986). This publication dates back to the 1980s and utilized wave height observations by mariners on board ships. This predates sophisticated numerical modelling and satellite measurements. The co-sponsors accept that mariner observations represented best practice for gathering of wave data at that time. However, modern metocean studies (e.g. for the oil and gas and renewable sectors), typically utilize complex numerical models which are calibrated against satellite measurements and wave buoy readings. Hence, modern techniques allow a complete assessment of a whole region and reliably identify the most onerous conditions.

[1] The North Atlantic has for many years been considered by class societies as representing the harshest environmental conditions that a ship can encounter. Hence, to ensure their ship structure rules are determining ship designs that are capable at all times of worldwide operation, it has been customary for class societies to base their analyses on North Atlantic wave data, i.e. such as the IACS Rec.34 standard wave data.

7 According to (Class NK, 2023), for Rev.2 of the wave data, IACS hindcast wave heights for the AIS tracks of over 20,000 ships crossing the North Atlantic between 2013 and 2020. Hence, even though modern best practice did not require the data to be based on the tracks of ships that are predominantly weather routed, IACS have chosen to do so, thereby unnecessarily replicating a key weakness of the Rev.1 data.

8 The co-sponsors are concerned that the methodology adopted for Rev.2 of the wave data implicitly assumes that all ships are routinely weather routed. If left unchallenged this may lead to a potentially dangerous situation owing to an unrealistic expectation that structural reliability is dependent upon universal and 100% effective weather routing.

9 The co-sponsors are aware that not all ships consistently weather route, and departures from this practice, can be due to:

.1 A master's decision not to weather route, e.g. due to the need to respond to a distress call;

.2 Inadequacies in weather routing services;

.3 Insufficient time to escape from a rapidly evolving and moving storm;

.4 Change of storm tracks in combination with limited vessel speed (i.e. the inability to evade the changed track of a storm);

.5 Responding to onboard emergencies, e.g. a medical emergency, fire, etc.;

.6 Partial or complete loss of propulsion due to mechanical failure, and;

.7 Forecasting inaccuracies or voyage planning errors.

10 Hence, it is the co-sponsors' view that the Rev.2 data will not include the most onerous conditions seen by ships on the North Atlantic and therefore do not represent the worst-case conditions.

11 For examples of ships not weather routing, please see the following clips:

Container vessel
Cruise ship
Bulk carrier
Tanker

12 The co-sponsors also note that although document MSC 107/INF.10, by IACS, includes the following requirement:

"Detailed plan to periodically review available wave data, taking into consideration weather routing as required."

There is no similar reference within the original audit report by the IMO Secretary-General's document MSC 96/5. Hence, it is unclear to the co-sponsors whether this aspect of the methodology was previously specified by this Committee, or the IMO auditors.

***Sea areas***

13 The Rev.1 wave data is based on sea areas 8, 9, 15 and 16. Figure 1 below is extracted from global wave statistics (BMT, 1986) and the shading has been added by the co-sponsors to indicate the included sea areas. As can be seen, these extend as far south as 38 degrees north.

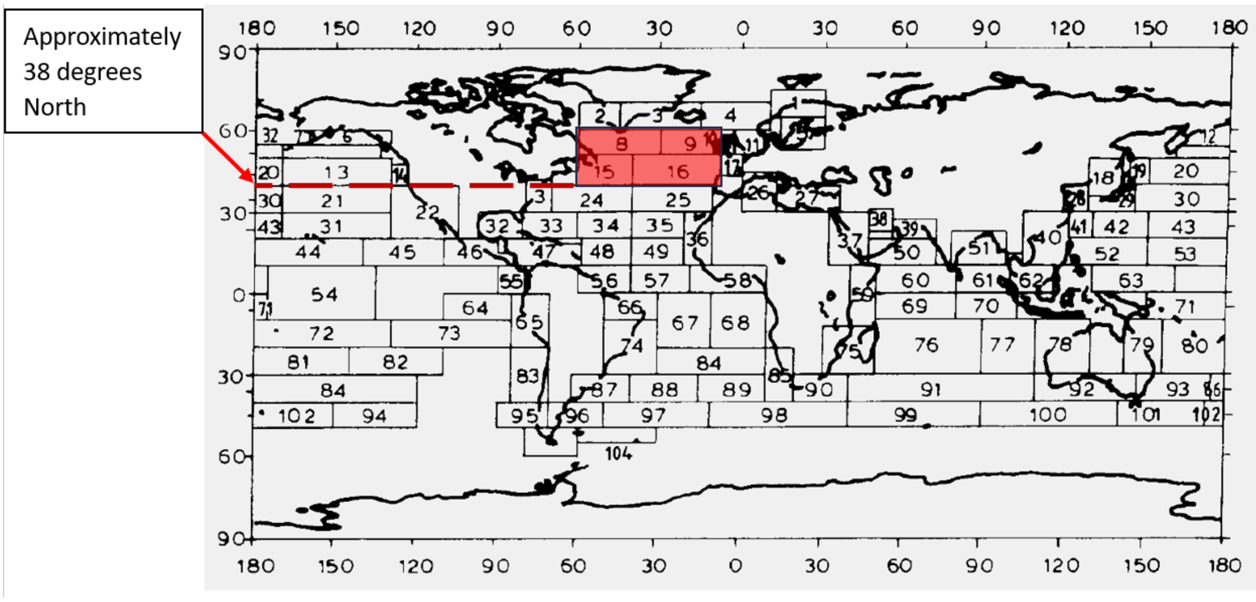


**Figure 1: The extent of the sea areas included within the IACS Rec.34 Rev.1 data**

14 In comparison, figure 2 is extracted from Rev.2 and shows the extent of sea areas considered by the revised wave data. This revised area extends as far south as 30 degrees north, i.e. about 420 miles further south. This additional area extends from the southern part of Spain and nearly as far south as the Canary Islands.

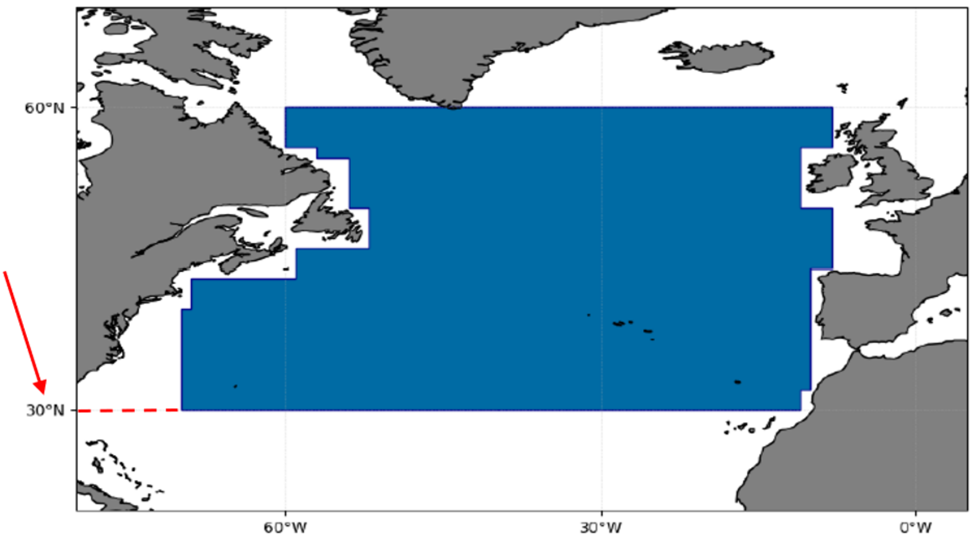


**Figure 2: The extent of the sea areas included within the IACS Rec.34 Rev.2 data**

15 Indeed, in July 2023, the Polish Register published an updated guidance document (PRS, 2023) on wave loading which includes the new Rev.2. scatter diagram. Within these guidelines it confirms that sea areas 24 and 25 have been added to Rev.2, owing to the requirements within MSC 287(87):

> "According to the Functional Requirement II.2 of IMO GBS (Resolution MSC.287(87)) the sea environmental conditions … is to be the North Atlantic, i = 1, covering the zones 8, 9, 15, 16, 24 and 25 of (BMT, 1986)".

16 However, when the co-sponsors refer to paragraph II.2 of resolution MSC.287(87), there is only a reference to "North Atlantic environmental conditions", and the sea areas are not listed. Therefore, the co-sponsors are unclear where the decision to add sea areas 24 and 25 to Rev.2 was initiated.

17 For clarity, the co-sponsors have shaded the respective areas adopted for the two sets of wave data on the below sea area charts:

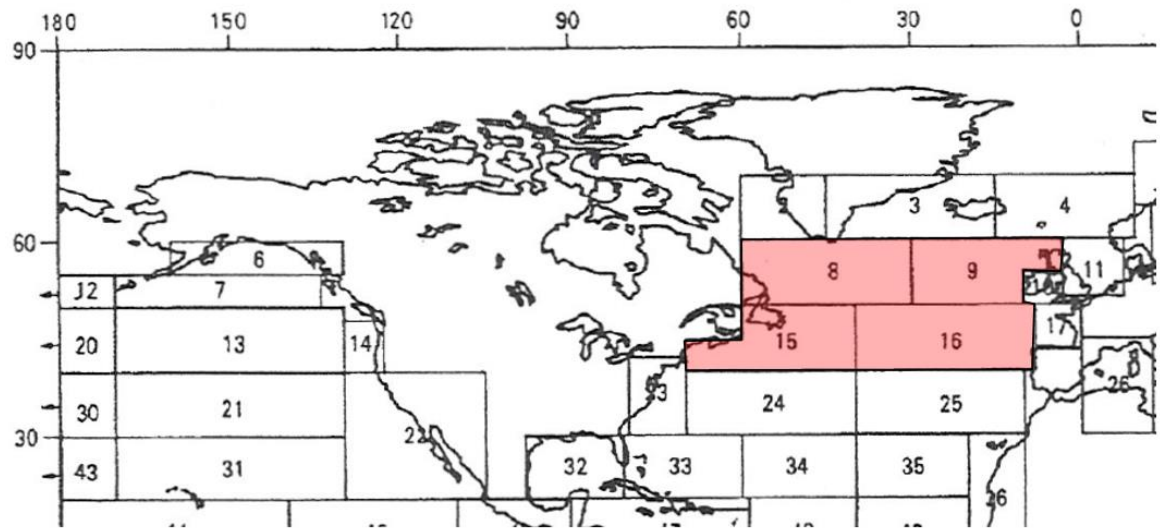

**Figure 3: Sea areas utilized for Rev.1**.

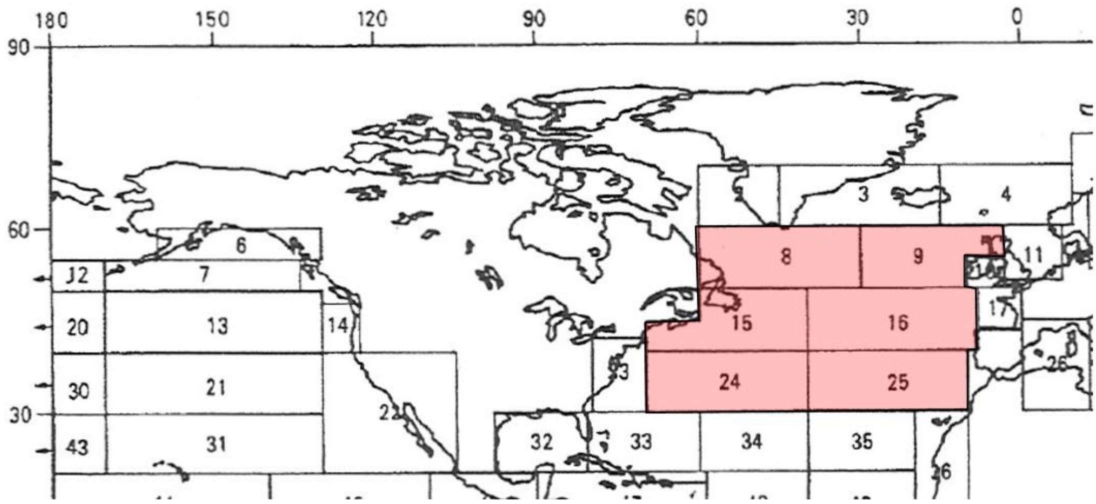

**Figure 4: Sea areas utilized for Rev.2**

18 Heading towards the equator, the general trend is for the significant wave height to reduce, and therefore extending the sea area further south will have included data that is less onerous than for the Rev.1 data. For example, (Phillippe Gleizon et al. , 2017), includes the contour plot reproduced in figure 5 below, which demonstrates a clear reduction in mean significant wave height when moving from 60 degrees north to 30 degrees north:

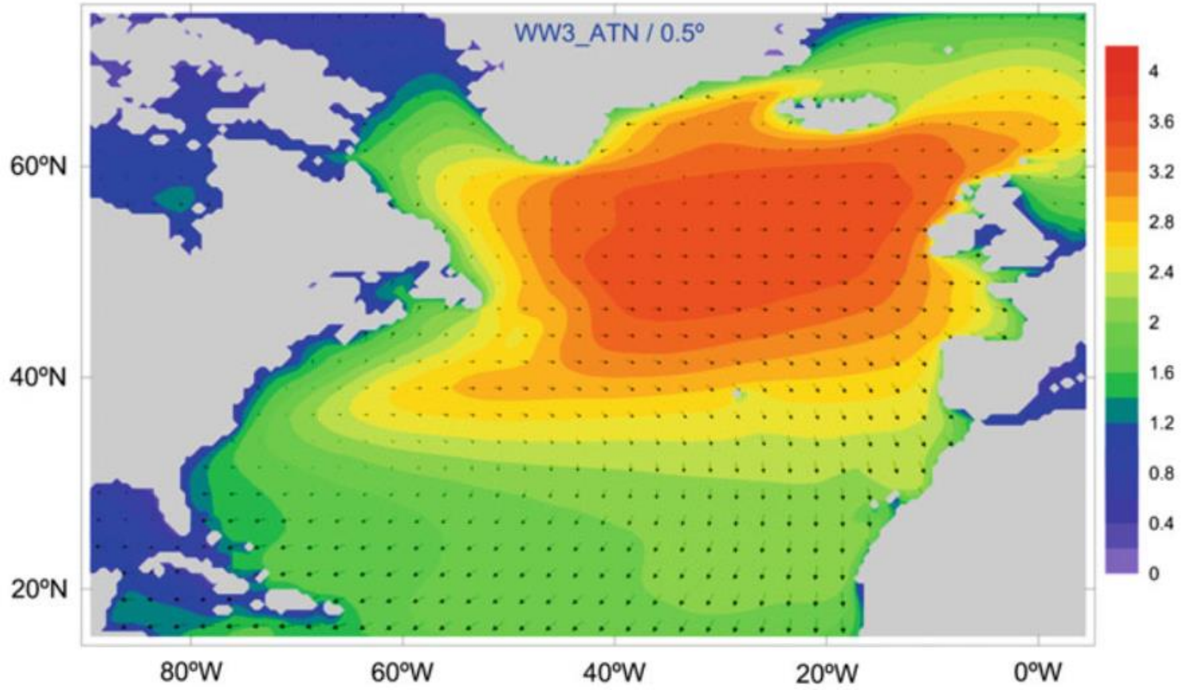


**Figure 5: Mean significant wave height in metres over the North Atlantic (Phillippe Gleizon et al. , 2017).**

19 It is not clear to the co-sponsors why the area has been extended and now includes an area that is clearly less onerous than previously considered. The co-sponsors are again concerned that this approach is not consistent with wave data that should be representing global worst-case conditions.

***Comparison of Rev.1 and Rev.2 data***

<u>Histogram of wave height versus number of waves</u>

20 Figure 6 below simply refers to the wave scatter diagrams for each set of wave data and plots the number of waves versus the significant wave heights.

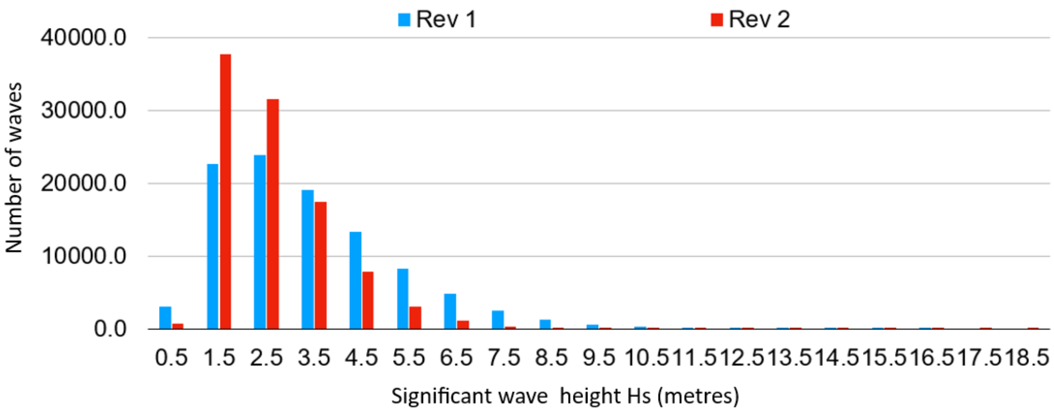


**Figure 6: Histogram of wave height versus number of waves**

21 Although the total number of waves in each scatter diagram is the same, it is apparent that for the new data there are proportionately more waves of low to moderate wave heights, and proportionately fewer of moderate to extreme wave height.

***Comparison of mean significant wave height***

22 Appendix 1 of this submission includes a calculation of the mean significant wave height of the two sets of data and table 1 below summarizes the results.

| **Wave Data** | **Mean significant wave height (metres)** |
|---|---|
| Rev.1 | 3.41 |
| Rev.2 | 2.61 |

**Table 1: Comparison of mean significant wave height**

23 Hence, the new Rev.2 data has a mean significant wave height of 0.8 metres less than the old Rev.1 data. In figure 7 below, and for comparison, the co-sponsors have plotted this data at example locations that match the mean significant wave heights.

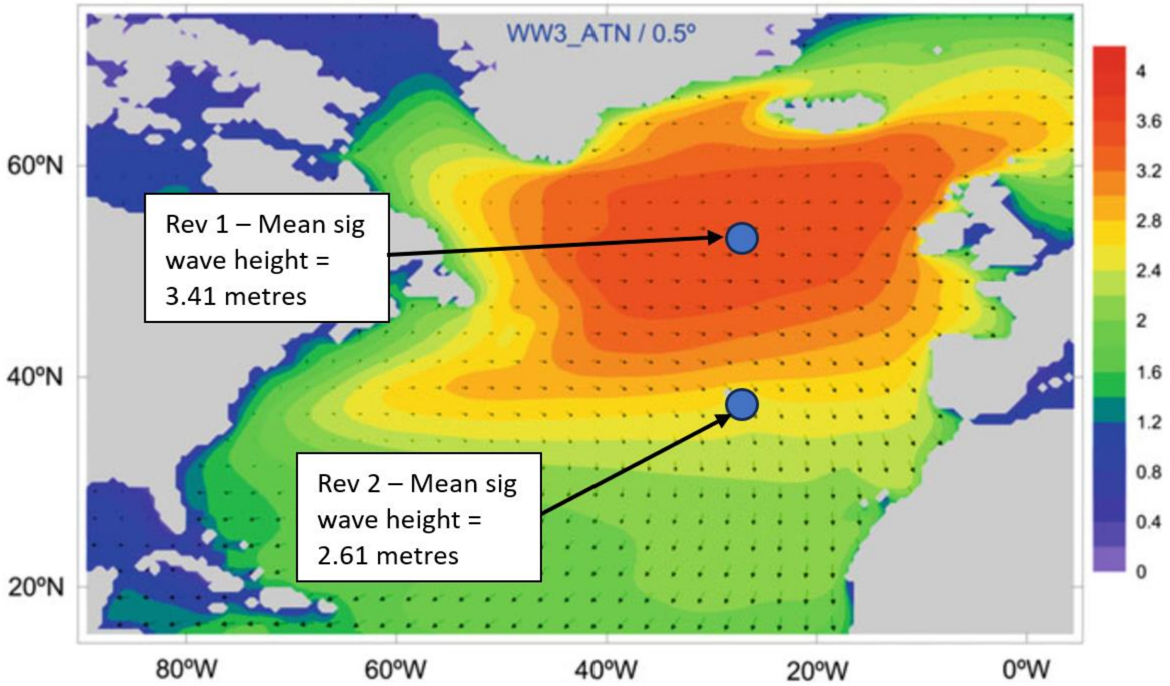


**Figure 7: Contours of mean significant wave height (metres) for the Atlantic Ocean (Phillippe Gleizon et al. , 2017), with the mean values for Rev.1 and Rev.2 overlaid.**

24 Although the Rev.1 data mean significant wave height is consistent with a North Atlantic location, the co-sponsors conclude that the Rev.2 data is of a magnitude more usually associated with a significantly more southerly location, and therefore cannot represent the worst case for structural design.

***Comparison of 100-year significant wave height data***

25 The 1-, 10- and 100-year significant wave heights are often used by naval architects and engineers as a guide to how onerous a region's sea state is. Appendix 2 of this submission includes such a calculation of the 1-,10- and 100-year significant wave height for the two sets of data, and table 2, below, summarizes the results.

| **Wave data** | **1-Year return period** | **10-year return period** | **100-year return period** |
|---|---|---|---|
| **Rev.1** | 12.54 | 15.11 | 17.57 |
| **Rev.2** | 9.66 | 12.01 | 14.33 |

**Table 2: Comparison of 1-year, 10-year and 100-year significant wave heights**

26 Considering just the 100-year significant wave height, and as a benchmark, referring to the 100-year wave height contours displayed in figure 8,[2] the difference between 17.57 metres and 14.33 metres is equivalent to the difference in metocean conditions experienced off the Shetland Islands and central North Sea. These two regions would normally be considered to have distinctly different metocean environments. For comparison, if two identical fixed floating installations were deployed to these locations (e.g. an FPSO) they would be expected to have markedly different performance in terms of hull fatigue.

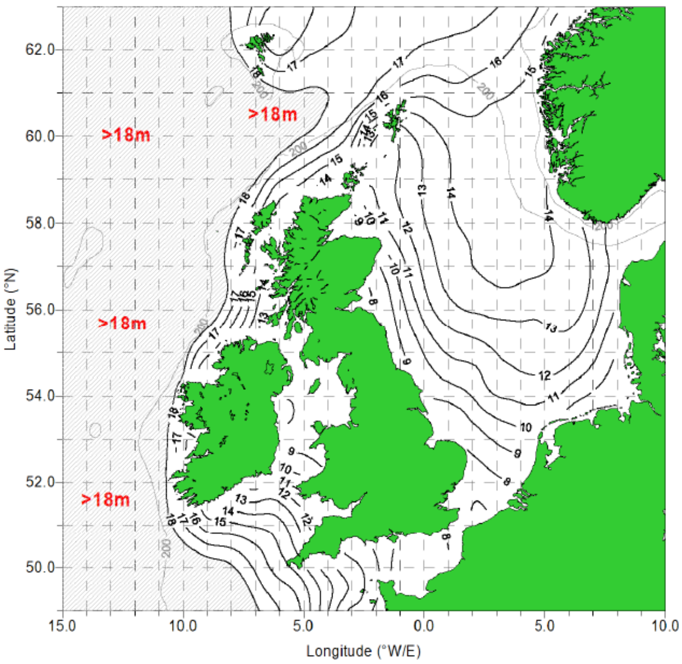


**Figure 8: Contours of 100-year wave height (metres) (UK HSE , 2005)**

[2] Figure 8 is extracted from (UK HSE , 2005), which updates the UK Health and Safety's wave data for the Eastern North Atlantic and North Sea wave data. The update utilized a complex numerical model called NEXTRA which hindcast significant wave heights at 3-hour intervals for the period 1964 to 1998. The model was validated and calibrated against measured wave height data from eight offshore installations and four localized areas covered by satellites.

***Summary of comparisons***

27 On all three measures, the new Rev.2 data is appreciably less onerous than the old Rev.1 data. In other words, the difference between the Rev.1 and Rev.2 data represents a significant difference in metocean environments, with the new data reflecting a distinctly less onerous environment.

28 It should also be noted that figure 8 is indicating maximum 100-year significant wave heights off the continental shelf of greater than 18 metres, which of course is in excess of either the Rev.1 data (17.57 metres) or the Rev.2 data (14.33 metres).

**Historical wave height trends**

29 An extensive review of studies of historic wave height trends is included within (DNV, 2013), and this concludes:

> "The reviewed studies agree that there has been an increase in significant wave height (SWH) from the middle of the twentieth century to the early twenty-first century in the northern hemisphere winter in high latitudes in the north Atlantic and the north Pacific, with a decrease in more southerly latitudes of the northern hemisphere. The increase of the 99-percentile SWH has been observed to be 0.5–1.0 % per year."

**Future wave height trends and level of uncertainty**

30 An extensive review of future wave height trends is also included within (DNV, 2013) and this concludes:

> "There will be regional increases in the sea states, more pronounced for extreme wind speed and SWH than for their means; e.g. the North and Norwegian Seas, immediately west of the British Isles, off the northwest of Africa, around 30 degrees N from the east coast of the United States to 50 degrees W and in the Pacific between 25 and 40 degrees N and from the west coast of the United States to 170 degrees W.
>
> The increases in extremes, represented by the 20-year return period of SWH or the highest storms in 20–30 year intervals are generally in the range 0.5–1.0 m in the North Atlantic, but larger increases can also be read off some graphs in the reviewed papers."

31 Nevertheless, (DNV, 2013) notes there are relatively large uncertainties associated with projected extremes under different climate or emission scenarios. Therefore, their confidence in the projections is limited.

**Summary of historical and future wave height trends**

32 Hence, according to (DNV, 2013) the recent trends in the North Atlantic have been for increasing wave height, i.e. the opposite to the trend exhibited by the differences between the Rev.1 and Rev.2 data. Projecting forward, (DNV, 2013) urges caution due to the inherent uncertainties, but the authors' overall assessment is that it is still prudent to consider a possible increase in extreme wave height for the North Atlantic.

**Impact of the Rev.2 data on hull scantlings**

***Consideration of hull girder buckling***

33 (DNV, 2013) includes a detailed assessment of the likely impact of the increasing North Atlantic wave heights on a sample of five tankers ranging from a product tanker to a VLCC. The review utilized the Common Structural Rules (IACS, 2023), to assess the impact on structural design, and focused on the collapse of deck structures under extreme hull bending, i.e. the failure mode indicated in figure 9.

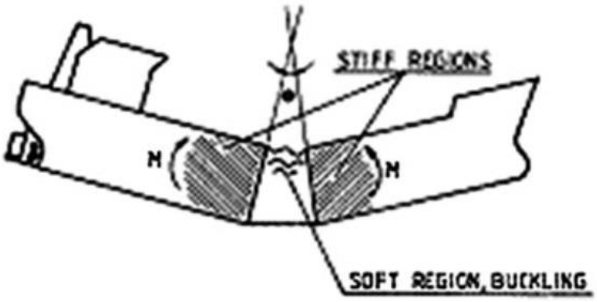


**Figure 9: Failure mode considered by (DNV, 2013)**

34 (DNV, 2013) concluded that the probability of deck failure increased by about 50% for each increase in significant wave height by 0.5 metres.

35 Noting that the mean significant wave height for the Rev.2 data has decreased relative to Rev.1 by 0.8 metres, the results of the study (DNV, 2013) therefore suggest that in terms of potential hull girder damage, the Rev.1 data is significantly more onerous than the Rev.2 data.

***Consideration of hull fatigue***

36 Generally, changes in wave height are expected to significantly impact on hull fatigue performance. Within their guidance document, (TSCF, 2017), the Tanker Structure Cooperative Forum [3] explains this relationship as follows:

> "An uncertainty in the stress range of +/-10% due to change in the average wave height for the predominant damage sea states, may lead to a +/- 30% variability in calculated fatigue damage."

37 A more detailed study (A. Yosri et al., 2022) was conducted by the Universities of Aalto (Finland), and Alexandra and Port Said (Egypt). This investigated the impact of sea state on the fatigue performance of the side structural details of a 248 metre-long double hulled tanker. Such side shell details are typical of the locations where fatigue cracks can develop within tanker structures.

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[3] The TSCF is an informal technical body, whose membership is voluntary and comprised of oil companies, independent owners/operators and classification societies.

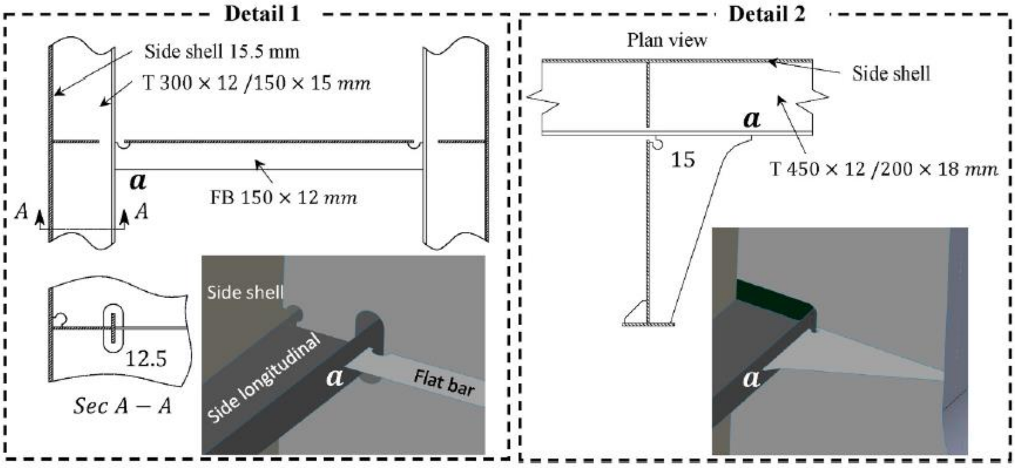



**Figure 10: Tanker side shell structural details that were subject to the spectral fatigue analyses (A. Yosri et al., 2022)**

38 Varying sea states were considered, and a sophisticated spectral analysis approach was utilized to determine the extent of fatigue damage. As indicated by figure 11 below, for a North Atlantic sea state, the greatest extent of fatigue damage was attributable to a significant wave height of around 5.5 metres and wave period of about 9.5 seconds. Within the Rev.1 wave scatter diagram there are a total of 2373 waves of this height and period, whereas for the Rev.2 data there are just 811. Therefore, in terms of potential fatigue damage, the results of the study (A. Yosri et al., 2022) again suggest that the Rev.1 data represents a significantly harsher metocean environment than Rev.2.

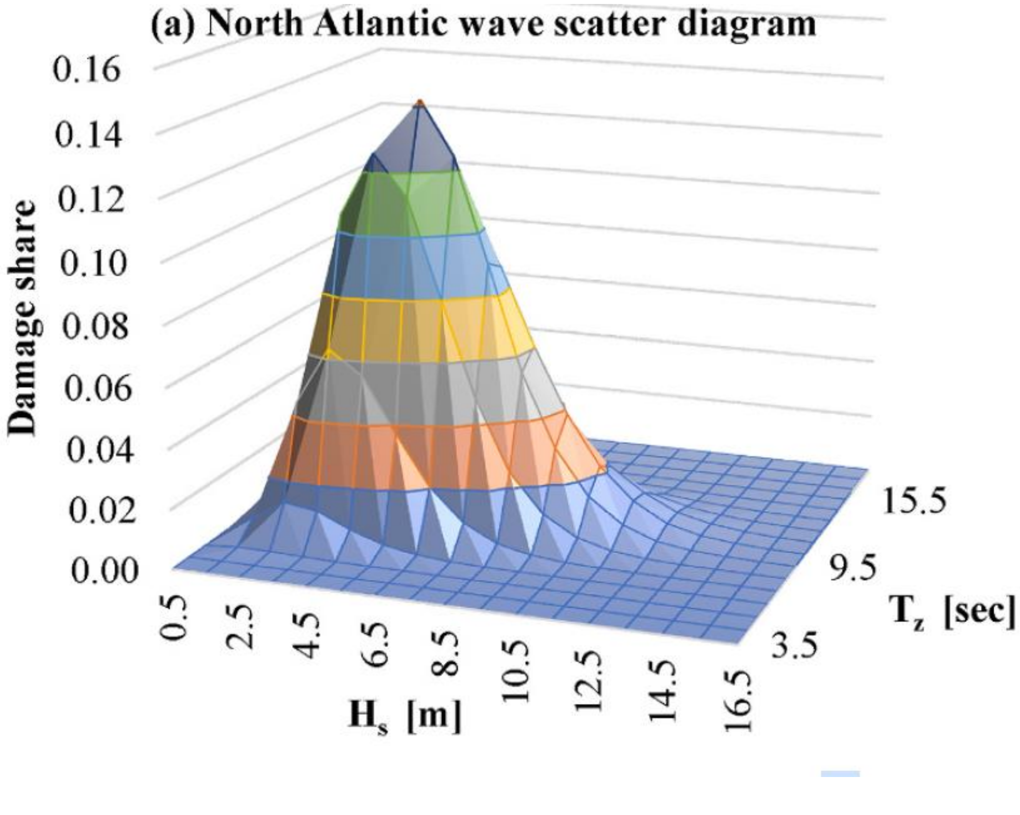



**Figure 11: Contribution of the significant wave height Hs and Period Tz to the accumulated fatigue damage (A. Yosri et al., 2022)**

**Action requested of the Committee**

39 The co-sponsors understand that the IMO GBS auditors will review the Rev.2 data in early 2024. Noting the importance of the North Atlantic wave data to the structural reliability of ships, the co-sponsors invite the Committee to request the IMO GBS auditors to consider the following factors during their review:

.1 Most ships do weather route, but not all. Hence, basing the Rev.2 data on hindcasts of many AIS tracks of ships crossing the North Atlantic will have produced wave data which does not represent the most extreme conditions experienced by ships.

.2 Weather routing services are not 100% reliable, and even for ships that use such services, there are still occasions when storms are encountered, e.g. when responding to distress calls.

.3 The inclusion of sea areas 24 and 25 in the Rev.2 wave data has extended the sea area about 420 miles further south, into a region which is not associated with extreme weather. Relative to Rev.1 this will have reduced the mean wave heights and the 1-,10- and 100-year significant wave heights. The co-sponsors are not aware of any justification for this change.

.4 Comparing the Rev.2 data with Rev.1, the mean significant wave height has reduced by 0.8 meters and the 100-year significant wave height has reduced from 17.57 to 14.33 metres. In the co-sponsors' opinion these represent large differences and the co-sponsors have seen no justification for these reductions. Such differences are normally only seen when moving between regions with substantially different metocean conditions.

.5 For the North-East Atlantic, the UK Health and Safety Executive's wave data (UK HSE , 2005) lists 100-year significant wave heights exceeding 18 metres. Although Rev.1 is not dissimilar (17.57 metres) Rev.2 is substantially lower (14.33 metres). The co-sponsors are not aware of any justification for such a discrepancy.

.6 Consideration of both hull girder strength and fatigue performance suggest that the Rev.2 data could enable the development of class rules that would require structurally less robust ships. The co-sponsors are not aware of any justification for enabling such scantling reductions.

***

## ANNEX

## References

A. Yosri et al. (2022). Accumulated fatigue damage assessment of side structural details in a double hull tanker based on spectral fatigue analysis approach. *Ocean Engineering*.

BMT. (1986). *Global Wave Statistics.*

Class NK. (2023). *Update of wave statistics Standards for Classification Society Rules, Havard Nordtveit Austefjord, Guillaume de Hautecloque, Michael Johnson, Tingyao Zhu.*

DNV. (2010). *Climate Change and Effect on marine Structure Design.* DNV.

DNV. (2013). *Ship and Offshore Structure Design in Climate Change Perspective.*

IACS. (2001). *Recommendation 34 Standard Wave Data Rev 1 Corr.*

IACS. (2022). *Recommendation 34 Standard Wave Data Rev 2.*

IACS. (2023). *Common Structural Rules for Bulk Carriers and Oil Tanlers.*

IMO. (2010). *Resolution MSC.287(87) ADOPTION OF THE INTERNATIONAL GOAL-BASED SHIP CONSTRUCTION STANDARDS FOR BULK CARRIERS AND OIL TANKERS .*

IMO. (2018). *RESOLUTION MSC.454(100) REVISED GUIDELINES FOR VERIFICATION OF CONFORMITY WITH GOAL-BASED SHIP CONSTRUCTION STANDARDS FOR BULK CARRIERS AND OIL TANKERS.* IMO.

K. Tran Nguyen, Y. G. (2012). Spectral fatigue damage assessment of tanker deck structural detail subjected to time dependent corrosion. *International Journal of Fatigue*.

Phillippe Gleizon et al.. (2017). *Wave Energy Resources Along the European Atlantic Coast.*

PRS. (2023). *Informative publication no. 35/I - Wave Loads on Ships.*

TSCF. (2017). *TSCF IP 001/2017Guidance Note on Specification of Fatigue for Double Hull Oil Tankers Complying with the Common Structural Rules Rev 1.*

UK HSE . (2005). *Wave mapping in UK waters.*

Xavier Bertin ∗, E. P. (2013). A significant increase in wave height in the North Atlantic Ocean over. *Global and Planetary Change*.

Zhiyuan Li, J. W. (2013). Time-domain fatigue assessment of ship side-shell structures. *International Journal of Fatigue*.

## APPENDIX 1

**Calculation of the mean significant wave height for the Rev.1 and Rev.2 data.**

| | Rev 1 data | | Rev 2 data | |
|---|---|---|---|---|
| A | B | A*B | C | A*C |
| Hs midpoint (metres) | Number of waves | | Number of waves | |
| 0.5 | 3050 | 1525 | 780.73 | 390.365 |
| 1.5 | 22575 | 33862.5 | 37724.81 | 56587.215 |
| 2.5 | 23810 | 59525 | 31530.96 | 78827.4 |
| 3.5 | 19128 | 66948 | 17445.07 | 61057.745 |
| 4.5 | 13289 | 59800.5 | 7812.64 | 35156.88 |
| 5.5 | 8328 | 45804 | 3027.47 | 16651.085 |
| 6.5 | 4806 | 31239 | 1086.83 | 7064.395 |
| 7.5 | 2586 | 19395 | 378.09 | 2835.675 |
| 8.5 | 1309 | 11126.5 | 131.78 | 1120.13 |
| 9.5 | 626 | 5947 | 48.88 | 464.36 |
| 10.5 | 285 | 2992.5 | 19.23 | 201.915 |
| 11.5 | 124 | 1426 | 7.89 | 90.735 |
| 12.5 | 51 | 637.5 | 3.32 | 41.5 |
| 13.5 | 21 | 283.5 | 1.37 | 18.495 |
| 14.5 | 8 | 116 | 0.57 | 8.265 |
| 15.5 | 3 | 46.5 | 0.22 | 3.41 |
| 16.5 | 1 | 16.5 | 0.08 | 1.32 |
| 17.5 | 0 | 0 | 0.04 | 0.7 |
| 18.5 | 0 | 0 | 0.02 | 0.37 |
| Total | 100000 | 340691 | 100000 | 260521.96 |
| | Mean wave height (metres) = | **3.41** | Mean wave height (metres) = | **2.61** |

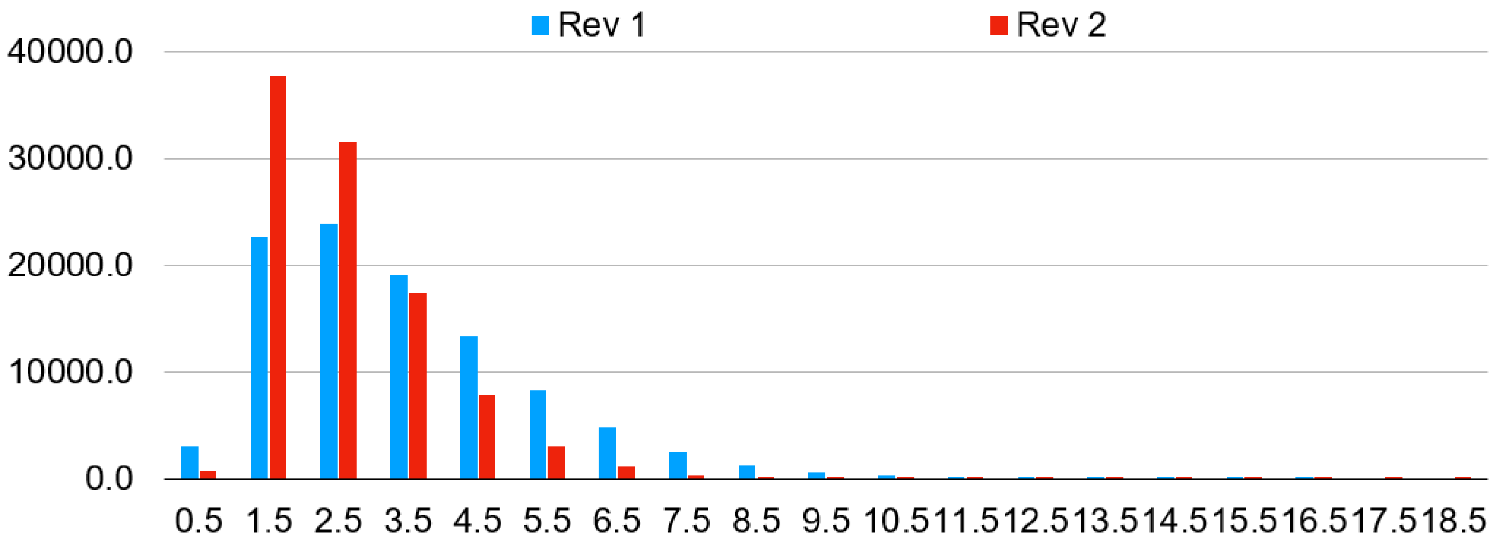
$$\text{Mean significant }\backslash = \frac{\sum \text{(Wave height x number of waves of that height)}}{\text{Total number of waves}}$$

**Difference in mean height (metres) = 0.80**

## APPENDIX 2

**Calculation of 1-, 10- and 100-year return period significant wave height**

| Hs | Rev 1 | Rev 2 |
|---|---|---|
| 0.5 | 3050.0 | 780.73 |
| 1.5 | 22575.0 | 37724.81 |
| 2.5 | 23810.0 | 31530.96 |
| 3.5 | 19128.0 | 17445.07 |
| 4.5 | 13289.0 | 7812.64 |
| 5.5 | 8328.0 | 3027.47 |
| 6.5 | 4806.0 | 1086.83 |
| 7.5 | 2586.0 | 378.09 |
| 8.5 | 1309.0 | 131.78 |
| 9.5 | 626.0 | 48.88 |
| 10.5 | 285.0 | 19.23 |
| 11.5 | 124.0 | 7.89 |
| 12.5 | 51.0 | 3.32 |
| 13.5 | 21.0 | 1.37 |
| 14.5 | 8.0 | 0.57 |
| 15.5 | 3.0 | 0.22 |
| 16.5 | 1.0 | 0.08 |
| 17.5 | 0 | 0.04 |
| 18.5 | 0.0 | 0.02 |
| Sum | 100000.0 | 100000.0 |

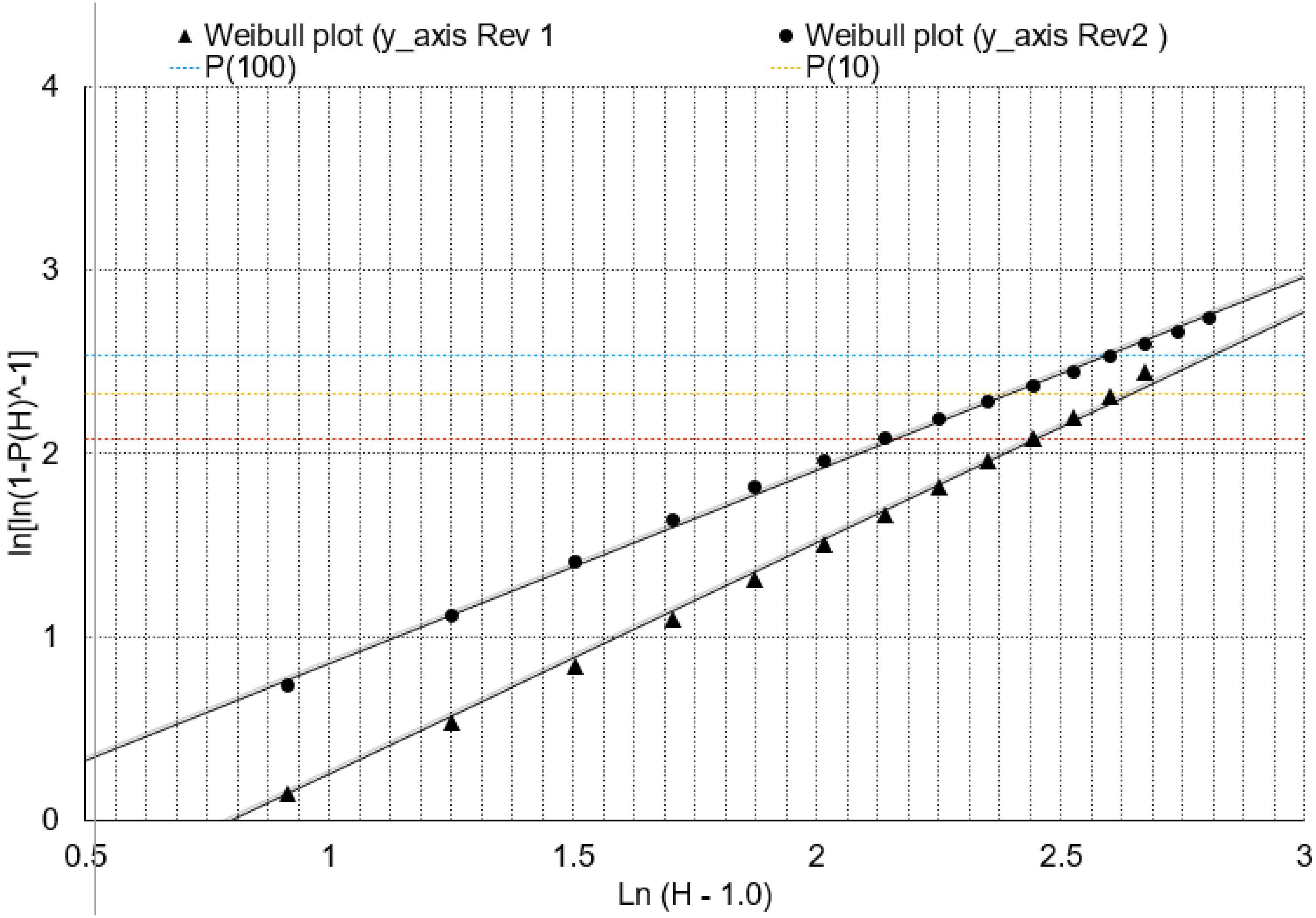


| | Hs Probability Rev 1 | Hs Probability Rev 2 | Hs Cumulative Probability P(H)_Rev 1 | Hs Cumulative Probability P(H)_Rev 2 | Weibull plot (x) | Weibull plot (y_axis Rev 1 | Weibull plot (y_axis Rev2 ) | P(100) | P(10) | P(1) |
|---|---|---|---|---|---|---|---|---|---|---|
| **0.5** | 3.050E-02 | 7.807E-03 | 3.050E-02 | 7.807E-03 | | | | | | |
| **1.5** | 2.258E-01 | 3.772E-01 | 2.563E-01 | 3.851E-01 | | | | 2.533 | 2.330 | 2.077 |
| **2.5** | 2.381E-01 | 3.153E-01 | 4.944E-01 | 7.004E-01 | 0.405 | -0.383 | 0.187 | 2.533 | 2.330 | 2.077 |
| **3.5** | 1.913E-01 | 1.745E-01 | 6.856E-01 | 8.748E-01 | 0.916 | 0.146 | 0.731 | 2.533 | 2.330 | 2.077 |
| **4.5** | 1.329E-01 | 7.813E-02 | 8.185E-01 | 9.529E-01 | 1.253 | 0.535 | 1.117 | 2.533 | 2.330 | 2.077 |
| **5.5** | 8.328E-02 | 3.027E-02 | 9.018E-01 | 9.832E-01 | 1.504 | 0.842 | 1.408 | 2.533 | 2.330 | 2.077 |
| **6.5** | 4.806E-02 | 1.087E-02 | 9.499E-01 | 9.941E-01 | 1.705 | 1.096 | 1.635 | 2.533 | 2.330 | 2.077 |
| **7.5** | 2.586E-02 | 3.781E-03 | 9.757E-01 | 9.979E-01 | 1.872 | 1.313 | 1.816 | 2.533 | 2.330 | 2.077 |
| **8.5** | 1.309E-02 | 1.318E-03 | 9.888E-01 | 9.992E-01 | 2.015 | 1.502 | 1.962 | 2.533 | 2.330 | 2.077 |
| **9.5** | 6.260E-03 | 4.888E-04 | 9.951E-01 | 9.997E-01 | 2.140 | 1.670 | 2.082 | 2.533 | 2.330 | 2.077 |
| **10.5** | 2.850E-03 | 1.923E-04 | 9.979E-01 | 9.999E-01 | 2.251 | 1.821 | 2.187 | 2.533 | 2.330 | 2.077 |
| **11.5** | 1.240E-03 | 7.890E-05 | 9.992E-01 | 9.999E-01 | 2.351 | 1.958 | 2.281 | 2.533 | 2.330 | 2.077 |
| **12.5** | 5.100E-04 | 3.320E-05 | 9.997E-01 | 1.000E+00 | 2.442 | 2.081 | 2.368 | 2.533 | 2.330 | 2.077 |
| **13.5** | 2.100E-04 | 1.370E-05 | 9.999E-01 | 1.000E+00 | 2.526 | 2.200 | 2.450 | 2.533 | 2.330 | 2.077 |
| **14.5** | 8.000E-05 | 5.700E-06 | 1.000E+00 | 1.000E+00 | 2.603 | 2.315 | 2.528 | 2.533 | 2.330 | 2.077 |
| **15.5** | 3.000E-05 | 2.200E-06 | 1.000E+00 | 1.000E+00 | 2.674 | 2.443 | 2.601 | 2.533 | 2.330 | 2.077 |
| **16.5** | 1.000E-05 | 8.000E-07 | 1.000E+00 | 1.000E+00 | 2.741 | | 2.662 | 2.533 | 2.330 | 2.077 |
| **17.5** | | 4.000E-07 | | 1.000E+00 | 2.803 | | 2.736 | 2.533 | 2.330 | 2.077 |
| **18.5** | | 2.000E-07 | | 1.000E+00 | 2.862 | | | 2.533 | 2.330 | 2.077 |
| **Sum** | 1.000E+00 | 1.000E+00 | | | 3 | | | 2.533 | 2.330 | 2.077 |

**Weibull fit**

| | | |
|---|---|---|
| **Rev 1** | y=1.258x - 0.9997 | x= (y+0.9997) / 1.258 |
| **Rev 2** | y=1.0568x - 0.2049 | x= (y+0.2049) / 1.0568 |

| | **Significant wave heights $H_s$ (Metres)** | |
|---|---|---|
| | **Rev 1 data** | **Rev 2 data** |
| **1 Year return period** | 12.54 | 9.66 |
| **10 Year return period** | 15.11 | 12.01 |
| **100 Year return period** | 17.57 | 14.33 |


▲ Weibull plot (y_axis Rev 1
● Weibull plot (y_axis Rev2 )
P(100)
P(10)
4
3
2
1
0
0.5
1
1.5
2
2.5
3
ln[ln(1-P(H)^-1]
Ln (H - 1.0)

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