Evaluation of the Ship Operational Effect Based on Actually Encountered Sea States by Ships

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1. INTRODUCTION

Since ships are operated from various perspectives that include security of lives and hull structural safety, prevention of cargo collapse, protection of the machinery and equipment and energy-saving operation, it is essential to ensure accurate assessment of the actually encountered sea states by ships. Numerous studies have examined the actual tendencies of ship operation in service and the ship operational effect on hull structural strength.[1)-5)] Although the current Classification Rules already take the ship operational effect into consideration implicitly, more rational technical background is required based on the accurate data of the actually encountered sea states.

In recent years, the automatic identification system (AIS) has made it possible to obtain the data of global ship position and timestamp information, while the wave data in ocean can be obtained from wave hindcast. Therefore, the wave data corresponding to the ship position and timestamp information enables the evaluation of the actually encountered sea states by ships. Our previous studies performed a quantitative evaluation of the ship operational effect on roll motion, vertical bending moment amidships and hydrodynamic pressure at the bottom centerline amidships based on the actually encountered sea states in the North Atlantic used AIS data and wave hindcast for a period of 2 years and 11 months to those based only on the natural sea states in the North Atlantic.[6) 7)]

For the Society to complete the comprehensively revision of Part C of the Rules for the Survey and Construction of Steel Ships related to hull structures, it was essential to perform a quantitative evaluation of the ship operational effect regarding to the wave scatter diagram in the North Atlantic Areas in the recommendation No. 34 (hereinafter “IACS Rec. No. 34”)[8)] specified by the International Association of Classification Societies (IACS).

The present study conducted a quantitative evaluation of the ship operational effect on ship motions (heave, roll, pitch) and wave loads (vertical wave bending moment amidships and hydrodynamic pressures at the bottom centerline and waterline amidships) by using of the wave scatter diagrams based on the actually encountered sea states by merchant ships such as bulk carriers, oil tankers and container ships navigating in the North Atlantic and the IACS Rec. No. 34.

2. AIS DATA AND WAVE DATA

The present study was carried out using AIS data from Vessel Tracker.[9)] The AIS data were obtained via satellites and onshore base stations and allowed extraction of the position and timestamp information of the desired ships. Table 1 shows the outline of the AIS data. The AIS dataset used in the study covered a total of 8,456 ships (4,509 bulk carriers, 1,875 oil tankers and 2,072 container ships) that navigated in the North Atlantic during a period of 2 years and 11 months (January 2014 and January 2015 to October 2017). Note that January 2014 was the month when the North Atlantic experienced the most severe sea states during the 25 years period from 1994 to 2018.[10)] In the present study, the AIS data at 0 knots ship speed were excluded, and the AIS data for irregular time intervals were thinned out to an interval of 1 hour.

The wave hindcast from the ERA5 (ECMWF)[11)] and IOWAGA (IFREMER)[12)] datasets were used in this study. Table 2 shows the outline of these wave hindcast. The navigation areas selected for the present study were the same areas used in the IACS Rec. No. 34 shown in Fig. 1 (GWS Areas 8, 9, 15, 16). Both the wave hindcast datasets were validated by comparison with the measured data from buoys and satellites.[10)] Here, the AIS data thinned out to one-hour intervals mentioned above were corresponding to the sea state based on wave hindcast at the nearest timestamp points in the 30 minutes before and after the AIS data. Then, the sea state corresponding to the AIS data is considered as a one-hour-long short-term sea state in this study to be used to constitute the wave scatter diagram with ship operational effect.

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Table 1 Outline of AIS data

Time period	January 2014 and January 2015 through October 2017
Navigation area	GWS Areas 8, 9, 15, 16 (North Atlantic)
Number of ships	8,456 (Bulk carriers: 4,509 / Oil tankers: 1,875 / Container ships: 2,072)

Table 2 Outline of wave hindcast

Data set	ERA5	IOWAGA
Organization	ECMWF	IFREMER
Spatial resolution	0.36 deg	0.5 deg
Time step	1 h	3 h
Wave model	ECWAM	WW3-st4
Wind forcing	Coupled model	NCEP-CFSR

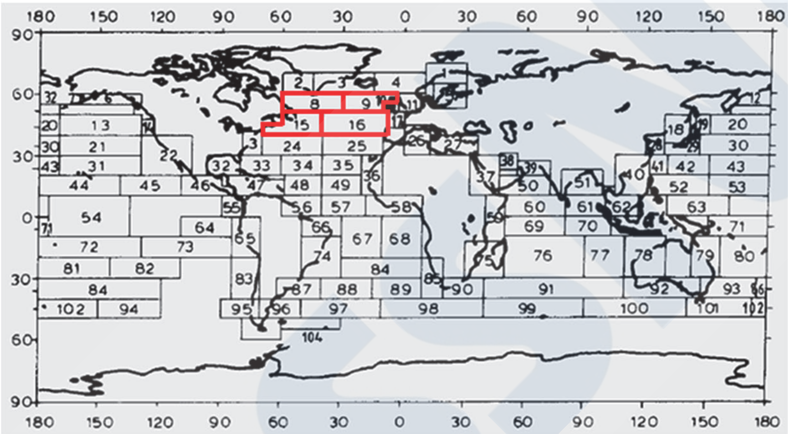

Fig. 1 Definition of the extent of the North Atlantic in IACS Rec. No. 34

3. QUANTITATIVE EVALUATION OF SHIP OPERATIONAL EFFECT

The following steps show the procedure for evaluating the ship operational effect considering the significant wave heights and wave periods actually encountered by ships[6) 7)]:

1) Prepare the following wave scatter diagrams:
   (A) Wave scatter diagrams with ship operational effect (based on AIS data and wave hindcast) respectively for ERA5 and IOWAGA
   (B) IACS Rec. No. 34
2) Use the wave scatter diagrams mentioned above in 1) to calculate the long-term prediction values at the probability level 10^{-8} for heave, roll, pitch, vertical wave bending moment amidships (VBM), hydrodynamic pressure at the bottom centerline amidships (Pcl) and hydrodynamic pressure at the waterline amidship (Pwl) by a linear strip method. As an example, Fig. 2 shows the exceedance probability distributions of long-term prediction of vertical wave bending moment amidships (VBM) for a Panamax bulk carrier.
3) The ship operational effect $\mathrm{F}_{op\_rec.No.34}$ as the ratio of the long-term prediction value at the probability level 10^{-8} based on the scatter diagram with ship operational effect respectively for ERA5 or IOWAGA to that based on the IACS Rec. No. 34 was calculate by the following formula:

$$\mathrm{F}_{op\_rec.No.34} = \frac{long-term\ \ prediction\ \ at\ \ 10^{-8}\ (with\ \ ship\ \ operational\ \ effect)(\mathrm{A})}{long-term\ \ prediction\ \ at\ \ 10^{-8}\ (\mathrm{IACS\ \ Rec.No.34})(\mathrm{B})}$$

Table 3 shows the outline of targeted ships (22 bulk carriers, 27 oil tankers and 26 container ships) used in a series of calculations, while Table 4 shows the analysis conditions for the long-term predictions. It should be noted that the targeted ships in Table 3 are different from the ships with the AIS data in Table 1.

Fig. 3 shows the statistics (mean value ± 2 standard deviations) of $F_{op\_rec.No.34}$, while Fig. 4 to Fig. 9 show the ship operational effect $F_{op\_rec.No.34}$ of heave, pitch, roll, VBM, Pcl and Pwl regarding ship lengths for both the wave hindcasts ERA5 and IOWAGA regardless of the ship types. The range of the mean value ± 2 standard deviations of $F_{op\_rec.No.34}$ shown in Fig. 3 is from 0.75 to 0.84. From Fig. 4 to Fig. 9, the significant variation could not be confirmed in $F_{op\_rec.No.34}$ for the different wave hindcasts, different ship lengths and different ship types used in the series of calculations.

Table 3 Outline of targeted ships used in the series of calculations

Ship type	Bulk carrier	Oil tanker	Container ship
Ship length [m]	110 to 285	110 to 320	110 to 350
Number of ships	22	27	26
Loading condition	Full load		

Table 4 Analysis conditions for the long-term predictions

Program	Linear strip method
Parameters	Heave, Roll*, Pitch, Vertical bending moment amidships (VBM), Hydrodynamic pressure at bottom centerline amidships (Pcl), Hydrodynamic pressure at water line amidships (Pwl)
Ship speed	5 knots
Wave direction	All headings

*Excluding container ships

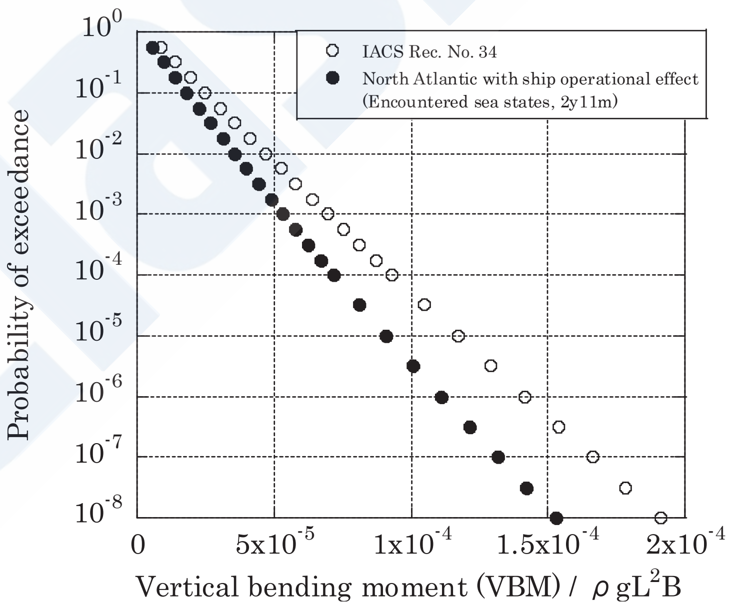

Fig. 2 Example of the exceedance probability distributions of long-term prediction of vertical wave bending moment amidships (VBM) based on the wave scatter diagram with the ship operational effect (ERA5) and IACS Rec. No. 34

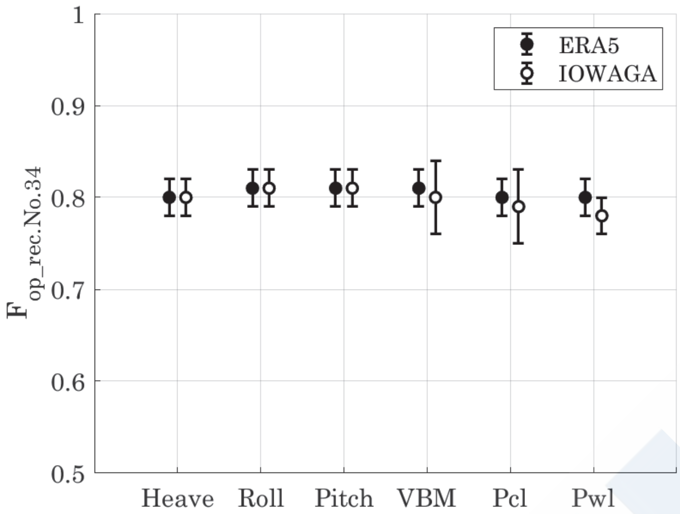

Fig. 3　Summary of the ship operational effect $F_{op\_rec.No.34}$ for heave, roll, pitch, VBM, Pcl and Pwl depending on each wave hindcast

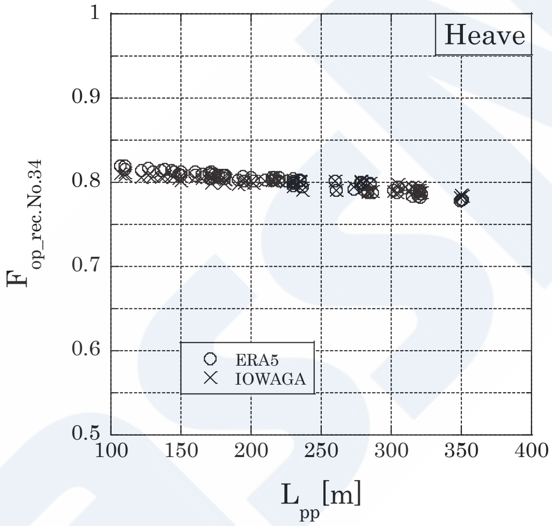

Fig. 4　Ship operational effect $F_{op\_rec.No.34}$ of heave depending on ship length

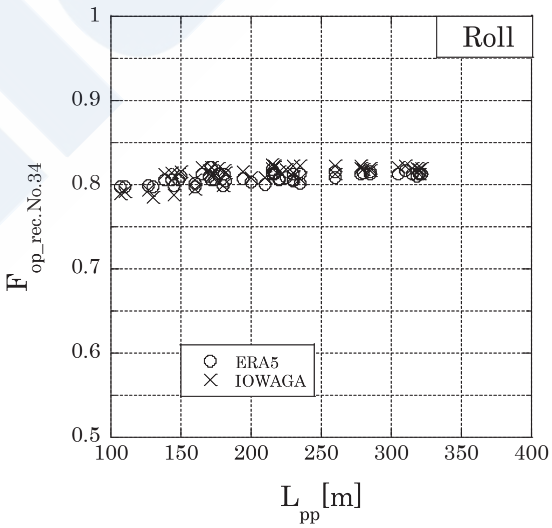

Fig. 5　Ship operational effect $F_{op\_rec.No.34}$ of roll depending on ship length

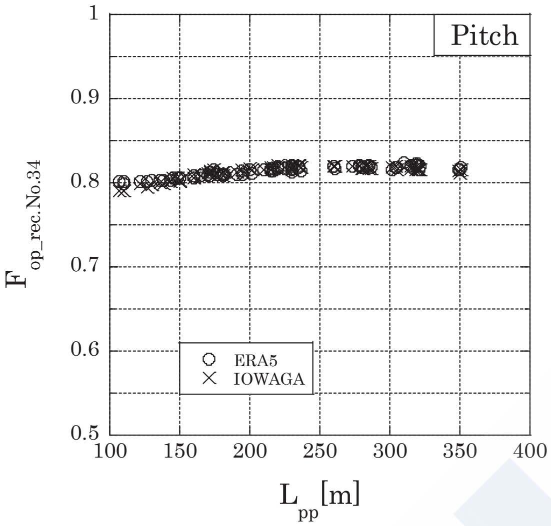

Fig. 6 Ship operational effect $F_{op\_rec.No.34}$ of pitch depending on ship length

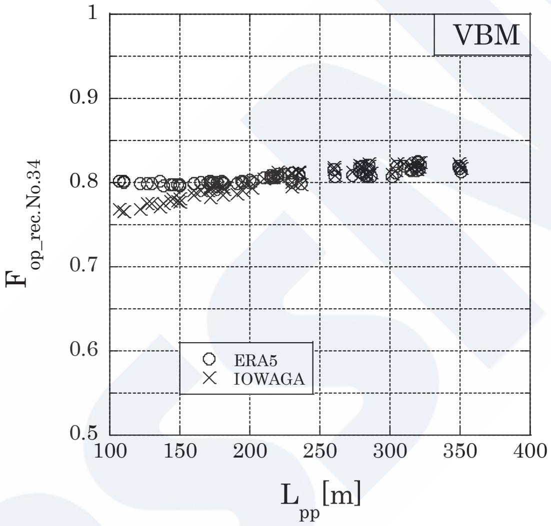

Fig. 7 Ship operational effect $F_{op\_rec.No.34}$ of vertical wave bending moment amidships (VBM) depending on ship length

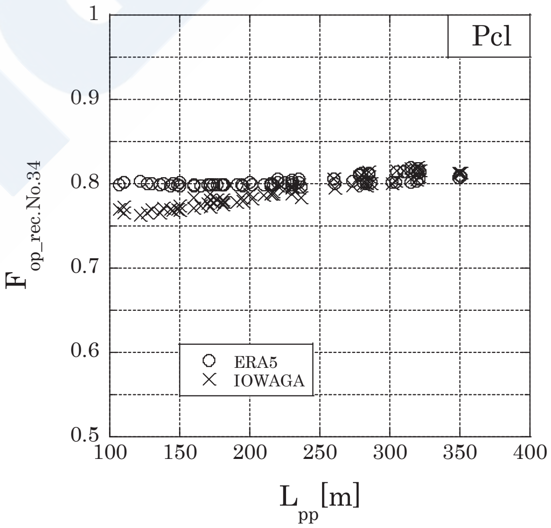

Fig. 8 Ship operational effect $F_{op\_rec.No.34}$ of hydrodynamic pressure at bottom centerline amidships (Pcl) depending on ship length

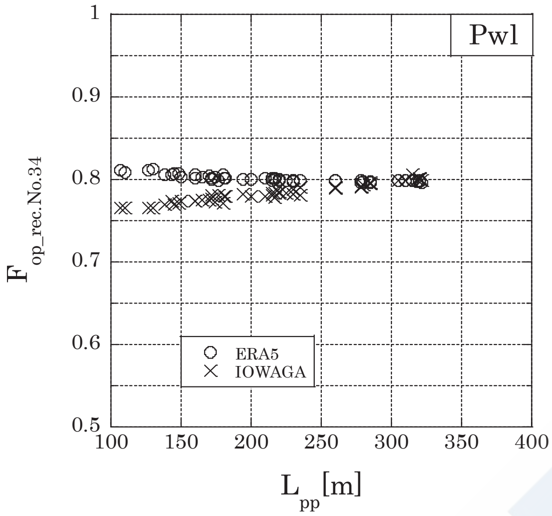

Fig. 9 Ship operational effect $F_{op\_rec.No.34}$ of hydrodynamic pressure at waterline amidships (Pwl) depending on ship length

4. CONCLUSION

In the present study, the authors performed a quantitative evaluation of the ship operational effect which is a gap between the wave scatter diagram constituted by the actually encountered sea states in the North Atlantic Areas by merchant ships and the wave scatter diagram in the IACS Rec. No. 34 in order to contribute to the comprehensively revision of Part C of the Rules for the Survey and Construction of Steel Ships related to hull structures. Considering the actually encountered sea states by merchant ships (bulk carriers, oil tankers and container ships) in the North Atlantic, we performed a quantitative evaluation of the ship operational effect for heave, roll, pitch, vertical wave bending moment amidships (VBM), hydrodynamic pressures at bottom centerline amidships (Pcl) and hydrodynamic pressures at waterline amidships (Pwl). The following conclusions were obtained:

1) The range of mean value ± 2 standard deviations for the ship operational effect $F_{op\_rec.No.34}$ based on the IACS Rec. No. 34 is from 0.75 to 0.84.
2) The significant variation could not be confirmed in $F_{op\_rec.No.34}$ for the different wave hindcasts, different ship lengths and different ship types used in the series of calculations.

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