The Effect of Local Environmental Condition on the Ship Construction Design Standard

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Abstract. This study was aimed to clarify the classification rules requirements for the ship hull structure. The main focus is on the effect of environment conditions to that of rules formula variable. Generally, the classification rules is assumed that the requirements is determined and formulated based on the worst ocean environmental in the world, 'North Atlantic Ocean condition' (IACS rec.34). This assumption was recommended by IACS rec.34 for the worldwide shipping voyage. Kurniawan et al. (2016) and Prasetyo et al. (2018) presented the comparison of environmental condition between the North Atlantic Ocean and non – North Atlantic Ocean (Indonesian water and Australian water). It was founded that the largest ratio of significant wave height between North Atlantic Ocean and the target ocean was up to 700%. Since that the classification society assumed that ship structure be designed on the basis of 10^{-8} long term exceedance of probability of scatter spectrum of environmental condition, this condition might give the substantial deterioration on the design standard that is used specially only in specific area, i.e Indonesian waterways. In this study, the effect of ocean environment of specific area (Indonesian waterways) is compared with that of North Atlantic Ocean on the structural assessment of vessel that might be operated at Indonesian waterways. The characteristics of results are analyzed and examined. The classification rules requirement is reviewed and discussed based on the comparative results.

Keywords: Indonesian waterways · North Atlantic Ocean · Classification society rules · Service area

1 Introduction

The recent development of major classification society (CS) rules are should based on IMO regulatory framework on goal based standard of rules development and making process [1] since that the SOLAS regulation has adopted and amended by the IMO [2]. Here, IMO as the International maritime organization and the part of the United Nation organization has the role to create the regulation for the shipping industry and its supporting. IACS Common Structural Rules for Bulk Carriers and Oil Tankers [3] is

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the example of rules that is developed by Classification society as Recognized Organization and it comply with IMO Goal Based construction standards for Bulk Carriers and Oil Tankers [4].

IMO Goal based construction standards for Bulk Carriers and Oil Tankers 'IMO GBS' has functional requirements in order to achieve the goals as defined in SOLAS 1974, as amended regulation II-1/3-10 [2]. Hereafter, one of those functional requirements is environmental conditions and it shall be designed in accordance with North Atlantic environmental conditions and its wave scatter diagrams. This assumed conditions also apply to the major CS's rules that was developed based on non GBS requirements. The additional question is coming how shipdesigner will take into account the environmental condition if the chosen operating area is not the North Atlantic Ocean (e.g. Indonesian waterways, Chinese domestics water, Japanese domestics waters, etc.).

Previously, several work has been conducted in order to answers the above question, especially that is coming from local shipowner regarding the different and effect of environmental assumption in the CS rules and the ship's actual operation. Kurniawan [5, 6] conducted the initial study to mitigate the wave scatter mapping and its characteristics based on North Atlantic Ocean and Indonesian waterways. Furthermore, Prasetyo [7–9] found some interesting results based on the Kurniawan's initial study in term of application on the structural assessment of ship design.

In this report, the effect of ocean environment on chosen specific area (Indonesian waterways) is compared with that of North Atlantic Ocean for the structural assessment of vessel that might be operated in the chosen area. The characteristics of results are analyzed and examined. The classification rules requirement is reviewed and discussed based on the comparative results.

2 Environmental Conditions

2.1 Wave Data

Since, the major CS rules used the North Atlantic Ocean as the assumption of the environmental condition, Fig. 1 depicts the description of North Atlantic Ocean. While, Indonesian waterways is depicted in Fig. 2. Both of the wave data from both of service area, are based on the scatter diagram. The wave scatter diagram of North Atlantic Ocean is described and tabled by IACS [10] and covering areas 8, 9, 15 and 16 of Global Wave Statistics (GWS). Those areas are located around 60°N to 40°N and 66° W to 0°W of Fig. 1. Thus, the wave scatter diagram of Indonesian water is explained and described by Prasetyo [9]. The wave scatter data was compiled from the wave data that is measured in area of Fig. 2 and located around 10°N to 10°S and 90°E to 140°E and the boundary of Indonesian waterways territory is defined based on the regulation of Indonesian Government [11].

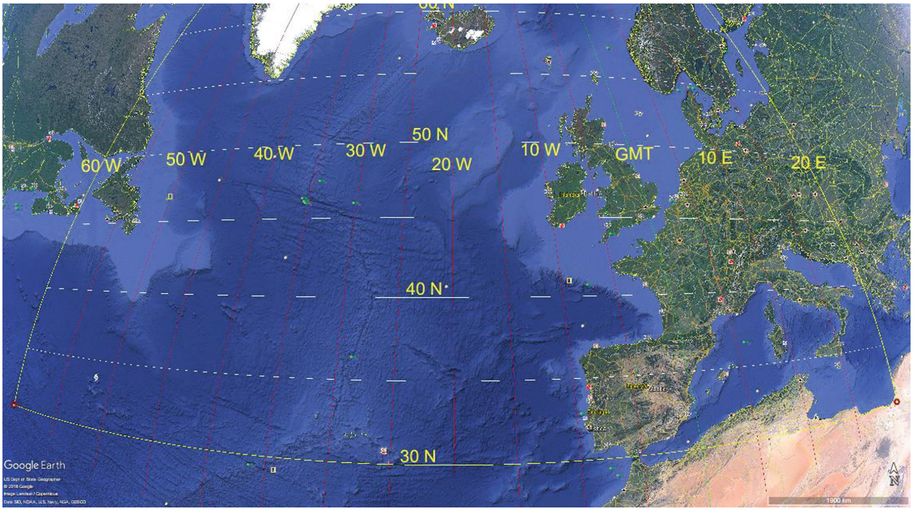


Fig. 1. North Atlantic Ocean location.

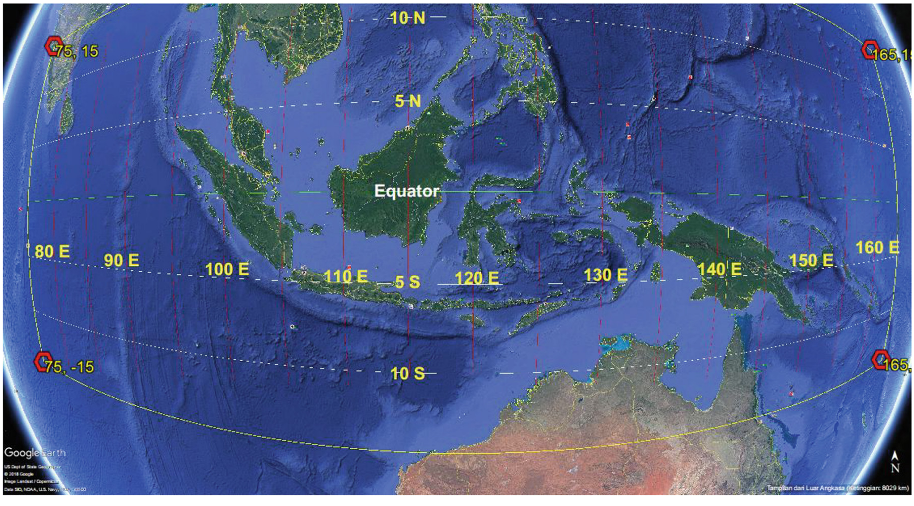


Fig. 2. Indonesian waterways location.

2.2 Seastate Characteristic

Prasetyo [9] showed that the wave scatter diagram of North Atlantic Ocean and Indonesian Waterways could simulate the prediction of the long-term distribution of significant wave height (Hw) by using the Weibull distribution. The comparison of long term design wave operation at both locations is shown in Fig. 3. In the CS's structural rules, 3 (three) value of probability are used in term of ship structural design assessments. The first one is 10^{-8} for the ship design life (e.g. 20 years ship design life), the second is 10^{-6} is for assumed planned operation time and 10^{-4} is for fatigue assessment. Figure 3 shows that for the worst condition of assumed environmental condition, 10^{-8} exceedance probability, the Hw of Indonesian waterways is extremely lower than North Atlantic Ocean. The ratio of Hw between North Atlantic Ocean and Indonesian waterways is 2.75. This condition may give further assumption that any value related to the assumed environmental condition could deteriorate the basis of rules assumption. This first postulate will be further discussed in the following section.

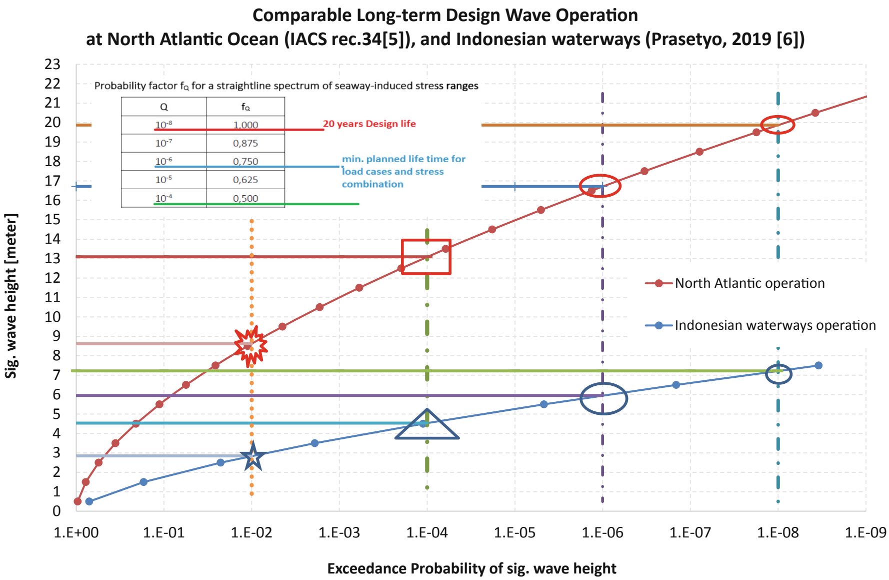


Fig. 3. Comparison long-term design wave operation based on wave scatter diagram described by [9] and [10].

3 Construction Rules Analysis

3.1 Sampling Target

Ship structure analysis is conducted on several ships with different principle dimensions. In general, 5 (five) ships are chosen. The data of principle dimensions of the chosen ship are shown at Table 1. The chosen ships range from 95.00 m to 160.00 m in length. The chosen ships have several type of ships, there are General Cargo, Oil Tanker and Chemical Tanker.

Table 1. Principle dimensions of sampling target.

	Ship 0	Ship 1	Ship 2	Ship 3	Ship 4
Loa [m]	96.585	98.00	99.985	106.25	157.00
Lpp [m]	95.285	92.00	94.50	99.20	149.50

(*continued*)

Table 1. (*continued*)

	Ship 0	Ship 1	Ship 2	Ship 3	Ship 4
B [m]	21.044	21.00	16.00	20.40	27.70
D [m]	8.754	8.20	7.70	6.50	12.00
T [m]	6.5	6.20	6.40	4.20	7.00
W_{deck} [m^3]	2.39	2.49	3.37	9.42	4.9
W_{bottom} [m^3]	3.51	4.35	2.35	2.336	6.16

3.2 Method of Analysis

In this work, the structure rules requirements as stipulated in CS' rules [12] is used as main references. Hereafter, the plate thickness requirements of ship hulls (bottom, side shell and deck plate) is formulated based on the ship length criteria.

Prescriptive net plate thickness requirement is formulated as following

$$t = C_{var} * n_f * \boldsymbol{a} * P \tag{1}$$

where, C_{var} is constant value that is depending on the ship length and the position of plate thickness. n_f is constant value related to framing system of ship structure. $\boldsymbol{a}$ is frame spacing of ship structure and P is applied load on the chosen plate thickness position (lateral and/or in-plane load).

Applied load on the ship structure, that is specifically to apply on the bottom, side shell and deck, is influenced by static and dynamic component and its relate to the wave parameters. The wave parameter is formulated on the basis of wave coefficient and service area. [12, 13] formulates the wave parameters as following:

$$\begin{aligned} c_0 &= [0.04 * \boldsymbol{L} + \boldsymbol{4.1}] * \boldsymbol{c_{RW}} && \textit{for } L < 90\,\text{m} \\ &= [10.75 - [(300 - \boldsymbol{L}) * 0.01]^{1.5}] * \boldsymbol{c_{RW}} && \textit{for } 90 \le L < 300\,\text{m} \\ &= 10.75 * \boldsymbol{c_{RW}} && \textit{for } 300 \le L < 350\,\text{m} \end{aligned} \tag{2}$$

where, $\boldsymbol{L}$ is ship length for construction rules and $\boldsymbol{c_{RW}}$ is the parameter for service area.

Furthermore, the net plate thickness requirement is assessed by using the combination load that is consisted of lateral and in-plane load. These combination loads has acceptance parameters on the basis of permissible design stress. The parameter is presented by following formula of minimum section modulus (W_{min}) and Vertical wave bending moment (M_{wv});

$$W_{min} = k \cdot c_0 \cdot \boldsymbol{L}^2 \cdot \boldsymbol{B} \cdot (\boldsymbol{C}_B + 0,7) \cdot 10^{-6} \left[\text{m}^3\right] \tag{3}$$

$$M_{WV} = \boldsymbol{L}^2 \cdot \boldsymbol{B} \cdot c_0 \cdot c_1 \cdot c_L \cdot c_M \quad [\text{kNm}] \tag{4}$$

where, k is material factor, $\boldsymbol{B}$ is the greatest moulded of ship breadth, $\boldsymbol{C}_{\text{B}}$ is moulded block of the ship at load draught $\boldsymbol{T}$, c_0 is wave coefficient, c_1 is hogging or sagging condition parameter, c_L is ship length coefficient and c_M is distribution factor (see [12]).

The effect of different environmental condition will be analyzed by using the previous equations and the results is discussed in the following section. The first of all, the effect of wave coefficient due to different environmental condition will be examined. Thus, the relation between wave bending moment and environmental condition is also examined. Finally, the correlation between the required net thickness, applied load and changing of wave parameter due to environmental condition is examined.

4 Results and Discussions

4.1 Wave Parameters

References [12–15] describes that the wave parameters is related with standard wave data used as assumption in the CS's rules application. The wave parameter (c_0) is calculated according Eq. 2, has maximum value of 10.75 [15]. Many statements explain that this value (10.75) is related with IACS standard wave data on North Atlantic Ocean [10]. The references to support this fact is not yet published, however, this work will reference to recent fact corresponding to the correlation between the value of 10.75 and the wave scatter diagram data of North Atlantic Ocean.

Wave Coefficient

This work will present the correlation between the value of 10.75 and that of the wave scatter diagram of North Atlantic Ocean. The wave scatter diagram is defined by [10]. It is found that the 10.75 does not correlate with the worst condition of North Atlantic Ocean long term design wave 10^{-8}. Figure 3 shows that the 10^{-8} tend to Hw equals with 19.9 m. Furthermore, it is found that IACS rec.34 [10] scatter diagram has the mean of Hw equal to 3.4 m and it is about one third of 10.75 value.

By using the same procedure as explained in the previous paragraph, Indonesian waterways scatter diagram [9] has the average Hw equal to 2.29 ms. Thus, multiply by 3 (three) times of those average, we will have 7.22 value for c_0 parameter of Indonesian waterways. The ratio c_0 between of Indonesian waterways (7.22) and North Atlantic Ocean (10.75) is relatively closed to 0.7.

Figure 4 shows the plotting of relation between ship's length and wave coeffisien. The c_0 of unlimited service of North Atlantic Ocean ($\boldsymbol{c_{RW}}$ is 1.0) is determined by using the Eq. 2, and plotted in this figure. The c_0 of proposed Indonesian waterways is 30% of Unlimited Service of North Atlantic Ocean.

Wave Bending Moment

In order to review the further effect of wave parameters, the wave bending moment of 'Ship0' of Table 1 is calculated based on the 19.9 m Hw of North Atlantic Ocean. The wave bending moment of the ship is determined by using 3D motion software to generate the respon amplitude operator (RAO) load of Mwv with heading angle equals to 180° in the midship location (see Fig. 5). Thus, the RAO of Mwv is multiply by energy wave spectrum (see Fig. 6) and the results is compared with CS's rules requirement as presented at Fig. 7.

Figure 7 shows that the vertical wave bending moment distribution of Ship0 is lower than that rules requirements. The graphical pattern of both curves series is

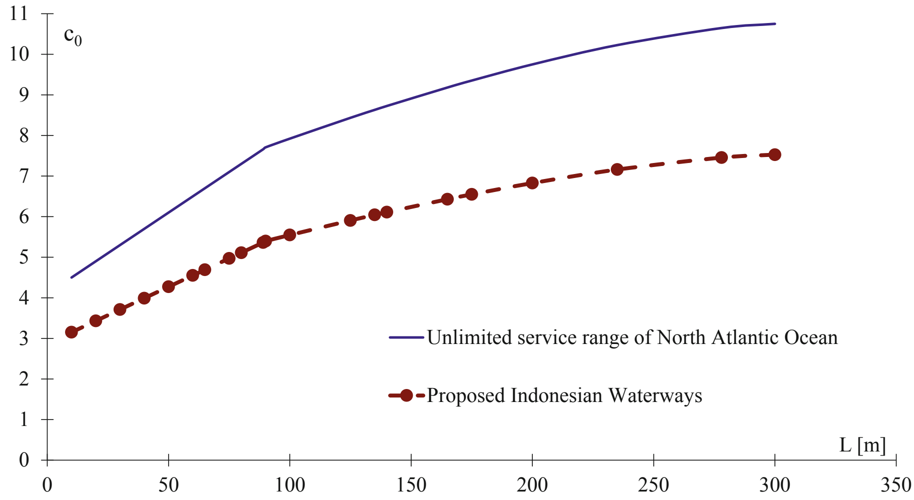


Fig. 4. Comparison of wave parameters c_0 based on North Atlantic Ocean and proposed for Indonesian waterways.

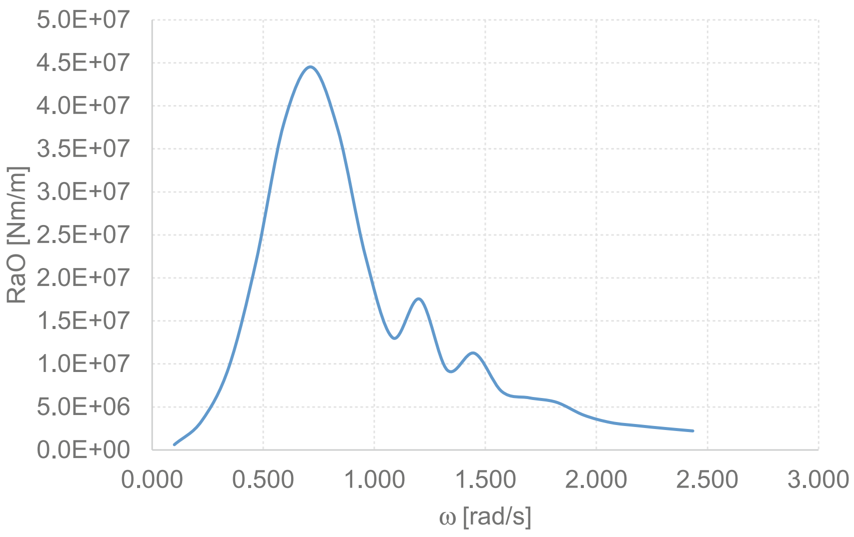


Fig. 5. RAO Mwv load of the 'Ship0' for 180° heading angle located in midship.

different. This is caused by the different assumption that be used in both curves series. The rules requirements assume that the range of ($x/L < 0.25$ and $x/L > 0.75$) is linear and $0.25 \leq x/L \leq 0.75$ is constant. However, the determined wave bending moment is assumed by following sinusiodal function.

In order to get the consistency between the rules requirements and ship dimension, the ship dimension is optimized and the ratio of **L/B** and **B/H** are 5.5 and 1.25. The vertical bending moment for the ship with dimension based on the optimized ratio are

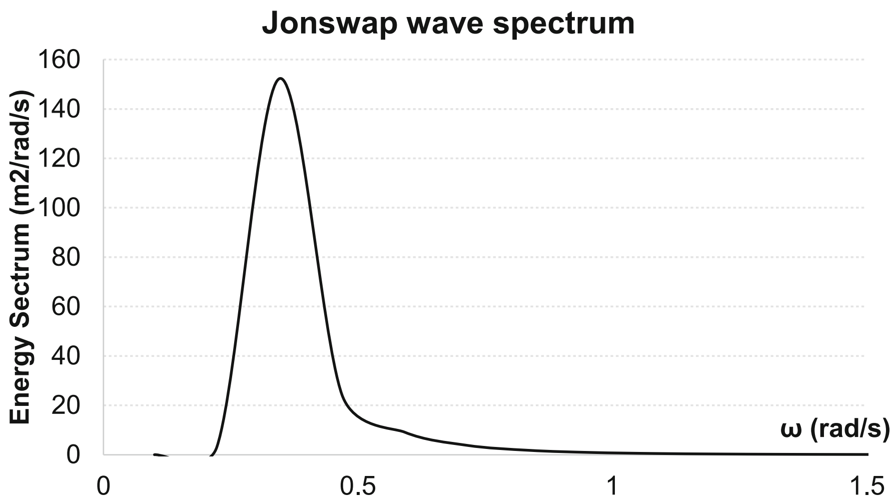


Fig. 6. JONSWAP wave spectrum with 19.9 m Hw.

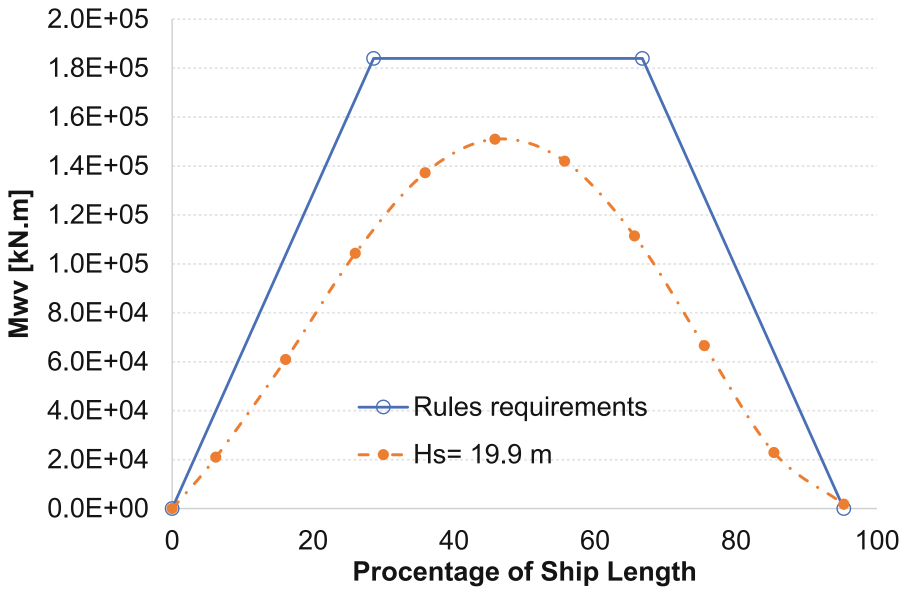


Fig. 7. Vertical bending moment distribution for 'Ship0'.

determined by using 16.8 m Hw of North Atlantic Ocean. The distribution of vertical bending moment presents in Fig. 8.

Thus, the same ship dimension that has been optimized according the description in previous paragraph are used to determined the vertical bending moment in the Indonesian waterways. Kurniawan [5, 6] figured out the worst condition of Indonesian

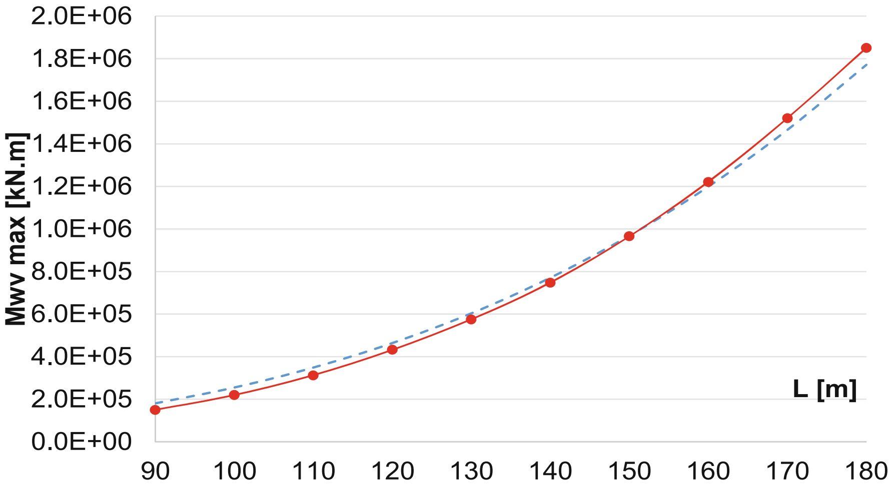


Fig. 8. Comparison of Mwv for optimization purpose for ship length 90 m to 180 m.

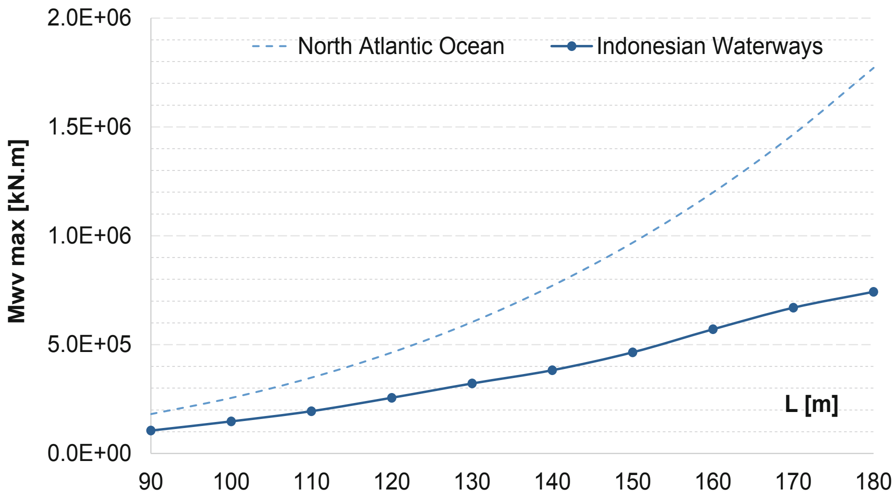


Fig. 9. The comparison vertical bending moment Mwv by taking into account environmental condition. North Atlantic Ocean and Indonesian waterways.

waterways that is about 7.0 m Hw. Hereafter, the vertical bending moment that derive from 16.8 m Hw of North Atlantic Ocean is compared with 7 m Hw of Indonesian waterways. Figure 9 shows the comparison both of maximum vertical bending moment for the specific ship length ***L***. Figure 9 shows that the Mwv of Indonesian waterways is significantly lower than North Atlantic Ocean for each ***L***. It could be assumed that the global structural strength become more strong if apply the North Atlantic ocean design standard.

4.2 Structural Assessment

Local Strength

SSC-446 [16] and Daley [17] shown that the influence of quasi static/dynamic load (p_O) to static load (p_s) in the total lateral load ($\boldsymbol{P}$) is about 20%. This means that the total lateral load is almost equal to 120% of static load. The relation p_O, p_s and P is shown at Eq. 5.

$$\begin{aligned} \boldsymbol{P} &= p_0 + p_s \\ &= 0.2 * p_s + p_s = 1.2 * p_s \\ &\cong 6 * p_0 \end{aligned} \tag{5}$$

where, $\boldsymbol{P}$ is total lateral load, p_O is dynamic load due to wave parameters and p_s is static load due to hydrostatic force.

Based on the Eq. 2, the wave parameter are simulated with reduction. The effect due to reduction of c_0 to the dynamic load p_0 are plotted at the Fig. 10. Thus, the net plate thickness requirement will be reduced due to the reduction of p_0 are also figured at Fig. 11. These means that if dynamic load will have 35% reduction, the reduction of net plate thickness requirement become 2.9%. The real case could show if original requirement for North Atlantic operation is 10 mm, the Indonesia waterways will reduce to 9.1 mm plate thickness requirement.

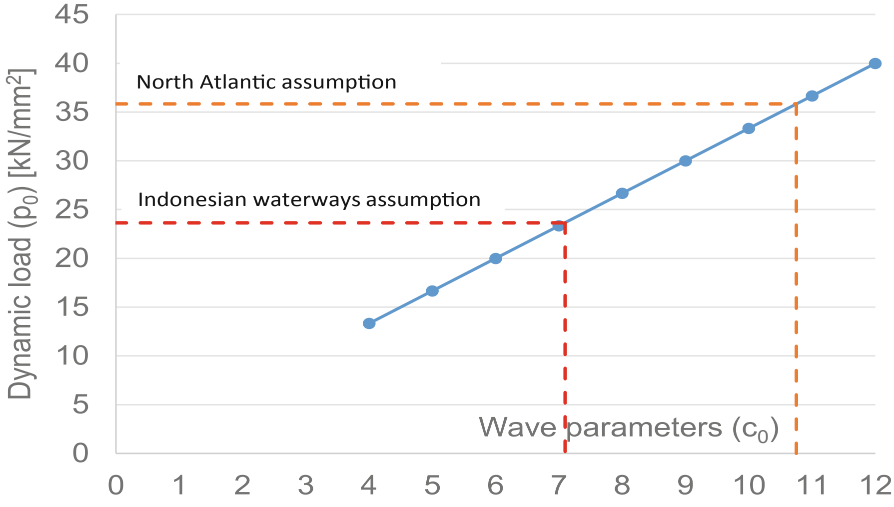


Fig. 10. The effect of dynamic load reduction due to reduction of wave parameter.

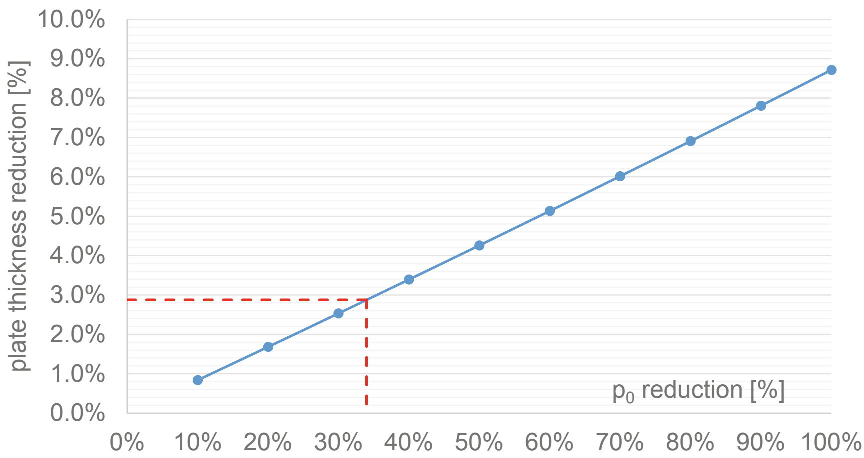


Fig. 11. The effect of net plate thickness requirement reduction due to reduction of lateral load.

Global Strength

The global strength of ship structure for the 4 target ship of Table 1, 'Ship1', 'ship2', 'ship3' and 'ship4' are conducted by direct strength analysis using the commercial FE software program (Patran). Figure 12 shows the example of FE model from the target ship.

Boundary Condition

Yudo et al. [18] proposed the specific boundary condition to analyze the pure bending load applied to cylindrical pipe. Here, the boundary condition concept is applied by changing the object (cylindrical pipe to beam model of cargo area). The FE model has been set up the boundary condition by assuming that the part of ship in the midship section will not have translation (ux = uy = uz = 0) and rotation (rx = ry = rz = 0). The load is representing from the bending moment that placed in the forepeak and afterpeak bulkhead. The illustration of loading condition and boundary condition of typical FE model are figured in the Fig. 13.

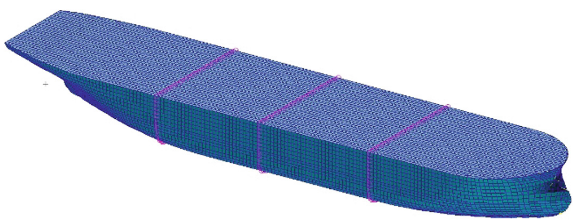


Fig. 12. FE model of General Cargo Ship from Table 1.

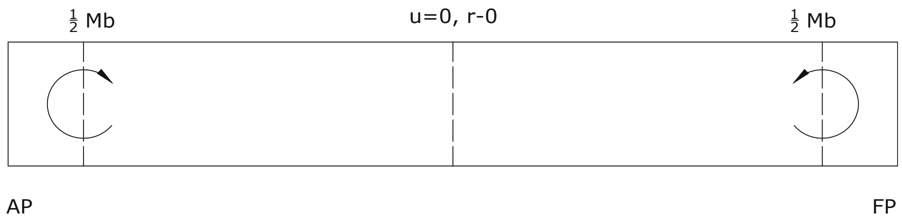


Fig. 13. The illustration of load and boundary condition on the FE model.

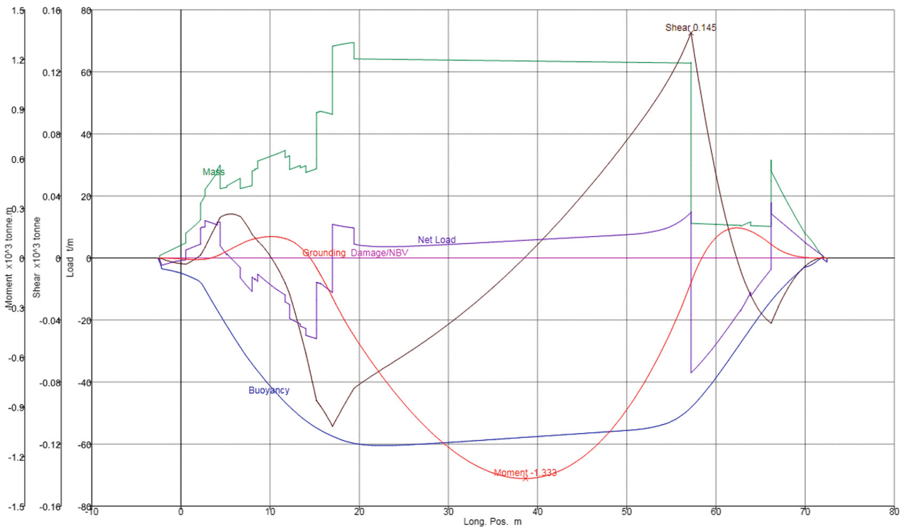


Fig. 14. The example of respon vertical bending moment for Sagging condition.

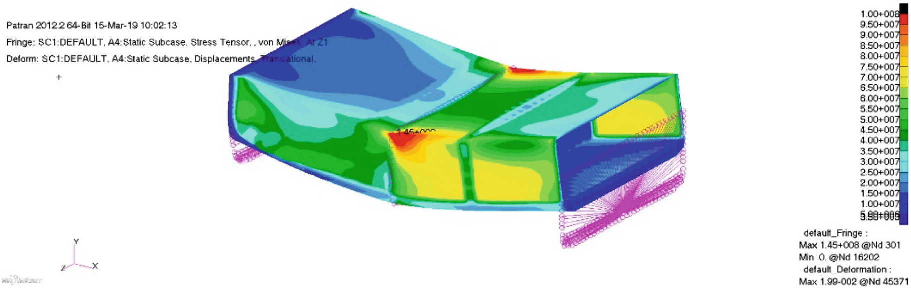
The bending moment applied to FE model is determined from the resultant of weight distribution and hydrodynamic distribution due to trim condition. The integral summation of force distribution will produce the shear force distribution and further integral summation will also derive the vertical bending moment. Figure 14 shows the example of vertical bending moment response applied to the FE model of target ship. The Table 2 shows the maximum respon of vertical bending moment for each target ships.

Figure 15 and Fig. 16 shows the example post processing result of FE model on General Cargo ships. Furthermore, the results will compare to the engineering theory by following Eq. 6. Table 3 shows the resume of validation error between FE analysis and the engineering theory. It is shown that maximum correction is lower than 4%. This condition means that the FE model analysis is acceptable.

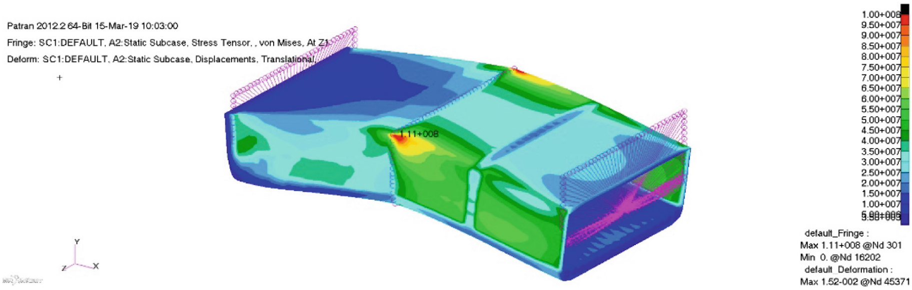
Table 2. The vertical bending moment of target ship.

	Maximum vertical bending moment [Nm]				
	Stillwater	North Atlantic Ocean*		Indonesian waterways**	
		Hogging	Sagging	Hogging	Sagging
Ship1	2.139×10^7	2.699×10^8	-3.529×10^8	1.310×10^8	-1.192×10^8
Ship2	4.747×10^7	1.472×10^8	-5.940×10^7	1.250×10^8	-2.981×10^7
Ship3	6.533×10^7	2.784×10^8	-4.263×10^8	1.710×10^8	-1.260×10^8
Ship4	1.718×10^8	9.252×10^8	-8.642×10^8	5.073×10^8	-3.441×10^8

*The wave condition of North Atlantic Ocean is 10.75 m Hw.
**The wave condition of Indonesian waterways is 3.74 m Hw.



(a). Sagging condition for North Atlantic operation



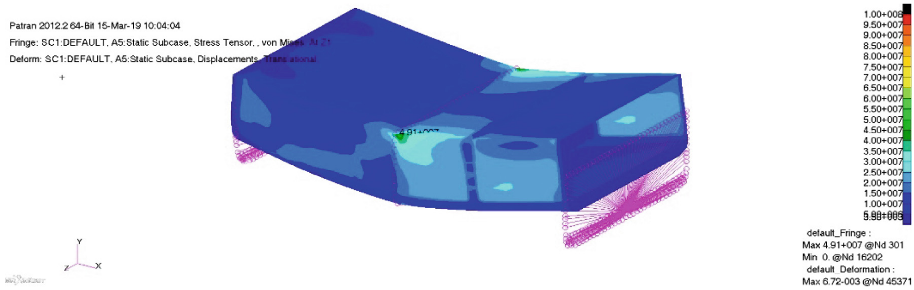
(b). Hogging condition for North Atlantic operation

Fig. 15. The normal stress for both sagging and hogging condition of North Atlantic operation on General Cargo ship.

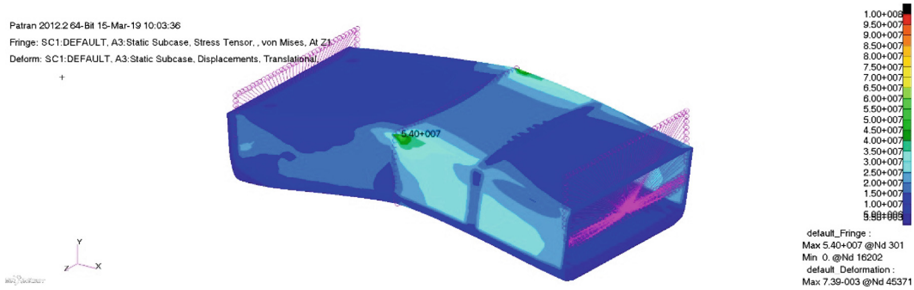
$$s = VBM\,(1/W)\,\left[N/mm^2\right] \tag{6}$$

where, W is section modulus of target ship at midship section. VBM is vertical bending moment.

Table 4 shows the reduction of Von Mises Equivalent stress that determined based on North Atlantic operation and Indonesian waterways operation. The reduction from



(a). Sagging condition for Indonesian waterways



(b). Hogging condition for Indonesian waterways.

Fig. 16. The normal stress for both sagging and hogging condition of Indonesian waterways operation on General Cargo ship.

Table 3. The validation between FE model result and teory.

	VBM	W	σ (N/mm^2)		
	Nm	m^3	Teoritical	FEA	%
Ship1	2.139×10^7	2.45	8.54	8.81	3.07
Ship2	4.747×10^7	2.35	19.80	19.10	3.85
Ship3	6.533×10^7	2.36	27.19	26.8	2.46
Ship4	1.718×10^7	6.16	27.37	26.9	2.75

North Atlantic to Indonesian waterways is ranging between 18% to 51%. In general, the stress does not exceed the maximum permissible stress (175 N/mm^2).

Figure 17 shows the structure capacity of Ship1 (General cargo ship type). The relation between Vertical bending moment and curvature is ploted in the figure. It shows that, Ship1 applied with VBM for hogging and sagging condition as valued at Table 2, it is lower than the ship structure capacity.

Table 4. The reduction of Von Mises equivalent stress based on North Atlantic operation and Indonesian waterways operation.

	North Atlantic Operation		Indonesian waterways operation		% of reduction
	Hogging	Sagging	Hogging	Sagging	
Ship1	112	147	54.4	45.9	51.43
Ship2	59.1	23.9	48.4	12	18.10
Ship3	114	160	61.8	70.2	38.42
Ship4	145	135	79.3	53.8	45.31

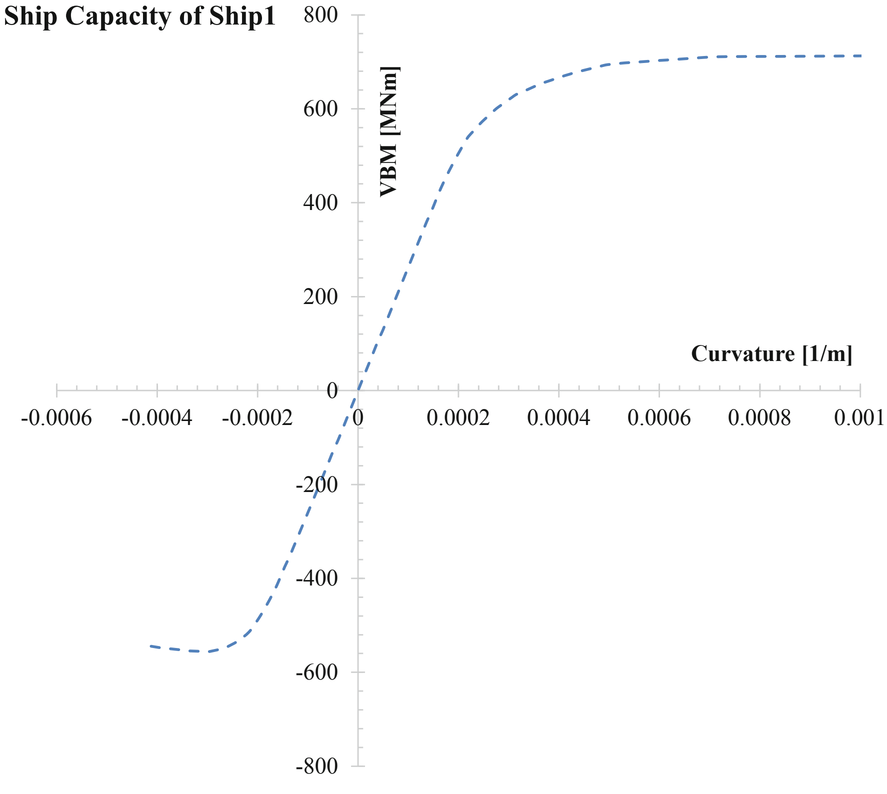


Fig. 17. The capacity of ship structure due to relation between vertical bending moment and curvature on General Cargo ship.

5 Conclusion

Wave scatter diagram from different ocean environmental, North Atlantic Ocean and Indonesian waterways operation, are assembled and compared. The Classification society rules are based on the North Atlantic ocean assumption. This ship structure rule is analyzed and examined by considering two environmental condition. As the result conclusion and future plan is summarized as the following:

- The wave parameters could have a reduction based on wave scatter diagram. The Indonesian waterways wave parameter reduces 30% comparing with the c0 of North Atlantic Ocean.
- The vertical bending moment response to ship with $L > 90$ m length at Indonesian waterways is lower than North Atlantic ocean.
- The structural assessment shows that local net plate thickness will reduce to 2.9% if wave parameter reduce 35%.
- The global strength assessment based on the direct strength analysis give reduction of Normal stress on Indonesian waterways operation about 18% to 51% comparing with North Atlantic operation.
- In order to give more sufficient results analysis, it is needed additional work in the future. The additional work includes the analysis of ship capacity during both of intact and damage condition along North Atlantic ocean operation and Indonesian waterways operation.
- The revision of dedicated ship structural rules is required in order to facilitate the above finding, especially to ship operate in the special area that different with the North Atlantic Ocean.

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