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Procedia Structural Integrity 47 (2023) 812–819

Structural Integrity
Procedia

www.elsevier.com/locate/procedia

27th International Conference on Fracture and Structural Integrity (IGF27)

Application of the limit design state to hull-girder ultimate strength evaluations on the ship-shaped structures

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Abstract

This paper evaluates limit state design in ship-shaped steel structures. Limit state design is divided into four categories, namely serviceability limit state (SLS), ultimate limit state (ULS), fatigue limit state (FLS), and accidental limit state (ALS). The four categories represent the conditions that can occur throughout the design's service lifetime. ULS will be described in more detail using a ship-shaped structure as the basis for discussion. ULS represents a structural failure both in whole and in part that can decrease the strength of the structure. Determination of ULS values in ship-shaped structures is carried out by comparing total loads with the ultimate limit state. There are various methods to determine the ultimate strength of a ship-shaped structure, one of which is to use the Smith's method. This method considers the ultimate strength of the ship-shaped structure by first reducing the overall structure to a hull girder. The hull girders are further categorized into stiffener, stiffened plate, or hard corner elements. Each of these categories is then taken into account separately before being reunited. To improve the accuracy of calculating the ultimate strength of hull girder (HGUS), many studies have been carried out by adding variables in the determination of HGUS, such as corrosion, non-uniform uniaxial thrust, and initial imperfection effect at each structure member.

Keywords: Hull girder ultimate strength; limit design state; ultimate limit state; Smith's method; IACS-CSR

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10.1016/j.prostr.2023.07.038

1. Introduction

Structural design is the most important process in the process of making the overall design of a product [Dabit et al., 2020; Nubli et al., 2022]. In the design process, especially structures, it is necessary to consider the design's ability to withstand operational loads and environmental and unexpected accidents throughout the expected lifetime. Throughout the expected lifetime, a structure will be exposed to various conditions that will decrease its strength and durability. This condition will have a greater influence on moving structures such as ship vessels. Based on a European Marine Safety Agency report, throughout 2020, there were 2837 shipwrecks with 675 people injured and 38 victims [EMSA, 2021]. In the process of structural design, there is a limit state that can be used to test the feasibility of the structure; the limit state consists of a serviceability limit state (SLS), ultimate limit state (ULS), fatigue limit state (FLS) and accidental limit state (ALS) [Paik and Thayambali, 2007]. These limit states represent conditions that can affect the strength and feasibility of the structure throughout the expected lifetime. SLS represents the criteria for the structure's ability to support operational use needs. ULS represents failures that may occur in structures or components due to loads on the structure. In this paper, ULS will be discussed further. FLS represents the accumulation of damage as the effect of repeated actions that can cause cracks in the structure. ALS represents abnormal and unpredictable conditions such as collisions and the like. The most important thing in determining ULS design is accurately calculating each component's buckling strength in the structure [Paik, 2018]. Even so, it is worth highlighting the plate structure with the backburner of each component working by influencing each other. This calculates buckling strength on the plate structure complex. Basically, in the calculation of buckling strength, the more complex the calculation, the higher the accuracy. However, simplification in buckling strength calculations can be done without reducing its accuracy much, with a note of paying attention to its conditions and needs. The empirical formulation is the most efficient but accurate method for predicting buckling or ultimate strength in a structure [Kim et al., 2018].

In the case of ship vessels, as a reinforced plate, the determination of buckling strength is taken into account by uniting the entire component. The unification of the buckling strength of each component into the structure can be represented using Hull Girder Ultimate Strength (HGUS) [Adiputra et al., 2023]. There are various methods of determining HGUS that have been developed so far. Caldwell [1965] formulated the HGUS calculation formula by looking at the bending moment value caused by reducing stress in vessels under longitudinal bending. Ueda and Rashed [1991] developed an idealized structural unit method (ISUM) that analyzes the structure by separating each member, such as support members, beam-columns, rectangular plates, and stiffened panels. Smith [1977] formulated formulas that have been replicated quite a lot to date, one of which is by the International Association of Classification Societies at IACS-CSR [2022]. Smith [1977] formulated HGUS by applying the progressive collapse method. In Smith's formulation, the hull girders are categorized separately into a combination of plate-stiffener beam-column components. In this paper, the calculation of HGUS, especially Smith's method, will be explained further.

2. Limit State Design

During its service time, a structure, especially a ship-shaped moving structure, will experience degradation caused by various things. Paik [2018] describes several factors that significantly influence structural degradation. The factors are as follows:

- Geometric factors include structural characteristics, buckling, deformation, and bending.
- Material factors include metal phase composition and mechanical properties.
- The fabrication and merging processes related to initial imperfections are mainly due to the welding process between each component.
- The temperature factor is mainly extreme heat or cold for a long time.
- Impact factors, including collisions with hard objects, waves, or falling objects that hit the structure directly.
- Human factors, such as misuse [Montewka et al., 2017; Ahn et al., 2022].
- Degradation factors due to lifespan, such as reduced thickness due to corrosion and cracking due to fatigue [Fajri et al., 2021;2021; Bintaro et al., 2021].
- Accident damage factors, such as collision, grounding, explosion, and fire damage [Kim et al., 2021; Kim et al., 2022; Nubli et al., 2022; Prabowo et al., 2019; 2020; 2021; 2022; Zhang et al., 2022; Tunçel et al., 2023].

All of these factors can be represented in limit state design which is then categorized into serviceability limit state (SLS), ultimate limit state (ULS), fatigue limit state (FLS), and accidental limit state (ALS) [Paik and Thayambali, 2007]. Research on limit state design, especially on stiffened plates, only began in the early 1970s when there were many bridge failures in Europe [Bedair, 2009]. The Merrison Committee of Enquiry [1973] investigated the design and construction procedures on three collapsed steel box girder bridges. Based on the investigation, it was concluded that the design rules for stiffened panels were insufficient.

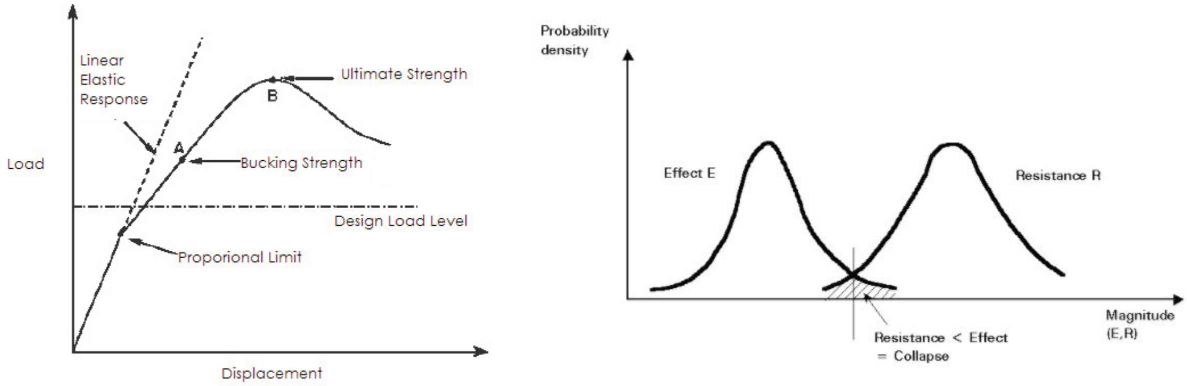
The partial safety factor determines the structure's safety capacity against the limit state design. The partial safety factor is a method to obtain the safety level of structure design by applying load and resistance factors that represent the capacity of the design and design needs during service time [Folley, 2016]. In determining safety factors, the nominal value of capacity (C_k) and nominal value of demands (D_k) is expressed as the mean value of the random variable. Meanwhile, design capacity (C_d) and design demands (D_d) are stated to follow the specified percentage of the area under the random variable curve. A design can be declared safe if the value of the partial safety factor is greater than 1 ($\eta > 1$). The value of partial safety factor can be expressed as follows:

$$\eta = \frac{C_d}{D_d} = \frac{1}{\gamma_C \gamma_D} \frac{C_k}{D_k} > 1 \tag{1}$$

Where γ_C is the partial safety factor associated with capacity, and γ_D is the partial safety factor associated with demand.

3. Ultimate Limit State

The ultimate limit state (ULS) in the structure represents the structure collapse of either part or all of the components due to various loads' loss of stiffness and strength. ULS is closely related to the loss of structural equilibrium, the achievement of the maximum resistance value of the structure, and the structure's instability due to the collapse of support members and plating [Paik, 2018]. In the structure of plate stiffener, calculation can be simplified by basing the ULS value on the ultimate strength derived from the buckling strength of each member.



(a) (b)

Fig 1. Illustration of the limit state: (a) structural design based on the ultimate limit state, and (b) collapse condition when design resistance (R) is less than effect of actions (E) (Nathoo, 2017).

In Fig. 1 buckling strength value is represented as point A, and the ultimate strength is represented as point B. In reality, the accurate value of ultimate strength or the true ultimate strength cannot be known for certain. This makes the safety margin almost inaccurate as well. The following formula can be used to determine ULS using Eq. 2 [Paik and Thayambali, 2007].

$$C_d - D_d > 0 \tag{2}$$

C_d represents the value of ultimate strength and D_d represents working loads and stress about structure. In a ship-shaped structure where the structure was subjected to multiple loads components must be stated as the corresponding interaction functions while taking the results of coupled actions into account. Specifically, the ULS value for ship-shaped structures subject to bending moment can be stated as follows [Paik and Thayambali, 2007]:

$$\frac{M_u}{\gamma_u} = \gamma_s M_{sw} + \gamma_w M_{wv} \tag{3}$$

Where M_u is the ultimate bending moment, M_{sw} is the still-water bending moment, M_{wv} is the wave-induced bending moment and γ_u, γ_{sw}, γ_w is a partial safety factor for each bending moment. γ_u, γ_{sw}, γ_w values must be greater than one or greater than the specific rules of each type of ship structure to be safe. Based on IACS-CSR [2022], M_{sw} and M_{wv} divided into two calculations based on the conditions imposed on hull.

For hogging (Eqs. 4-5)

$$M_{sw-h-min} = f_{sw}(171C_w L^2 B(C_b + 0.7) - M_{wv-h-mid}) \tag{4}$$

$$M_{wv-h-mid} = 0.19 f_{nl-vh} f_m f_p C_w L^2 B C_b \tag{5}$$

For sagging (Eqs. 6-7)

$$M_{sw-s-min} = -0.85 f_{sw}(171C_w L^2 B(C_b + 0.7) + M_{wv-s-mid}) \tag{6}$$

$$M_{wv-s-mid} = -0.19 f_{nl-vh} f_m f_p C_w L^2 B C_b \tag{7}$$

Failure in ship-shaped structures should ideally occur in a ductile state so that the structure is able to redistribute internal stress to all its members [Paik, 2018]. Thus, the structure is able to absorb more energy and last longer before it completely collapses. There are several conditions that need to be met in order for the structure to collapse in a buckling state, these conditions are:

- Mechanical properties of materials, especially toughness, have met the requirements
- Structural design and joints allow plastic deformation to occur
- Each member of the structure forms an array that allows a decrease in the capacity of the structure not to occur suddenly.
- There are no initial imperfections in the structure that can trigger structural failure.

4. Ultimate Strength of Ship-Shaped Structures

Ship-shaped structure is a structure based on plates that are given stiffeners or also known as stiffened plates. The occurrence of ultimate strength on stiffened plates can ideally be divided into 5 conditions: pre-buckling, buckling, post-buckling, collapse (ultimate strength), and post-collapse [Paik and Thayambali, 2007]. The buckling plate in the elastic zone will be stable, where additional loads can still be held by the structure until the structure is completely collapsed. Since there is little residual strength of the structure in the inelastic zone, the inelastic zone can be considered as the ULS of the stiffened plate. Ship-shaped structure failure is controlled by buckling, ultimate strength, and yielding of longitudinal structural elements. Determining the ultimate strength of a ship-shaped structure can be done using a variety of methods. One of the accurate and most effective methods is to use empirical formulations. Empirical formulations of ship-shaped structures are usually done by dividing the overall structure into hull girders. One empirical formulation that is pretty much used and replicated and also developed is Smith's method. In Smith's method, the ultimate strength of the hull girder (HGUS) value is analogous to the hull girder bending moment.

HGUS calculations using Smith's methods that have been replicated in IACS-CSR [2022] are based on a progressive collapse that occurs in hull girders. Progressive collapse is analogous to an increase in bending moments as an effect of hogging or sagging conditions received by ships during service lifetime. The bending moment accretion is analogous to curvature (x) which can be formulated as follows:

$$x_n = \Delta x = 0.01 \frac{R_{eH}}{E} \frac{1}{Z_D - Z_n} \tag{8}$$

Where:

R_{eHs} : minimum yield stress, in N/mm^2, of the plate
Z_D : Z coordinate, in m, of strength deck at side
Z_n : Z coordinate, in m, of each *n* curvature
E : Modulus Young, in N/m^2

In the calculation of HGUS using Smith's method hull girder is divided into several parts. These parts are categorized into stiffener, stiffened plate, or hard corner elements [IACS-CSR, 2022]. Each of these categories is considered separately following the increase in curvature value. The calculation of each of these categories is as formulated in Eqs. 9 - 13.

- Beam column buckling

$$\sigma_{CR1} = \phi\sigma_{C1}\frac{A_{s-n50} + A_{pE-n50}}{A_{s-n50} + A_{p-n50}} \tag{9}$$

- Torsional Buckling

$$\sigma_{CR2} = \phi\frac{A_{s-n50}\,\sigma_{C2} + A_{p-n50}\,\sigma_{CP}}{A_{s-n50} + A_{p-n50}} \tag{10}$$

- Web local buckling of stiffeners made of flanged profiles

$$\sigma_{CR3} = \phi\frac{10^3 b_E\, t_{n50}\;\, R_{eHp} + \left(h_{we}\, t_{w-n50} + b_f\, t_{f-n50}\right)R_{eHs}}{10^3 s t_{n50} + h_w\, t_{w-n50} + b_f\, t_{f-n50}} \tag{11}$$

- Web local buckling of stiffeners made of flat bars

$$\sigma_{CR4} = \phi\frac{A_{P-n50}\,\sigma_{CP} + A_{s-n50}\,\sigma_{C4}}{A_{p-n50} + A_{s-n50}} \tag{12}$$

- Plate buckling

$$\sigma_{CR5} = min\begin{cases} R_{eHp}\phi \\ \phi R_{eHp}\left[\frac{s}{\ell}\left(\frac{2.25}{\beta_E} - \frac{1.25}{{\beta_E}^2}\right) + \;0.1\left(1 - \frac{s}{\ell}\right)\left(1 + \frac{1}{{\beta_E}^2}\right)^2\right] \end{cases} \tag{13}$$

Where:
ϕ : edge function
$\sigma_{C1,2,4}$: critical stress in N/mm^2 for each respective buckling mode
σ_{CP} : buckling stress of attached plate in N/mm^2
R_{eHs} : minimum yield stress, in N/mm^2, of the plate
A_{s-n50} : net sectional area, in cm^2, of stiffener
A_{p-n50} : net sectional area, in cm^2, of attached plating
A_{pE-n50} : effective area, in cm^2
β_E, h_{we} : effective width and height of the stiffener
t_{n50}, t_{f-n50}, t_{w-n50} : thickness of plate, flange and web respectively
h_w : net web thickness
s : ordinary stiffener spacing
ℓ : longer side of the plate in m
β_E : $10^3\frac{s}{t_{n50}}\sqrt{\frac{\varepsilon\, R_{eHp}}{E}}$

The buckling calculation that is used in Eqs. 9 - 13 is based on critical stress due to compression. The critical stress due to compression value varies by category but has the same basis of formulation, namely Euler's column formula. The Euler column formula in column buckling determines the critical buckling loads of a lengthy column with pinned ends. Euler column buckling formula formulated as follows:

$$F = \pi^2 n\frac{E\,I}{L^2} \tag{14}$$

Where:
E : modulus of elasticity (N/mm^2)
L : length of column (m)

I : moment of Inertia (m^4)

n : factor counting for end conditions; where $n = 1$ for column pivoted in both ends, $n = 4$ for both ends fixed, $n = 2$ one end fixed, the other end rounded, $n = 0.25$ one end fixed, one end free.

Particularly for Eq.10, the Euler column buckling value derived from the equation as follows:

$$\sigma_{ET} = \frac{G\, I_T}{I_p} + \frac{\pi^2\, E\, C_w}{I_p l_e^2} \tag{15}$$

Where:

I_p : polar moment of inertia about the shear center

I_T : St. Venant torsional constant

l_e : effective length with respect to warping

C_w : warping constant

I_T and C_w values were calculated by adjusting the shape of the cross section. For a tee stiffener I_T and C_w as stated in Det Norske Veritas [1995] was formulated as:

$$I_T = \frac{1}{3}(2\, b\, t^3 + h\, d^3) \tag{16}$$

and

$$C_w = \frac{h^2 b^3 t}{24} \tag{17}$$

5. Development of HGUS Calculation

The more complex the calculation of the ultimate strength in the structure, the more accurate the calculation results will be. On this basis, various research has been carried out with the addition of essential variables to improve the accuracy of HGUS calculations. Several of the studies on HGUS that have been carried out includes:

- Non-uniform uniaxial thrust
  Anyfantis [2020] conducted research by changing displacement due to loads that are often calculated using uniform axial thrust to non-uniform axial thrust. The research is based on the relative angle and vertical location of the elements which according to the neutral axis, axial strain and axial displacement deviate from uniformity (become non-uniform) [Anyfantis, 2019]. The closer are presentative element from the neutral axis, the more the aforementioned ratio departs from unity. Thus, the use of uniform thrust will reduce the accuracy of HGUS calculations. Based on his research, Anyfantis concluded that non-uniform loads negatively affect the value of HGUS [Anyfantis, 2020].

- Discretizing each structural component
  Besides adding variables, combining calculation methods can improve the accuracy of the HGUS calculation results. Ölmez and Bayraktarkatal [2015] analyze the effects of discretizing each structural component in the hull girder section, initial plate deflection, residual welding stress, and 50% corrosion margin on the overall hull girder strength. The calculation was done using ten benchmark ships' cross-sections for validation. The method used comprised ISUM-based component discretization and Smith method-based progressive collapse analysis. In this combination method, single plate, single stiffener, and stiffened panel components are used instead of just plate-stiffener combination beam-column components as used in conventional Smith's method.

- Corrosion effect
  A number of researchers have conducted testing on the influence of age on the strength of ship structures. The tests included corrosion which was recognized as the most common threat to the integrity of ship hull girders [Zayed et al., 2018]. The corrosion effect depicts a constant corrosion rate that causes a linear decline in plate thickness throughout the course of service. The typical assumption used in the development of algorithms to predict the behavior of ship structures is that corrosion will uniformly reduce the thickness of structural components for undamaged structures [Woloszyk and Garbatov, 2022]. Ikeda et al. [2001] examined the structural features of 11

single-hull tankers that had average levels of corrosion, the section modulus drop was less than 15% of the original value.

- Initial Imperfections

  During the process of assembling, an iron structure will experience initial imperfections as a result of welding. Initial imperfections in welded metal structures include initial distortions, residual stresses, or softening in the weld fusion zone or heat affected zone (HAZ) [Paik, 2018]. The initial imperfections on steel structures are categorized into six different types resulting from improper welding techniques and fabrication procedures [ISSC, 2009;2012]:
  - Initial distortion of the plating between the stiffeners,
    $w_{opl} = A_0 sin\frac{x\pi m}{a} sin\frac{y\pi}{b}$ (18)
  - Column-type initial distortion of the stiffener,
    $w_{oc} = B_0 sin\frac{x\pi}{a} sin\frac{y\pi}{B}$ (19)
  - Sideways initial distortion of the stiffener,
    $w_{os} = C_0 \frac{z}{h_w} sin\frac{x\pi}{a}$ (20)
  - Residual stress in the plating between the stiffeners.
    σ_{rc}^{p} for compressive and (21)
    σ_{rt}^{p} for tensile (22)
  - Residual stress in the stiffener web.
    σ_{rc}^{s} for compressive and (23)
    σ_{rt}^{s} for tensile (24)
  - Softening in the heat-affected zone.

  The ultimate strength of stiffened plates can be greatly decreased by the initial geometric defects [Paik and Thayamballi, 2003]. The results by Zaczynska et al. [2020] indicate that the ultimate strength may be 15% lessened when the amplitude of the flaw is equal to 10% of the plate thickness.

6. Conclusions

Limit state design calculations are mandatory methods that must be passed through the design process, especially those that go through the structural design process. The limit state design consists of a serviceability limit state (SLS), ultimate limit state (ULS), fatigue limit state (FLS), and accidental limit state (ALS). The four types of limit state design represent every condition that may occur in the product during the service lifetime. ULS represents a structural failure either in whole or in part of the members of the component. ULS calculation is the most important calculation in determining the level of safety of a structural design. In a ship-shaped steel structure, ULS value can be determined by determining the margin between ultimate strength and design loads. The method of determining the ultimate strength in a ship-shaped steel structure is to determine the hull girder of the overall structure. The hull girder is then calculated empirically using various methods, one of which is Smith's method. The accuracy of HGUS calculations can be said to correlate with the degree of complexity of the calculations.

Acknowledgments

This work was supported by the RKAT PTNBH Universitas Sebelas Maret Year 2023, under the Research Scheme of “Penelitian Kolaborasi Internasional” (KI-UNS), with research grant/contract no. 228/UN27.22/PT.01.03/2023. The support is gratefully acknowledged by the authors.

References

Adiputra, R., Yoshikawa, T., Erwandi, E., 2023. Reliability-Based Assessment of Ship Hull Girder Ultimate Strength. Curved and Layered Structures, 10, 20220189.

Ahn, S.I., Kurt, R.E., Turan, O., 2022. The hybrid method combined STPA and SLIM to assess the reliability of the human interaction system to the emergency shutdown system of LNG ship-to-ship bunkering. Ocean Engineering, 265, 112643.

Anyfantis, K.N., 2019. Ultimate compressive strength of eccentrically loaded stiffened panels in ship structures: a computational study. In: Proceedings of the 38th International Conference on Ocean. Offshore & Arctic Engineering, Glasgow, Scotland.

Anyfantis, K.N., 2020. Ultimate strength of stiffened panels subjected to non-uniform thrust. International Journal of Naval Architecture and Ocean Engineering, 12, 325-342.

Bedair, O., 2009. Analysis and Limit State Design of Stiffened Plates and Shells: A World View. Applied Mechanics Reviews, 62(2), 020801.

Bintoro, S.R., Prabowo, A.R., Triyono, Muhayat, N., 2021. Influence of element discretization types to fatigue behaviors in finite element analysis. Materials Today: Proceedings, 57, 531-538.

Caldwell, J.B., 1965. Ultimate longitudinal strength. Transactions of RINA, 107, 411–430.

Dabit, A.S., Lianto, A.E., Branta, S.A., Nubli, H., Laksono, F.B., Prabowo, A.R., Muhayat, N., 2020. Design of Fish Feed Spreader Unmanned Vessels in Coastal Areas Based on Arduino Microcontroller. Mekanika, 19(2), 74-82 (In Indonesian).

EMSA, 2021. Annual Overview of Marine Casualties and Incidents 2021, European Marine Safety Agency, Lisbon, Portugal.

Fajri, A., Prabowo, A.R., Muhayat, N., 2022. Assessment of ship structure under fatigue loading: FE benchmarking and extended performance analysis. Curved and Layered Structures, 9, 163-186.

Fajri, A., Prabowo, A.R., Muhayat, N., Smaradhana, D.F., Bahatmaka, A., 2021. Fatigue Analysis of Engineering Structures: State of Development and Achievement. Procedia Structural Integrity, 33, 19-26.

Folley, M., 2016. Numerical Modelling of Wave Energy Converters: State-of-the-Art Techniques for Single Devices and Arrays: Academic Press, London, United Kingdom.

IACS-CSR, 2022. Common Structural Rules for Bulk Carriers and Oil Tankers. International Association of Classification Societies, London, United Kingdom.

Ikeda, A., Yao, T., Kitamura, O., Yamamoto, N., Yoneda, M., Ohtsubo, H., 2001. Assessment of ultimate longitudinal strength of aged tankers. Practical Design of Ships and Other Floating Structures, 2, 997–1003

ISSC, 2009. Report of specialist committee III.1 Ultimate strength. In: Proceedings of the 17th International Ship and Offshore Structures Congress, Seoul, Korea, 1, 1–77.

ISSC, 2012. Report of specialist committee III.1 Ultimate strength. In: Proceedings of the 18th International Ship and Offshore Structures Congress, Rostock, Germany, 1, 1–107.

Kim, D.K., Lim, H.L., Yu, S.Y., 2018. A technical review on ultimate strength prediction of stiffened panels in axial compression. Ocean Engineering, 170, 392-406.

Kim, H., Cerik, B.C., Choung, J., 2022. Effects of fracture models on structural damage and acceleration in naval ships due to underwater explosions. Ocean Engineering, 266, 112930.

Kim, S.J., Kðrgesaar, M., Ahmadi, N., Taimuri, G., Kujala, P., Hidaris, S., 2021. The influence of fluid structure interaction modelling on the dynamic response of ships subject to collision and grounding. Marine Structures, 75, 102875.

Merrison Committee, 1973. Inquiry into the Basis of Design and Method of Erection of Steel Box Girder Bridges. Interior Design and Workmanship Rules, London, United Kingdom.

Montewka, J., Goerlandt, F., Innes-Jones, G., Owen, D., Hifi, Y., Puisa, R., 2017. Enhancing human performance in ship operations by modifying global design factors at the design stage. Reliability Engineering & System Safety, 159, 283-300.

Nathoo, S., 2017. Different Types of Limit State Design Philosophies. https://www.linkedin.com/pulse/different-types-limit-state-design-philosophies-sh%C3%A1nal-nathoo (Accessed in January 25, 2023).

Nubli, H., Utomo, F.S., Diatmaja, H., Prabowo, A.R., Ubaidillah, Susilo, D.D., Wibowo, Muttaqie, T., Laksono, F.B., 2022. Design of the Bengawan Unmanned Vehicle (UV) Roboboat: Mandakini Neo, Mekanika 21(2), 64-74.

Ölmez, H., Bayraktarkatal, E., 2016. Effects of Key Factors on Hull Girder Ultimate Strength Estimation by Progressive Collapse Calculations. Latin American Journal of Solids and Structures, 13(13), 2371-2392.

Paik, J.K., 2018. Ultimate Limit State Analysis and Design of Plated Structures, 2nd Edition. John Wiley & Sons, New Jersey, United States.

Paik, J.K., Thayamballi, A.K., 2007. Ship-Shaped Offshore Installations. Cambridge University Press, New York, United States.

Prabowo, A.R., Bae, D.M., 2019. Environmental risk of maritime territory subjected to accidental phenomena: Correlation of oil spill and ship grounding in the Exxon Valdez's case. Results in Engineering, 4, 100035.

Prabowo, A.R., Do, Q.T., Cao, B., Bae, D.M., 2020. Land and Marine-based Structures subjected to Explosion Loading: A review on Critical Transportation and Infrastructure. Procedia Structual Integrity, 27, 77-84.

Prabowo, A.R., Ridwan, R., Tuswan, T., Imaduddin, F., 2022. Forecasting the Effects of Failure Criteria in Assessing Ship Structural Damage Modes. Civil Engineering Journal, 8, 2053-2068.

Prabowo, A.R., Tuswan, T., Ridwan, R., 2021. Advanced Development of Sensors' Roles in Maritime-Based Industry and Research: From Field Monitoring to High-Risk Phenomenon Measurement. Applied Sciences, 11, 3954.

Smith, C.S., 1977. Influence of local compressive failure on ultimate longitudinal strength of a ship's hull. Proceedings of International Symposium on Practical Design in Shipbuilding, 73–79.

Tunçel, A.L., Beşikçi, E.B., Akyuz, E., Arslan, O., 2023. Safety analysis of fire and explosion (F&E) accidents risk in bulk carrier ships under fuzzy fault tree approach. Safety Science, 158, 105972.

Ueda, Y., Rashed, S.M.H., 1974. Idealized Structural Unit Method (ISUM) Applied to Marine Structures. Transactions of JWRI, 20, 123-136.

Woloszyk, K., Garbatov, Y, 2022. Advances in Modelling and Analysis of Strength of Corroded Ship Structures. Journal of Marine Science and Engineering, 10, 807.

Zaczynska, M., Abramovich, H., Bisagni, C., 2020. Parametric studies on the dynamic buckling phenomenon of a composite cylindrical shell under impulsive axial compression. Journal of Sound and Vibration, 482, 115462.

Zayed, A., Garbatov Y., Guedes Soares, C., 2018. Corrosion degradation of ship hull steel plates accounting for local environmental conditions. Ocean Engineering, 163, 299–306.

Zhang, M., Kujala, P., Hirdaris, S., 2022. A machine learning method for the evaluation of ship grounding risk in real operational conditions. Reliability Engineering & System Safety, 226, 108697.