

Ship Structures

Joško Parunov ^{1,*}  and Yordan Garbatov ^{2,*} ¹ Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, 10000 Zagreb, Croatia² Centre for Marine Technology and Ocean Engineering (CENTEC), Instituto Superior Técnico, Universidade de Lisboa, 1049-001 Lisbon, Portugal

* Correspondence: jparunov@fsb.hr or josko.parunov@fsb.hr (J.P.); yordan.garbatov@tecnico.ulisboa.pt (Y.G.)

1. Introduction

This book contains fifteen recent research studies in the broad field of ship structural design, analysis and degradation, where two studies deal with corrosion degradation in ship structures, while the remaining contributions belong to three major steps in the efficient design and analysis of ship structures, i.e., modelling of the environment and environmental loads, analysis of a ship structural response, and the definition of criteria for different failure modes of ship structures.

More specifically, the first two works are related to the probabilistic description of environmental parameters relevant to the analysis of ship structures [1,2], while the other two cover modelling of the environmental loads [3,4].

A ship structural response is divided into static, quasi-static and dynamic, and one of the contributions belongs to the latter group, i.e., vibratory ship structural response [5].

The criteria that ship structures should satisfy are identified according to three different limit states, i.e., ultimate limit state (ULS), serviceability limit state (SLS) and accidental limit state (ALS). The ULS represents serious failure of ship structures, which has an immediate impact on the ship's structural safety. Such a failure is caused by an overload of the structure, resulting in either a large spread of plasticity, due to the material yielding, or elastic–plastic buckling collapse, caused by compressive loads. The ULS may be associated with the structural failure of different components of ship structures, such as the plates and stiffened panels, or to the whole ship hull girder. Four studies are dedicated to different aspects of the ultimate strength of ship structures [6–9].

The SLS represents the failure modes that disturb the normal functioning of the ship's structural components, although the structural safety is not immediately put in danger. Excessive structural vibration and fatigue failures of the ship's structural details are typical examples of the SLS. One of the studies presented deals with the vibratory response, while the other two analyze the fatigue capacity of the ship's structural components [10,11].

The ALS usually refers to the residual strength of the ship's structures after a marine accident, i.e., collision or grounding, and two studies are dedicated to these problems [12,13].

Besides fatigue structural failure, corrosion degradation is another important effect that appears once the coating protection has failed during the ship's service life. Understanding, modelling, analyzing and mitigating the corrosion phenomenon are important issues in the design and maintenance of the ship, as the ship structures should have satisfactory safety, even at the end of their lifetime. Two studies deal with the modelling and analysis of corrosion degradation in ship structures [14,15].

In the next section, a brief overview of the papers published in the book is presented, ordered according to this Introduction.

2. Paper Details

Wind and waves present the main causes of environmental loading on seagoing ships and offshore structures. A comprehensive description of the wind and wave climate in



Citation: Parunov, J.; Garbatov, Y. Ship Structures. *J. Mar. Sci. Eng.* **2022**, *10*, 374. <https://doi.org/10.3390/jmse10030374>

Received: 1 March 2022

Accepted: 1 March 2022

Published: 6 March 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

the Adriatic Sea is presented in [1]. The conditional modelling approach, i.e., the marginal distribution of significant wave height and the conditional distribution of peak period and wind speed, is used in the study. The model parameters are fitted and presented, while extreme significant wave heights are evaluated for 20-, 50- and 100-year return periods. The results are shown for 39 uniformly spaced locations across the offshore Adriatic Sea, which can serve as an input for almost all kinds of analyses of ships and offshore structures.

Uncertainties in the prediction of extreme waves are presently a concern for the research community, having important practical implications in the design and operation of ships and offshore structures. Uncertainty, caused by the choice of probability distributions and fitting techniques in the analysis of extreme values of wave heights, is discussed in [2]. Methods and fitting techniques are tested on a long-term database for a location in the Adriatic Sea. The variability of the results and trends of extreme wave height estimates for long return periods are presented, and the limitations of certain methods and techniques are pointed out.

The estimation of wind loads on exposed parts of ships and offshore structures represents a challenging task because of its implications for various aspects of exploitation. An extended method for estimating the wind loads on container ships is presented in [3], using the Generalized Regression Neural Network (GRNN). The obtained results are in favorable agreement with the experimental measurements in the wind tunnel, as well as with the computational fluid dynamics (CFD) simulation performed.

The computational method for calculating the extreme vertical wave-induced bending moments on a passenger ship along the shipping route, based on the hindcast database, is presented in [4]. An operability analysis is performed to account for the ship's operational restrictions. Conducting an integrated operability analysis and extreme wave load computation is the main objective of the study. The method is employed to analyze a passenger ship sailing across the Adriatic Sea.

The vibratory structural response of connecting beams, using the component mode synthesis method, is improved in [5]. Polynomials that combine simple and fixed supports have been proposed to satisfy the boundary conditions at a junction. A comparison with the finite element results shows that they have good agreement with the method for practical purposes. The method is useful for the vibration analysis of many local structures in a ship, such as equipment supports.

The ultimate structural capacity assessment, particularly of the longitudinal strength, is crucial to ensure the safety of ships, crews, the marine environment, and the cargoes carried. A review of the references dealing with the collapse strength of the plates, stiffened panels and the entire hull is provided in [6]. The main contributions of the paper are the conclusions and suggestions about potential future research in the field.

The ultimate strength of rectangular plates subjected to cyclic load reversals is studied in [7]. The finite element solution is implemented to estimate the load-carrying capacity, accounting for the influence of the initial imperfections, plate thicknesses and aspect ratio. It was found that the uni-modal initial imperfection has a significant impact on the ultimate capacity reduction.

Residual stresses and the initial imperfections caused by the welding process are important for the prediction of the ultimate capacity of plates and stiffened panels. It is, therefore, challenging to predict these effects by using welding simulations when designing the ship. Recognizing that welding simulations coupled with structural analysis could be rather complex and time consuming, a simplified procedure for the welding simulations of a rectangular plate is developed in [8]. The collapse strength of the welded plates is then compared to the residual stress-free case, both for tension and compression, and including the initial imperfections. Based on the comparison of the results with codes and most of the established formulations, conclusions and recommendations about the applicability of the proposed method are provided.

A finite element method for predicting welding-induced distortion in multi-pass welding is developed in [9]. The study focuses on the extraction of the equivalent plastic

strain and heat-affected zone (HAZ) width through 3D thermal elastic–plastic analysis (TEPA) for each welding pass. The predicted welding distortion is compared with the measured experimental data, indicating that good agreement can be obtained.

The fatigue strength of T-type specimens under two-step repeating variable amplitude loading conditions is studied experimentally in [10]. Discussions about non-linear fatigue damage accumulation, and the effect of the interaction between the high- and low-amplitude loadings on the fatigue life were carried out, and relevant conclusions were obtained, according to the series of fatigue tests.

Hatch corners, especially those in large bulk carriers, are among the most important details regarding the potential appearance of fatigue cracks. Small-scale fatigue experiments of hatch corners are, therefore, performed in [11], aiming to investigate the effect of stress relaxation using shot peening treatment. The results show that the fatigue lives of the shot-peened ship hatch corner specimens are always longer than those of the untreated specimens.

The limit state function for the assessment of the longitudinal strength of damaged ships under combined bending moments is studied in [12]. As the limit state function cannot be obtained directly, the results for the residual strength are used for fitting the approximate limit state function. Various fitting methods have been proposed, and it is concluded that the weighted piecewise fitting method is the best choice for all the investigated cases.

The possibility of crack propagation during the towing period of a damaged ship, and the consequent reduction in the residual longitudinal strength, are investigated in [13]. Fluctuating wave-induced stresses are considered to be the main cause of crack propagation, which is studied using linear elastic fracture mechanics. The proposed method can be considered as part of the emergency response procedure during the salvage of a damaged ship.

Using the probabilistic model to estimate the percentage of corrosion depth for the inner bottom plates of ageing bulk carriers is proposed in [14]. The ratio, considered as the random variable, of the corrosion rate and the average initial inner bottom plate's thickness are studied. Three three-parameter distributions for estimating the cumulative probability distribution and the probability density function of the random variable are used. The statistical and empirical results are presented in numerical and graphical form, and conclusions are provided.

The research study presented in [15] deals with the mechanical behavior of butt-welded specimens made of shipbuilding steel, exposed to a natural marine environment for a relatively long period of up to 3 years. Relative mass change, due to corrosion degradation over time, is observed, along with the calculated corrosion rates. In addition, the corroded surfaces of specimens are inspected using optical and scanning electron microscopy. It is concluded that the sea splash generally has the most negative impact on the corrosion rate, while pit depths are generally the greatest in the heat-affected zone area of the specimen.

Author Contributions: Conceptualization, J.P. and Y.G.; writing—original draft preparation, J.P. and Y.G.; writing—review and editing, J.P. and Y.G.; supervision, J.P. and Y.G.; project administration, J.P. and Y.G.; funding acquisition, J.P. and Y.G. All authors have read and agreed to the published version of the manuscript.

Funding: Joško Parunov was supported by the Croatian Science Foundation, under the project MODUS IP-2019-04-2085, and Yordan Garbatov was supported by the Portuguese Foundation for Science and Technology (Fundação para a Ciência e Tecnologia—FCT), under contract UIDB/UIDP/00134/2020.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The editors wish to express sincere gratitude to all the authors and reviewers.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Katalinić, M.; Parunov, J. Comprehensive Wind and Wave Statistics and Extreme Values for Design and Analysis of Marine Structures in the Adriatic Sea. *J. Mar. Sci. Eng.* **2021**, *9*, 522. [\[CrossRef\]](#)
2. Katalinić, M.; Parunov, J. Uncertainties of Estimating Extreme Significant Wave Height for Engineering Applications Depending on the Approach and Fitting Technique—Adriatic Sea Case Study. *J. Mar. Sci. Eng.* **2020**, *8*, 259. [\[CrossRef\]](#)
3. Prpić-Oršić, J.; Valčić, M.; Čarija, Z. A Hybrid Wind Load Estimation Method for Container Ship Based on Computational Fluid Dynamics and Neural Networks. *J. Mar. Sci. Eng.* **2020**, *8*, 539. [\[CrossRef\]](#)
4. Petranović, T.; Mikulić, A.; Katalinić, M.; Ćorak, M.; Parunov, J. Method for Prediction of Extreme Wave Loads Based on Ship Operability Analysis Using Hindcast Wave Database. *J. Mar. Sci. Eng.* **2021**, *9*, 1002. [\[CrossRef\]](#)
5. Park, J.H.; Yoon, D.Y. A Proposal of Mode Polynomials for Efficient Use of Component Mode Synthesis and Methodology to Simplify the Calculation of the Connecting Beams. *J. Mar. Sci. Eng.* **2021**, *9*, 20. [\[CrossRef\]](#)
6. Tekgoz, M.; Garbatov, Y. Collapse Strength of Intact Ship Structures. *J. Mar. Sci. Eng.* **2021**, *9*, 1079. [\[CrossRef\]](#)
7. Tekgoz, M.; Garbatov, Y. Strength Assessment of Rectangular Plates Subjected to Extreme Cyclic Load Reversals. *J. Mar. Sci. Eng.* **2020**, *8*, 65. [\[CrossRef\]](#)
8. Gordo, J.M. Effect of Residual Stresses on the Elastoplastic Behavior of Welded Steel Plates. *J. Mar. Sci. Eng.* **2020**, *8*, 702. [\[CrossRef\]](#)
9. Lee, J.; Perrera, D.; Chung, H. Multi-Pass Welding Distortion Analysis Using Layered Shell Elements Based on Inherent Strain. *J. Mar. Sci. Eng.* **2021**, *9*, 632. [\[CrossRef\]](#)
10. Gan, J.; Sun, D.; Deng, H.; Wang, Z.; Wang, X.; Yao, L.; Wu, W. Fatigue Characteristic of Designed T-Type Specimen under Two-Step Repeating Variable Amplitude Load with Low-Amplitude Load below the Fatigue Limit. *J. Mar. Sci. Eng.* **2021**, *9*, 107. [\[CrossRef\]](#)
11. Gan, J.; Gao, Z.; Wang, Y.; Wang, Z.; Wu, W. Small-Scale Experimental Investigation of Fatigue Performance Improvement of Ship Hatch Corner with Shot Peening Treatments by Considering Residual Stress Relaxation. *J. Mar. Sci. Eng.* **2021**, *9*, 419. [\[CrossRef\]](#)
12. Zhu, Z.; Ren, H.; Wang, X.; Zhao, N.; Li, C. Methods for Fitting the Limit State Function of the Residual Strength of Damaged Ships. *J. Mar. Sci. Eng.* **2022**, *10*, 102. [\[CrossRef\]](#)
13. Gledić, I.; Mikulić, A.; Parunov, J. Improvement of the Ship Emergency Response Procedure in Case of Collision Accident Considering Crack Propagation during Salvage Period. *J. Mar. Sci. Eng.* **2021**, *9*, 737. [\[CrossRef\]](#)
14. Ivošević, Š.; Meštrović, R.; Kovač, N. A Probabilistic Method for Estimating the Percentage of Corrosion Depth on the Inner Bottom Plates of Aging Bulk Carriers. *J. Mar. Sci. Eng.* **2020**, *8*, 442. [\[CrossRef\]](#)
15. Vukelic, G.; Vizentin, G.; Brnic, J.; Brcic, M.; Sedmak, F. Long-Term Marine Environment Exposure Effect on Butt-Welded Shipbuilding Steel. *J. Mar. Sci. Eng.* **2021**, *9*, 491. [\[CrossRef\]](#)