SORTA

25th SYMPOSIUM ON THE THEORY AND PRACTICE OF SHIPBUILDING

2022

SORTA 2022 PROCEEDINGS

07 – 10 September 2022, Malinska, Croatia

FSB University of Zagreb
Faculty of Mechanical Engineering
and Naval Architecture

SORTA

25th SYMPOSIUM ON THE THEORY AND PRACTICE OF SHIPBUILDING 2022

SORTA 2022 PROCEEDINGS

25th SYMPOSIUM ON THE THEORY AND PRACTICE OF SHIPBUILDING 2022

***Editor-in-Chief*:**
Nastia Degiuli

***Executive editors*:**
Ivana Martić
Andrea Farkas

Technical Editor:
Mario Lesar

Publisher:
Faculty of Mechanical Engineering and Naval Architecture,
University of Zagreb
Zagreb, Croatia

Organizer:
Faculty of Mechanical Engineering and Naval Architecture,
University of Zagreb
Zagreb, Croatia

Printed in:
ITG d.o.o., Zagreb – 120 copies

A CIP catalogue record for this book is available from the National and University Library in Zagreb under 001146451.

ISBN 978-953-7738-86-0

25th SYMPOSIUM ON THE THEORY AND PRACTICE OF SHIPBUILDING
SORTA 2022

SCIENTIFIC COMMITTEE

ORGANIZING COMMITTEE

EDITORIAL BOARD

REVIEW COMMITTEE

Alar Vesna
Andrić Jerolim
Bakica Andro
Balen Igor
Ban Dario
Bašić Josip
Blagojević Branko
Bukovac Ozren
Bužančić Primorac Branka
Ćatipović Ivan
Ćorak Maro
Degiuli Nastia
Dejhalla Roko
Farkas Andrea
Grlj Carlo Giorgio
Hadjina Marko
Hadžić Neven
Jovanović Ivana
Katalinić Marko
Koričan Marija
Leder Nenad
Legović Dunja
Ljubenkov Boris
Martić Ivana
Matulja Tin
Mikulić Antonio
Mrakovčić Tomislav
Mrzljak Vedran
Parunov Joško
Perčić Maja
Prebeg Pero
Prpić-Oršić Jasna
Skejić Renato
Slapničar Vedran
Stojanović Ivan
Turk Anton
Zamarin Albert
Žigulić Roberto

STANDING COMMITTEE

Joško Parunov, FSB – Zagreb, chairman
Matko Bupić, UNIDU – Dubrovnik
Većeslav Čorić, FSB – Zagreb
Nastia Degiuli, FSB – Zagreb
Roko Dejhalla, RITEH – Rijeka
Marko Hađina, RITEH – Rijeka
Ivan Gospić, UNIZD – Zadar
Rajko Grubišić, FSB – Zagreb
Alan Klanac, Jadrolinija – Rijeka
Edi Kučan, 3. MAJ – Rijeka
Boris Ljubenkov, FESB – Split
Šime Malenica, Bureau Veritas – Paris
Siniša Ostojić, 3. MAJ – Rijeka
Darko Pappo, DiV Grupa – Split
Marta Pedišić Buča, Brodarski institut – Zagreb
Jasna Prpić-Oršić, RITEH – Rijeka
Siniša Reljić, Navis Consult – Rijeka
Ivo Senjanović, FSB – Zagreb
Vedran Slapničar, FSB – Zagreb
Dragan Sorić, TSI – Rijeka
Aris Večerina, MW Business Advisors – Liverpool
Pero Vidan, PFST – Split
Boris Vukušić, Bimex-prom, HGK – Zagreb
Nenad Vulić, PFST – Split
Paul Jurišić, CRS – Split

SUPPORTED BY

Croatian Academy of Sciences and Arts
Ministry of Science and Education

PREFACE

Dear colleagues,

In the name of the Standing Committee, it is my pleasure to announce the jubilar XXV Symposium Theory and Practice of Shipbuilding in memoriam prof. Leopold Sorta that will take place in Malinska, the island of Krk – Croatia, from September 7 -10, 2022, organized by the Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb. Traditionally, the Symposium is under the auspicious of the Croatian Academy of Sciences and Arts which obliges the Standing Committee to maintain a high scientific and professional level of presentations during technical sessions.

This year's Symposium is particularly challenging as it comes in the post-pandemic era and coincides with the global crisis caused by the terrible war in Ukraine, having negative consequences on many industry branches, including the shipbuilding as well, which is particularly sensitive to such crises. The unfavorable global situation caused the large shipbuilding industry in Croatia, which has been the main pillar of the Symposium since the first one held in Zagreb in 1974, to almost disappear. Professional knowledge and experience accumulated through the past decades, as well as considerable research and innovation potential, however, are still present at the universities, small shipyards, and design companies, which now took the leading role in supporting the Symposium.

49 technical presentations are planned for this XXV Symposium, representing a noticeable increase compared to 37 presentations in the last online symposium, which was successfully organized in 2020 in rather difficult pandemic conditions by the Technical Faculty in Rijeka. Following an analysis of Symposiums' trends, the Standing Committee has decided to change the format of submitted papers in a way that traditional full papers are replaced by two-page extended abstracts. This change was considered necessary, in the first place to allow the experts from the industry to actively participate in the Symposium without spending their precious time on writing full papers. Although two-page extended abstract is nowadays quite a common format for submissions in comparable symposiums and conferences, Standing Committee will carefully assess the consequences of this change and draw appropriate conclusions for the future. The International Scientific Committee, comprised of the leading scientists in the field of marine engineering and chaired by Professor Jasna Prpić-Oršić from Technical Faculty in Rijeka is established as the main advisory body to the Standing Committee regarding these hard but necessary strategic decisions.

Among extended abstracts submitted to the Symposium, nearly 20% will be presented by authors abroad from Croatia, representing higher share of the international participation compared to the previous symposiums. A fair number of papers will be presented by the authors from the industry, while several others will present the cooperation between universities and the industry. The majority of contributions represent dissemination activities of the ongoing or completed national and European projects. This proves that Symposium, despite unfavorable external circumstances still fulfills its main missions, i.e. linking universities and the industry, enhancing international cooperation, and disseminating reach scientific and professional shipbuilding-related activities in Croatia.

The authors of the most promising extended abstracts presented at the Symposium will be invited by the Editorial board of the WoS indexed journal „Brodogradnja" to submit the full paper to the Journal. It should be clearly stated that such papers must pass the review process as all other regular research contributions submitted to the Journal. This support of the journal „Brodogradnja" is gratefully acknowledged by the Standing Committee.

The Standing Committee expresses sincere gratitude to all sponsors of the Symposium, whose logos can be found at the end of this booklet. Among them is one large shipyard, two faculties having Naval Architecture studies, two ship classification societies and many SMEs. The organization of the Symposium would be impossible without their kind support. Thus we are looking forward to their cooperation with the future SORTA symposiums organizations!

Three plenary lectures will be presented at the opening session of the Symposium. The Standing Committee appreciates the time and efforts of Prof. Bettar el Moctar from University Duisburg-Essen, Mr. Josip Adrišić from FLOW Ship Design, and Mr. Hrvoje Krhen from LNG Croatia for their willingness to provide plenary lectures and thus contribute to the goals of the Symposium.

The Organizing Committee of this XXV Symposium SORTA, chaired by Professor Neven Hadžić, has been working hard for the past two years and carried most of the work for this Symposium, which is gratefully acknowledged by the Standing Committee. We also appreciate the large efforts of the Editorial Board, chaired by Professor Nastia Degiuli for editing this Book of Proceedings of the Extended Abstracts.

Last but not the least, Standing Committee would like to thank to all authors, co-authors and reviewers of the presentations that will be provided during Technical Sessions, as well as to all other members of the large SORTA community who will take part in this jubilar XXV Symposium Theory and Practice of Shipbuilding in memoriam prof. Leopold Sorta!

Zagreb, June 20, 2022

Professor Joško Parunov

Chairman of the Standing Committee of the Symposium SORTA

SORTA 2022 PROGRAM

	Wednesday 07.09.2022.
19:00 - 21:00	Welcome party

	Thursday 08.09.2022.
8:00-9:30	**Registration**
	Emilia
9:30-10:00	**Opening ceremony**
10:00-10:30	Invited speaker Bettar el Moctar (University Duisburg-Essen) **Numerical and Experimental Methods in Marine Engineering: Advances and Perspectives**
10:30-11:00	Invited speaker Josip Andrišić (FLOW ship design) **Ship Design: Current Trends and Challenges**
11:00-11:30	Invited speaker Hrvoje Krhen (LNG Croatia) **LNG Market: Global and Local Development Perspectives**
11:30-11:50	Coffee break

	Emilia	Katarina	Andrina
	Hydromechanics of vessels and offshore structures Chair: Jasna Prpić-Oršić	**Design of vessels and offshore structures, safety and offshore engineering** Chair: Roko Dejhalla	**Construction, strength and vibration of vessels and offshore structures** Chair: Joško Parunov
11:50-12:10	**Numerical Assessment of the Nominal Wake for the Japan Bulk Carrier** Andrea Farkas, Nastia Degiuli, Petar Gluščić, Ivana Martić, Carlo Giorgio Grlj	**Site Condition Assessment and Design Basis - Getting the Basics Right for a Successful Offshore Wind Project** Neil Morgan, Ivan Bubić, Gianpaolo Dalla Vedova	**Reliability Analysis of Secondary Hull Component** Siri Kolle Kleivane, Bernt Johan Leira, Sverre Steen
12:10-12:30	**The Prediction of Added Resistance in Waves at the Preliminary Design Phase of a Container Ship Based on an Artificial Neural Network** Ivana Martić, Nastia Degiuli, Andrea Farkas, Carlo Giorgio Grlj	**Adriatic Blue-Green Oil Tanker Class** Dario Ban	**FEA of Hyperelastic Structures: a Case From the Submarine Design** Marin Palaversa, Joško Parunov
12:30-12:50	**The Impact of Numerical Parameters on the Hydrodynamic Characteristics of a Post-Panamax Containership** Carlo Giorgio Grlj, Nastia Degiuli, Andrea Farkas, Ivana Martić	**General and Structural Design of Floating Garage** Iva Klara Lajtner, Josip Luka Erhardt, Vedran Slapničar, Jerolim Andrić	**Structural Design by Analysis of Touristic Submarine with Acrylic Hull** Maro Ćorak, Zdenko Šperanda, Juvel Ćokić, Joško Parunov
12:50-13:10	**Wave Response Prediction of a Containership Scale Model Using CFD with Overset Mesh Method** Ivan Sulovsky, Guillaume du Hauteclocque, Jasna Prpić-Oršić	**Design of LNG Tank Type C** Helena Galić, Vedran Slapničar, Smiljko Rudan	**Current State of Development of OOFEM, an Open-source Tool for FEA of Ship Structures** Marin Palaversa, Pero Prebeg, Jerolim Andrić, Stanislav Kitarović
13:10-13:30	**The Effect of Dominant Wind Patterns in Adriatic to the Long-term Extreme Significant Wave Heights** Antonio Mikulić, Joško Parunov	**Existing Floating Dock Part Extension to a Dewey Type 65000 t Floating Dock Initial Design** Luka Mudronja Robert Grubiša, Marko Pirija	**Structural Analysis of RO-RO Ship According to Lloyd's Register Rules for Direct Calculation** J. Andrić, K. Pirić, S. Pavletić, P. Prebeg, A. Dmitrašinović, M. Tomičić
13:30-15:00	Lunch		

	Emilia	Katarina
	Hydromechanics of vessels and offshore structures Chair: Andrea Farkas	**Design of vessels and offshore structures, safety and offshore engineering** Chair: Vedran Slapničar
15:00-15:20	**Energy Efficiency Improvement Possibilities of The Croatian Double-Ended Ferry Fleet** Božidar Šarić, Igor Lalović	**Wave Measurement in the Adriatic Sea Using Floating Buoy** Tamara Petranović, Ivana Gledić, Marko Katalinić, Petar Matić, Srđan Vujičić, Joško Parunov
15:20-15:40	**Energy Saving Devices in Ship Propulsion** Andro Bakica, Nikola Vladimir	**Reverse Engineering Methods in Deviation Measurements of Golden Horizon Masts** Ivana Željković, Ratko Mimica, Ante Katić,Tina Celić
15:40-16:00	**Hydrodynamic Interacton Effects between Ships in Restricted Water Depth** Renato Skejić	**Measurement of Ship Hull Deformations Using 3D Laser Scanning** Ivana Željković, Ratko Mimica, Ante Katić, Tina Celić
16:00-16:20	**Partially Rotating Grid Method for Prediction of Self-Propulsion Characteristics** Sanijo Đurasević, Inno Gatin, Hrvoje Jasak	**Innovative Developments in the Croatian Mariculture Within the Intel-Maric Project** Tena Bujas, Nikola Vladimir, Marija Koričan, Vladimir Soldo, Zdenko Tonković
16:20-16:40	**Multibody Dynamics Model for Wave Motions of Floating Photovoltaics** Ivan Ćatipović, Luka Ilić, Antonio Mikulić, Darko Smoljan	**IHC Technical presentation**
16:40-17:00	Coffee break	

	Emilia	Katarina
	Hydromechanics of vessels and offshore structures Chair: Nastia Degiuli	**Marine engineering, automation and equipment of vessels and offshore structures** Chair: Milan Kalajdžić
17:00-17:20	**Numerical Assessment of Appended Hull Resistance of a RoPax Shipp** Matej Dević, Branko Blagojević, Filip Raič, Josip Bašić, Martina Bašić	**Reduced Order Model of Airflow in a Room with Multiple Swirl Diffusers** Dario Pupić, Darko Smoljan
17:20-17:40	**Multi-Mode Variable Pitch Propeller and the Efficiency of its Operation as a Part of Coaxial Rotation Propellers** L. Vishnevskii, A. Togujac, M. Popov	**Test Rig for Validating of the Marine Sliding Bearings Properties** Nenad Vulić, Liane Roldo
17:40-18:00	**Estimation of Drag Coefficient of a Bare Hull of a Submarine Moving in Different Directions** Hassan Saghi, Antonio Mikulić	**Thermodynamic Analysis of Liquified Natural Gas Supply for Dual Fuel Engines** Damjan Bator, Danijel Zadravec, Nenad Ferdelji
18:00-18:20	**Procjena otpora trupa velikog jedrenjaka** Filip Raič, Branko Blagojević, Josip Bašić, Martina Bašić	**An Overview of Maintenance Procedures for Ship Machinery** Ivana Jovanović, Nikola Vladimir, Maja Perčić, Marija Koričan

Friday
09.09.2022.

	Emilia	Katarina
	Production and maintenance of vessels and offshore structures Chair: Marko Hadjina	**Design of vessels and offshore structures, safety and offshore engineering** Chair: Antonio Mikulić
9:00-9:20	**The Performance of Surface Treatments and the Use of Duplex Stainless Steel to Avoid Galvanic Corrosion between Shaft Casing and Shutter** M. Victoria Biezma-Moraleda, Paul Linhardt, Carlos Berlanga, Pablo Colve, Alberto Porras, David Arenal	**Power Output Estimation of Oscillating Surge Wave Energy Converter** Ivan Ćatipović, Robert Orlović, Neven Alujević, Vedran Slapničar
9:20-9:40	**Influence of Layer Thickness on Corrosion Protection Properties of Multilayer Coating System** Ivan Stojanović, Lovro Turkalj, Ivan Cindrić, Ivan Juraga, Vesna Alar, Vinko Šimunović, Marin Kurtela, Hrvoje Franjić	**Virtual Ship Simulation and Commissioning** Rodrigo Perez Fernandez, Mirko Toman
9:40-10:00	**Additive Manufacturing for Marine and Offshore: Key Breakthroughs and Future Perspective** Tolga Berkay Şirin, Arif Savaş	**Lasersko skeniranje kompozitnog kalupa za izradu jahti, obrada snimki i izrada 3D modela** Ivana Željković, Ratko Mimica, Ante Katić, Tina Celić
10:00-10:20	**High Density Polyethylene (HDPE) as a Prominent Marine Small Craft Building Material; Opportunities and Obstacles** Ayberk Sözen, Gökdeniz Neşer	**Primjena programa otvorenog koda d3v za vizualizaciju i utvrđivanje karakteristika analitički zadane forme** Pero Prebeg, Ivan Ćatipović, Ivan Munić, Gordan Šikić, Luka J. Erhardt, Tomislav Pavlović, Ivan Oreč
10:20-10:40	**Usporedba metoda predmontaže zakrivljenih sekcija u brodograđevnom procesu** Ivan Maslov, Karmela Prlac, Goran Kovačević, Boris Ljubenkov	
10:40-11:00	Coffee break	

	Emilia	Katarina
	Production and maintenance of vessels and offshore structures Chair: Boris Ljubenkov	**Maritime transport and economics** Chair: Ivana Martić
11:00-11:20	**A Simple Method to Estimate Key Performance Indicators of the Prefabrication and Fabrication Production Line in a Shipyard** Viktor Ložar, Neven Hadžić, Tihomir Opetuk, Hrvoje Cajner	**Energy Efficiency of Inland Vessels: Current Status** Milan Kalajdžić, Matija Vasilev, Nikola Momčilović
11:20-11:40	**Polylactic Acid (PLA) and Wood Composite as a Sustainable Material Alternative in Additive Boat Manufacturing and its Degradation in Marine Environment** Selin Barış Çamlı, Gökdeniz Neşer, Ayberk Sözen	**Enhancement of National Regulations for Preventing Marine Pollution in the Adriatic Ionian Region** Marija Koričan, Nikola Vladimir, Dario Omanović, Loukia Prentza, Eirini-Asimina Stamatopoulou, Nikolaos P. Ventikos
11:40-12:00	**Numerical Modeling of a Prefabrication and Fabrication Production Line in a Shipyard** Viktor Ložar, Tihomir Opetuk, Neven Hadžić, Hrvoje Cajner	**Utjecaj starosti ribarskih brodova na značajke energetske učinkovitosti** Ivica Ančić, Lidija Runko Luttenberger
12:00-12:20	**Analysis of Organizational Models of Shipbuilding Production in Selected Domestic and Foreign Shipyards** Rajko Rubeša, Tin Matulja, Marko Hadjina, Jakov Rajić	
12:20-12:40	**Ship Outfitting Efficiency Improvement** Petar Lisičić, Rajko Rubeša, Marko Hadjina, Tin Matulja	
13:00-14:30	Lunch	

	Emilia
14:30-15:30	Round Table **The future of Croatian shipbuilding (in Croatian)**
17:00-17:30	**Closing ceremony**
20:00-24:00	Conference dinner

Saturday
10.09.2022.

9:00-15:30	Conference excursion

TABLE OF CONTENTS

Hydromechanics of Vessels and Offshore Structures

Construction, Strength and Vibration of Vessels and Offshore Structures

Marine Engineering, Automation and Equipment of Vessels and Offshore Structures

Design of Vessels and Offshore Structures, Safety and Offshore Engineering

Production and Maintenance of Vessels and Offshore Structures

Maritime Transport and Economics

25th SYMPOSIUM ON THE THEORY AND PRACTICE OF SHIPBUILDING 2022

07 – 10 September 2022, Malinska – Croatia

Hydromechanics of Vessels and Offshore Structures

Numerical Assessment of the Nominal Wake for the Japan Bulk Carrier

Andrea Farkas *[1], Nastia Degiuli [1], Petar Gluščić [1], Ivana Martić [1], Carlo Giorgio Grlj [1]

[1] University of Zagreb,
Faculty of Mechanical Engineering and Naval Architecture, Zagreb, CROATIA.
(E-mail: afarkas@fsb.hr, nastia.degiuli@fsb.hr, pg210019@stud.fsb.hr,
ivana.martic@fsb.hr, carlo.g.grlj@fsb.hr)

Keywords: *Nominal wake, Japan Bulk Carrier, CFD, Turbulence models*

Abstract: In this study numerical assessment of nominal wake for the Japan Bulk Carrier at model scale is carried out. Numerical simulations based on Reynolds Averaged Navier-Stokes equations are carried out with $k-\omega$ SST and $k-\varepsilon$ turbulence model. The verification study is carried out and the numerical uncertainty in the prediction of a nominal wake is determined. The validation study is performed by comparison of the obtained results with the experimental data from the literature. It is demonstrated that Computational Fluid Dynamics can be a valuable tool in the assessment of nominal wake.

1. INTRODUCTION

The assessment of the nominal wake field is of crucial significance for the propeller design [1]. Thus, propeller design is directly influenced by the mean wake field, and other parameters such as power, revolutions, and ship speed. On the other hand, wake field distribution affects the propeller blade section design and pitch [2]. Consequently, there are several studies in the literature dealing with the assessment of the nominal wake [3, 4, 5]. In this study numerical assessment of nominal wake for Japan Bulk Carrier (JBC) at model scale ($\lambda = 40$) is carried out.

2. METHODS

Numerical simulations based on Reynolds Averaged Navier-Stokes equations are performed to assess the nominal wake field, a circumferential averaged non-dimensional axial velocity distribution, $w_N(r)$, and the integral value of nominal wake, w_N, for the JBC model. The numerical simulations are carried out with $k-w$ SST and $k-e$ turbulence model. The study is performed using both free surface simulations (FSS) and double body simulations (DBS). The verification study is carried out and the numerical uncertainty U_{SN} in the prediction of a nominal wake is determined using the Grid Convergence Index method. The validation study is performed by comparison of the obtained results with the experimental data from the literature.

3. RESULTS AND DISCUSSION

In the prediction of $w_N(r)$, the obtained U_{SN} is mostly below 4%, while for w_N the obtained U_{SN} is below 6%. The comparison with experimental results demonstrated that $k-w$ SST provides more accurate results than $k-\varepsilon$ turbulence model. Also, it has been shown that DBS can provide accurate results with significantly less computational effort than FSS.

The relative deviations of the numerically and experimentally obtained $w_N\,(r)$ are mainly below 10%. The comparison of the nominal wake obtained using $k - w$ SST within DBS and the experimental one is presented in Figure 1.

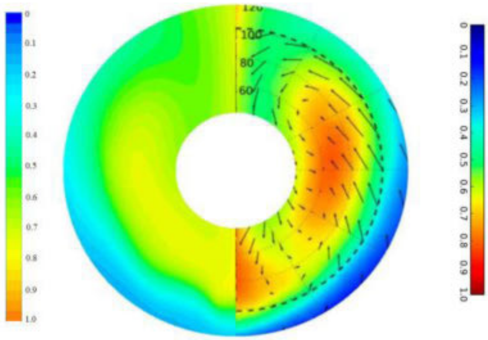


Figure 1. The numerically (left) and experimentally (right) obtained nominal wake

4. CONCLUSIONS

This study demonstrated that the nominal wake for slower merchant ship can be adequately assessed using DBS. The investigation of the scale effects on the nominal wake field will form a part of future work.

Acknowledgment: This study has been fully supported by the Croatian Science Foundation under project IP-2020-02-8568.

References:

[1] Farkas, A., Degiuli, N., Martić, I., Dejhalla, R., Numerical and experimental assessment of nominal wake for a bulk carrier, Journal of Marine Science and Technology, Vol. 24, 2019, pp. 1092-1104.

[2] Carlton, J.S. Marine propellers and propulsion, 3rd edition, Elsevier, Oxford, 2012.

[3] Pereira, F.S., Eça, L., Vaz, G., Verification and Validation exercises for the flow around the KVLCC2 tanker at model and full-scale Reynolds numbers, Ocean Engineering, Vol. 129, 2017, pp. 133-148.

[4] Sun, S., Chang, X., Guo, C., Zhang, H., Wang, C., Numerical investigation of scale effect of nominal wake of four-screw ship, Ocean Engineering, Vol. 183, 2019, pp. 208-223.

[5] Guo, C.Y., Wu, T.C., Zhang, Q., Luo, W.Z., Su, Y.M., Numerical simulation and experimental studies on aft hull local parameterized non-geosim deformation for correcting scale effects of nominal wake field, Brodogradnja, Vol. 68, No. 1, 2017, pp. 77-96.

The Prediction of Added Resistance in Waves at the Preliminary Design Phase of a Container Ship Based on an Artificial Neural Network

Ivana Martić *, Nastia Degiuli, Andrea Farkas, Carlo Giorgio Grlj

University of Zagreb,
Faculty of Mechanical Engineering and Naval Architecture, Zagreb, Croatia.
(E-mail: ivana.martic@fsb.hr, nastia.degiuli@fsb.hr, andrea.farkas@fsb.hr, carlo.g.grlj@fsb.hr)

Keywords: *Added resistance in waves, Artificial neural network, Container ship*

Abstract: A model based on Artificial Neural Network (ANN) that allows simple but sufficiently accurate and reliable evaluation of the ship added resistance in regular head waves is proposed for container ships. The results of added resistance in waves, obtained by performing hydrodynamic calculations based on the Boundary Integral Element Method (BIEM), are used to train and test the generalization ability of ANN.

1. INTRODUCTION

The added resistance in waves has a significant influence on an increase in fuel consumption and consequently CO_2 emissions [1]. For that reason, International Maritime Organization has emphasized the need for the development of the so-called "level 1 methods" [2], which should provide the simple estimation of added resistance in waves. Considering the advantages of ANN when it comes to their learning and generalization ability as well as adapting to non-linear multiple regression problems, it is not a surprise that they have been employed in describing complex hydrodynamic problems with great success [3, 4].

2. METHODOLOGY

Added resistance is calculated using the Boundary Integral Equations Method (BIEM) for various container ship hull forms and speeds. It should be noted that 95% of 11230 samples in total is used for training and 5% for testing purposes of the feedforward ANN with a backpropagation learning algorithm since the employed Levenberg-Marquardt learning algorithm with Bayesian regularization does not require the validation data set. The input data is standardized, and the output data normalized prior to the training process. Principal component analysis is performed as well to eliminate the collinearity of data.

3. RESULTS AND DISCUSSION

The comparison between the numerically obtained results, the ones obtained by ANN, and the experimental data for the KCS container ship is shown in Figure 1. The numerical results, obtained using BIEM and corrected in the range of high wave frequencies corresponding to short waves [6], are in good agreement with the experimental data. The results of ANN are in satisfactory agreement with the experimental and numerical data in the range of moderate wave frequencies. Similar to the numerical results, the results obtained by ANN underestimate the added resistance coefficients for short waves.

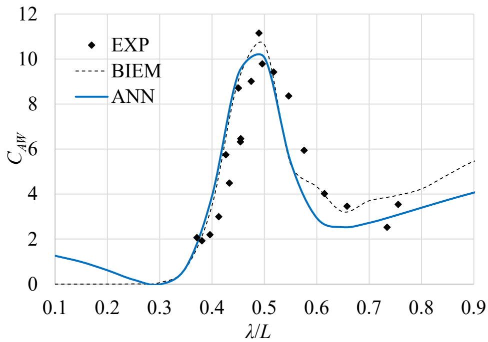


Figure 1. The comparison of the results obtained for the KCS container ship.

4. CONCLUSIONS

A simple and efficient model for the rapid determination of added resistance, within the preliminary ship design, is developed for container ships in regular head waves. Unlike the hydrodynamic calculations, it does not require a 3D model, but only the main ship characteristics and speed.

Acknowledgment: This study has been fully supported by the Croatian Science Foundation under project IP-2020-02-8568.

References:

[1] Degiuli, N., Martić, I., Farkas, A., Gospić, I., The impact of slow steaming on reducing CO_2 emissions in the Mediterranean Sea, Energy Reports, Vol. 7, 2021. 8131-8141.

[2] International Maritime Organization, Interim guidelines for determining minimum propulsion power to maintain the manoeuvrability of ships in adverse conditions – RESOLUTION MEPC.232(65), Vol. 232, 2013.

[3] Mittendorf, M., Nielsen, U. D., Bingham, H. B., Data-driven prediction of added-wave resistance on ships in oblique waves-A comparison between tree-based ensemble methods and artificial neural networks, Applied Ocean Research, Vol. 118, 2022, 102964.

[4] Martić, I., Degiuli, N., Majetić, D., Farkas, A., Artificial Neural Network Model for the Evaluation of Added Resistance of Container Ships in Head Waves. Journal of Marine Science and Engineering, Vol. 9, No.8, 2021, 826.

[5] Martić, I., Degiuli, N., Malenica, Š., Farkas, A. Discussions on the convergence of the seakeeping simulations based on the panel methods, International Conference on Offshore Mechanics and Arctic Engineering, OMAE 2018, Madrid, Spain, 2018.

The Impact of Numerical Parameters on the Hydrodynamic Characteristics of a Post-Panamax Containership

Carlo Giorgio Grlj *[1], Nastia Degiuli [1], Andrea Farkas [1], Ivana Martić [1]

[1] University of Zagreb,
Faculty of Mechanical Engineering and Naval Architecture, Zagreb, CROATIA.
(E-mail: carlo.g.grlj@fsb.hr, nastia.degiuli@fsb.hr, andrea.farkas@fsb.hr, ivana.martic@fsb.hr)

Keywords: *CFD, Containership, Discretization schemes, Full scale, Turbulence models Abstract:*

Abstract: For accurate prediction of the ship hydrodynamic characteristics by means of numerical simulations, it is important to determine the numerical and modelling errors. In this paper, the flow around a Post-Panamax 6750 TEU containership in full scale is simulated using Computational Fluid Dynamics (CFD). Within the numerical simulations of the resistance test, the influence of different numerical parameters on the total resistance and free surface elevation is assessed using different turbulence models. The numerical parameters included in this study are time step and discretization schemes for spatial and temporal discretization. The verification study of the results obtained from the numerical simulations is carried out using the Grid Convergence Index (GCI) method. The presented data consists of total resistance, free surface elevation, trim and sinkage data.

1. INTRODUCTION

Computational Fluid Dynamics (CFD) has been successfully applied to assess ship hydrodynamic characteristics in a full scale. Niklas and Pruszko [1] carried out full scale CFD simulations and demonstrated satisfactory agreement with sea trial data and extrapolated towing tank results. Farkas et al. [2] assessed the ship hydrodynamic characteristics of a full-scale ship at different draughts. Orych et al. [3] estimated the delivered power for a full-scale ship. Feng et al. [4] determined the total resistance of a Kriso containership (KCS) for different water depths both in model and full scale.

In this study, numerical simulations of the flow around the Post-Panamax 6750 TEU containership are performed using the geometry and inertial properties published in [5]. The verification study is conducted to estimate the numerical uncertainty.

2. METHODOLOGY

The numerical model is based on Reynolds Averaged Navier-Stokes equations which are discretized using the Finite Volume Method. To locate and track the free surface, the Volume of Fluid method was employed with the High-Resolution Interface Capturing scheme to maintain a sharp interface between two fluids. Ship motion is modelled using the Dynamic Fluid Body Interaction model which enables six degrees of freedom.

3. RESULTS AND DISCUSSION

The results obtained using three turbulence models i.e., Realizable $k - \varepsilon$ (RKE), Shear Stress Transport $k - w$ (SSTKO) and Reynolds Stress (RSM), are compared. The SSTKO yields lower values for the total resistance in comparison to other turbulence models. The discretization schemes for the convection and gradient terms as well as the temporal discretization are investigated. The total resistance converged faster in the case of the first- order schemes, but the median value is noticeably higher. Using a first-order scheme for temporal discretization leads only to faster convergence without the impact on the median value of total resistance. Figure 1 shows the impact of the discretization schemes on the free surface elevation at 25 kn. The total resistance obtained using first-order, second-order and third-order schemes are equal to 2804 kN, 2247 kN and 2212 kN, respectively.

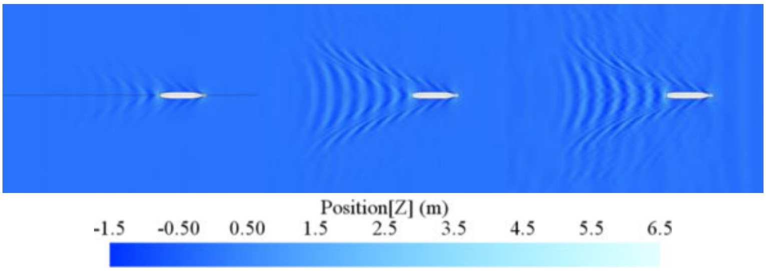


Figure 1. Free surface elevations for the first-order (left), second-order (middle), and third-order (right) schemes.

4. CONCLUSIONS

This study demonstrates that the best compromise between the accuracy and computational time is achieved in the case of the second-order scheme for convection and gradient terms and the first-order scheme for temporal discretization.

Acknowledgment: This study has been fully supported by the Croatian Science Foundation under project IP-2020-02-8568.

References:

[1] Niklas, K., Pruszko, H., Full-scale CFD simulations for the determination of ship resistance as a rational, alternative method to towing tank experiments, Ocean Engineering, Vol. 190, 2019, 106435.

[2] Farkas, A., Degiuli, N., Martić, I., Assessment of hydrodynamic characteristics of a full-scale ship at different draughts, Ocean Engineering, Vol. 156, 2018, pp. 135- 152.

[3] Orych, M., Werner, S., Larsson, L. Validation of full-scale delivered power CFD simulations, Ocean Engineering, Vol. 238, 2021, 109654.

[4] Feng, D., Ye, B., Zhang, Z., Wang, X., Numerical Simulation of the Ship Resistance of KCS in Different Water Depths for Model-Scale and Full-Scale, Journal of Marine Science and Engineering, Vol. 8, No. 10, 2020, pp. 745.

[5] Kim, Y., Kim, J.-H., Benchmark study on motions and loads of a 6750-TEU containership, Ocean Engineering, Vol. 119, 2016, pp. 262–273.

Wave Response Prediction of a Containership Scale Model Using CFD with Overset Mesh Method

Ivan Sulovsky *[1], Guilaumme de Hauteclocque [2], Jasna Prpić-Oršić [1]

[1] University of Rijeka,
Faculty of Engineering, Rijeka, CROATIA.
(isulovsky@riteh.hr, jasnapo@riteh.hr)

[2] Bureau Veritas M&O, Paris, France.
(guillaume.de-hauteclocque@bureauveritas.com)

Keywords: *CFD, Numerical Methods, Seakeeping, Overset Mesh Method*

Abstract: A numerical framework for estimating the wave response of an ultra-large container ship model using the CFD method, in particular with overset mesh method, is presented. The specified ship model is designed at the LHEEA laboratory in Nantes for a benchmark study [1], providing experimental data for test cases available. The open source CFD toolkit OpenFOAM® is deployed [2], in which the overset mesh method is used to handle large amplitude motions due to waves. The results of the CFD solution are compared with experimental data and the potential flow solution. Satisfactory accuracy is achieved with the experiment, while the potential flow code is again found to be inadequate for large amplitude responses.

1. INTRODUCTION

Excessive ship motions can adversely affect the energy efficiency of the ship, increasing harmful gas emissions. Nowadays, the most common methods for numerical estimation of ship motions are the use of potential flow codes or strip theory. However, these methods cannot properly capture nonlinear effects in high amplitude waves [3]. The overset mesh method within the fully viscous CFD provides a robust framework for capturing all sorts of dynamic effects without motion constraints. In the scope of marine hydrodynamics, it is often used to capture large amplitude motions such as parametric roll, broaching or even porpoising for high speed cases.

2. METHODOLOGY

The geometry of the numerical domain was created according to the guidelines proposed in [3], using the blockMesh tool with appropriate grid refinements in the vicinity of the ship and free surface. To solve the problem of numerical dissipation of wave height dampening along the tank, a two-dimensional wave tank is created with a wave gauge placed at the forward perpendicular, measuring the wave amplitude in time. In addition, background and overset meshes are created with special attention to their geometrical ratios and refinement levels, which are crucial for the mesh overlapping nature in this method. A realizable k-ε turbulence model is applied for the closure of the Reynolds Averaged Navier-Stokes (RANS) equations.

3. RESULTS AND DISCUSSION

Simulations are conducted for head waves with zero ship speed. *Courant- Friedrichs-Lewy* condition is imposed with limiting Courant number of 0.25 in the free surface area. Figure 2. shows the result of pitch response in waves of 0.23 m in height, compared with experiment and potential flow solution.

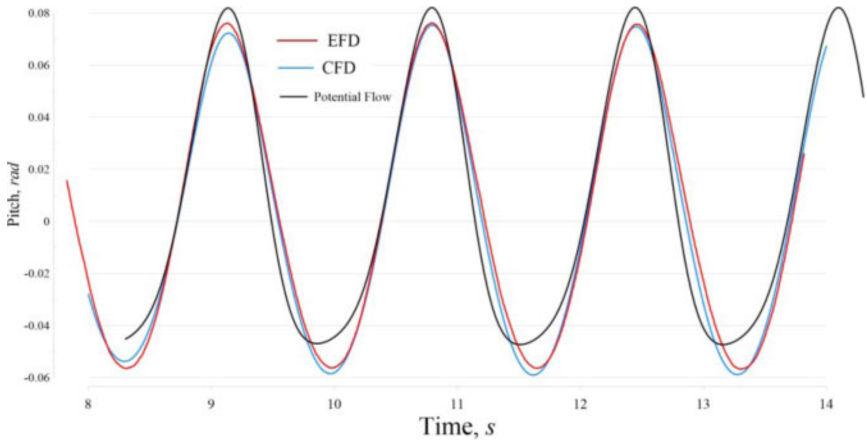


Figure 1. Pitch angle for $H = 0.23$ m

4. CONCLUSIONS

Numerical seakeeping model using overset mesh is presented in this paper. Pitch angles are compared with experiment and potential flow solution. Although computational costs of overset technique are quite high, comparing the results from the basin confirms the superiority of fully viscous flows in terms of accuracy.

Acknowledgment: This work has been supported by the Croatian Science Foundation under the Project IP-2018-01-3739. This work was also supported by the University of Rijeka (project no. uniri-tehnic-18-18 1146 and uniri-tehnic-18-266 6469).

References:

[1] G. de Hauteclocque et al. "Extreme Non-Linear Vertical Bending Moment – Model test compared to various numerical models," (2021.) in review

[2] H.G. Weller, G.Tabor, H.Jasak, and C.Fureby, "A tensorial approach to computational continuum mechanics using object orientated techiques," *Computers in Physics*, vol. 12, pp. 620-631, 1998.

[3] Clément, Constance. (2021). "Investigation of Floating Offshore Wind Turbine Hydrodynamics with Computational Fluid Dynamics." PhD Thesis

[4] Joakim Tveiten Vigsnes, "Seakeeping Analysis Comparison Beetween Viscous and Inviscid CFD" NTNU, 2018. MSc Thesis

The Effect of Dominant Wind Patterns in Adriatic to the Long-Term Extreme Significant Wave Heights

Antonio Mikulić *[1], Joško Parunov [1]

[1] University of Zagreb,
Faculty of Mechanical Engineering and Naval Architecture, Croatia
(E-mail: amikulic@fsb.hr, jparunov@fsb.hr)

Keywords: *Hindcast database, Long-term extremes, Significant wave heights, Wave directionality*

Abstract: The extreme significant wave heights (SWHs) prediction often neglects directionality. Based on 24 years of wind and wave data, the study considers sea states generated by different wind patterns and their potential influence on long-term predictions. Yearly extreme SWHs are extracted considering all directions together and separately. The extreme value distributions are fitted using the Annual Extreme Method. Long-term extreme values of SWHs are calculated for the directional distributions. Results are compared to ones neglecting the wave directionality effect.

1. INTRODUCTION

The Adriatic Sea, as well as some other geographical regions, experience dominant wind patterns generating distinct wave characteristics. The pioneering research of wave statistics in the Adriatic has been performed by Tabain [1]. The extreme sea state statistics are analysed in [2] and later [3] using different data sources. The effect of spatial correlation between sea states along the shipping route was studied in [4], while the effect of within-year wave climate variability was explored in [5]. Previous analyses considered all wind patterns together, i.e., directional effects are neglected. Two dominant winds for the surface waves creation in the Adriatic are bura and jugo. Characteristics of these two wind patterns and of consequent waves are completely different. While jugo wind has a longer fetch and has caused some of the highest recorded waves in the Adriatic, bura has a stronger intensity but a shorter fetch.

2. METHODOLOGY AND DATA

Wind and wave data are extracted from the WorldWaves (WWA), developed by Fugro Oceanor. It is the 3rd generation numerical wave model (WAM) calibrated by satellite and in- situ measurements, available for the 24 years period at a lat-log resolution of 0.5° × 0.5° (50 km × 50 km). The annual extreme SWHs are extracted for 4 main directions: bura - mean direction 45°, N-E quadrant; jugo - mean direction 135°, S-E quadrant; lebić - mean direction 225°, S-W quadrant; maestral - mean direction 315°, N-W quadrant. For all available years, at defined locations, the data is fitted with Gumbel extreme value probability density function (PDF), using the Maximum Likelihood Method (MLE) employing the Python code. The distribution of yearly extremes is also calculated from the directional distributions assuming the independence of the observed directional maxima. Finally, the return period is used to determine the probability of exceedance.

3. RESULTS AND DISCUSSION

Violin plots of the directional maxima for 8 locations are presented in Figure 1, displaying minimum, maximum, and mean values, the interquartile range, and a rotated kernel density plot on each side, illustrating distributions. The highest recorded waves have occurred in the southern-most location, where jugo has the greatest influence. The highest waves, in the south and middle Adriatic, are caused by jugo. In the north, for some locations, waves caused by bura slightly exceed those by jugo, although both wind patterns are almost equally important. A larger number of locations have negligible or small differences between results considering and ignoring directionality effects. The remaining locations experience larger differences, i.e., neglecting directionality underestimates the long-term extreme predictions of SWHs.

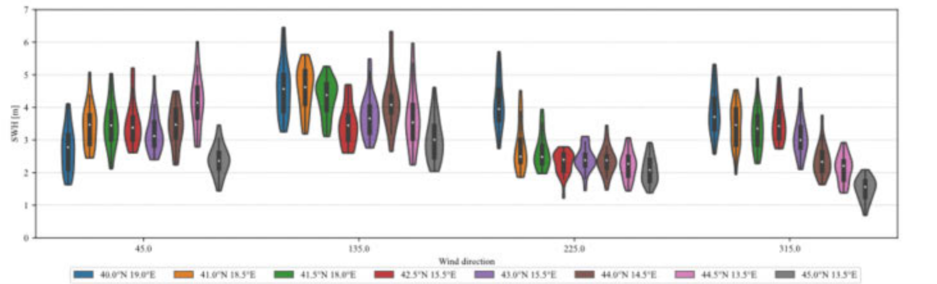


Figure 1. Violin plot of annual maxima by direction for studied locations.

4. CONCLUSIONS

The study aims to quantify the bias in the extreme significant wave heights prediction caused by neglecting directional effects for the Adriatic Sea. The effect of wave directionality on the extreme SWHs varies between locations. For some locations, the negligence of wave directionality has a significant effect on long-term predictions. The differences in results depend upon the variability of extreme value distributions between directions. The future work will further explore the influence of the variability and the number of directions.

Acknowledgment: This work has been fully supported by the Croatian Science Foundation under the project IP-2019-04-2085. The WorldWaves database is provided by Fugro OCEANOR AS.

References:

[1] Tabain, T., Standard wind wave spectrum for the Adriatic Sea revisited (1977-1997), Brodogradnja, Vol. 45, No. 4, 1997, pp. 303–313.

[2] Leder N, Smirčić A, Vilibić I., Extreme values of surface wave heights in the northern Adriatic, Geofizika, Vol. 15, 1998, pp. 1–13.

[3] Parunov J., Čorak M., Pensa M., Wave height statistics for seakeeping assessment of ships in the Adriatic Sea, Ocean Engineering, Vol. 38, 2011, pp. 1323–1330.

[4] Mikulić A, Katalinić M, Ćorak M, Parunov J., The effect of spatial correlation of sea states on extreme wave loads of ships. Ships and Offshore Structures Vol. 16, 2021, pp. 22-32.

[5] Mikulić A., Parunov J., Bias in estimates of extreme significant wave heights for the design of ship structures caused by neglecting within-year wave climate variability, Ships and Offshore Structures, 2022, DOI:

Energy Efficiency Improvement Possibilities of the Croatian Double-Ended Ferry Fleet

Božidar Šarić *[1], Igor Lalović [1]

[1] FLOW Ship Design d.o.o., CROATIA.
(E-mail: bozidar.saric@flowship.eu, igor.lalovic@flowship.eu)

Keywords: *Azimuth propulsion, Computational fluid dynamics, Double ended ferries*

Abstract: Croatian double-ended ferry fleet consists mostly of Greek designed vessels, which are specific for having low draft and high Cb and Cp values, all of which favors four propeller propulsion configuration. Almost all vessels in the Croatian fleet have four single propeller azimuth drives as a propulsion device. For the used configuration there are simple methods for improvement of the energy efficiency, those are optimization of the power distribution fore and aft and thruster yaw angle alignment optimization. Along with those two methods, another simple method which is commonly employed in other ship types, trim optimization, has been tested for double ended ferries. Also, effect of all those measures combined has been assessed and benchmarked against the baseline configuration.

1. INTRODUCTION

CO_2 emissions have a global climate impact and a concerted effort is being made worldwide towards their reduction. Legislation has been introduced to limit emissions with the introduction of an Energy Efficiency Design Index, EEDI. Apart from the well know measures of hull resistance reduction and propulsion efficiency increasement [1], some specific ship types like double ended ferries have their own specific methods that can be used to achieve reduction in emissions and propulsive power. These methods, which are standardly employed on north European and north American double ended ferries, especially when towing tank testing is performed in early project phase, are further mentioned in the references [2], [3]. This paper shows some of the possible ways to improve energy efficiency of the double ended ferry Adriatic Sea fleet without major investments and modifications.

2. METHODOLOGY

The study is performed using CFD simulations based on RANS equations and komega SST turbulence model. Self propulsion test are carried out using body force method. First, the baseline configuration has been assessed for resistance and self propulsion performance, and after that all other variations are benchmarked against baseline results. The aim of that approach is to show qualitatively and quantitatively the differences by using different power distribution, azimuth angle configurations and trim conditions.

3. RESULTS AND DISCUSSION

The results for different power distribution aft and fore showed that for 100% aft power relative resistance increasement (through thrust deduction) amounts to up to 15%. Resistance decomposition shows that majority of difference is in the frictional force on the hull being increased in area affected by propeller jet downstream.

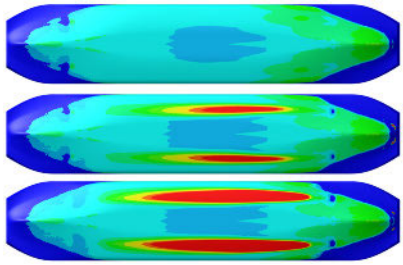


Figure 1. Viscous stress on hull for different power distributions (100% aft to 100% fore).

The results for the optimum azimuth angle showed that by having azimuth angles aligned with the flow instead along the x axis reduces appendage resistance, as well as reduces thrust deduction and makes wake field velocities more homogeneous.

The trim optimization study showed that trim by stern reduces the resistance due to more favorable buoyancy distribution as well as having finer waterlines at entrance, which reduces the bow wave.

4. CONCLUSION

The results show that there is a potential for energy efficiency improvement in the double ended ferry fleet by making simple modifications. These results present values obtained for a specific combination of the hull form and the design speed, and it can be expected that for different configurations, different values of power reduction will be obtained

References:

[1] Molland, T., Turnock, T., Hudson, M., Ship Resistance and Propulsion – Second Edition, 2017, pp. 451–469.

[2] Minchev, A., Simonsen, C., Zilcken, R, Double-Ended Ferries – Propulsive Performance Challenges and Model Testing Verification, Second International Symposium on Marine Propulsors, Hamburg, Germany, 2011, pp. 33–41.

[3] Krüger, S., Billerbeck, H., Haack, T, Double-Ended Ferries – The Propulsion and Maneuvering Concept of the BCF- Super C-Class Double End Ferries, PRADS, Houston, Texas, USA, 2007.

Energy Saving Devices in Ship Propulsion

Andro Bakica *[1], Nikola Vladimir [1]

[1] Faculty of Mechanical Engineering and Naval Architecture,
University of Zagreb, CROATIA.
(E-mail: andro.bakica@fsb.hr, nikola.vladimir@fsb.hr)

Keywords: *Energy Saving Devices, Ship propulsion, Propeller efficiency*

Abstract: An attractive way to increase the propeller efficiency is by means of Energy Saving Devices (ESDs). Given the improved accuracy of the hydrodynamic numerical models, ESDs have started to develop rapidly. There are many types of ESDs which differ in shape and position on the ship, but the goal of any kind of such device is to reduce the amount of kinetic energy losses around the ship propeller. This paper presents state-of-the-art in the field of ESDs. Overview of ESDs is given with the discussion addressing their effectiveness, classification, hydrodynamic design, and structural integrity.

1. INTRODUCTION

The recent changes in the regulations concerning ship efficiency are expected to significantly affect the shipping fleet. Newly built vessels have already been under the restrictions by the Energy Efficiency Design Index (EEDI) introduced in [1], but the new rules include the existing shipping sector through the Energy Efficiency eXisting ship Index (EEXI), [2]. The shipowners have a number of choices for improvement of ship efficiency and compliance with the new rules. One of the promising ways to decrease the ship GHGs emissions is by installing the Energy Saving Devices (ESDs). In general, all ESDs attempt to reduce the energy losses inevitably present in the propeller slipstream. According to [3], transversal losses hold a much larger portion of energy and are much more viable to exploit.

2. CLASSIFICATION AND HYDRODYNAMIC DESIGN

The ESDs are divided into three main categories on Zone I, II and III depending on their reference to the propeller plane. Zone I devices alter the incoming wake velocities to enable a propeller higher efficiency operation. Duct and pre-swirl devices are most often studied in this group. Zone II includes the non-standard propeller designs such as contracted loaded tip propeller. Zone III devices usually utilize the propeller post-swirl such as propeller boss cap fin.

The design of ESDs has significantly improved thanks to the developments in the Computational Fluid Dynamics (CFD) which enabled a highly accurate estimation of flow parameters with the inclusion of viscosity and turbulence. In the overall design, first a broad potential or hybrid analysis is established followed by the CFD estimation of most promising cases. Although model basin measurements are still used to verify the CFD results concerning ESDs [4], the scaling issues are shown to be an important factor due to significantly different wake profile at ship model or full-scale flows. It is important to note that the benefits are usually in the range of 1-5% which is promising for the long-term fuel efficiency perspective.

3. STRUCTURAL INTEGRITY

Unconventional loads and structural arrangements necessary for the installation of ESDs often lead to unexpected stress peaks and high dynamic loads since long and slender ESDs are known to suffer from structural issues. This leads to the development of the new methods for the accurate design of ESDs. The authors developed a direct approach in the case of the Pre-Swirl Stator considering the propeller and wave loads as well as influence of the propeller in waves which was found to be negligible [5]. For the proper estimation of loads hydro-structural coupling is necessary which leads to the considerable computational cost. On the other hand, it is important to mention that the classification rules and guidelines still lack a straightforward evaluation of the ESD structural design which reduces the long-term reliability of these devices.

4. CONCLUSION

This article featured a brief overview of the classification, hydrodynamic design, and structural evaluation of ESDs. With the restriction increase in gas emissions, both hydrodynamic and structural designs are expected to mature in the near future with respect to general methodology and geometrical shape.

Acknowledgment: This research is supported by the Croatian Science Foundation under the project Green Modular Passenger Vessel for Mediterranean (GRiMM), (Project No. UIP-2017-05-1253).

References:

[1] IMO, "Resolution MEPC.203(62) Inclusion of regulations on energy efficiency for ships in MARPOL Annex VI.," 2011.

[2] IMO, "MEPC 67 Further shipping GHG emission reduction measures adopted in MARPOL Annex VI.," 2021.

[3] J. Dang, G. Dong, and H. Chen, "An Exploratory Study on the Working Principles of Energy Saving Devices (ESDs): PIV, CFD Investigations and ESD Design Guidelines," in *International Conference on Ocean, Offshore and Arctic Engineering*, 2012, p. 25, doi: 10.1115/OMAE2012-83053.

[4] N. Sakamoto, K. Kume, Y. Kawanami, H. Kamiirisa, K. Mokuo, and M. Tamashima, "Evaluation of hydrodynamic performance of pre-swirl and post-swirl ESDs for merchant ships by numerical towing tank procedure," *Ocean Eng.*, vol. 178, no. February, pp. 104–133, 2019, doi: 10.1016/j.oceaneng.2019.02.067.

[5] A. Bakica, N. Vladimir, H. Jasak, and E. S. Kim, "Numerical simulations of hydrodynamic loads and structural responses of a Pre-Swirl Stator," *Int. J. Nav. Archit. Ocean Eng.*, vol. 13, pp. 804–816, 2021, doi: 10.1016/j.ijnaoe.2021.09.002.

Hydrodynamic Interaction Effects Between Ships in Restricted Water Depth

Renato Skejic *[1], Tor Einar Berg [2]

[1, 2] Ships and Ocean Structures, SINTEF Ocean, Trondheim, NORWAY
(E-mail: Renato.Skejic@sintef.no, Tor.E.Berg@sintef.no)

Keywords: *Close proximity ship maneuvering operations, Hydrodynamic interaction loads, Calm Water, Restricted Water Depth*

Abstract: Managing ships in confined waters and near other ships can impose significant operational and safety risks due to presence of the hydrodynamic interaction effects. The hydrodynamic interaction loads during the passage of one ship in proximity of another ship, can be further intensified in the vicinity of other barriers, see for instance [1] and [2]. Present study is focusing on the analysis of the hydrodynamic interaction loads in calm water between two ships executing proximity restricted water depth maneuvers. Based on the obtained results, the applicability of the developed theoretical approach within the marine simulator environments has been discussed.

1. INTRODUCTION

Current work is focused on the analysis of the hydrodynamic interaction loads in the horizontal plane in calm water between two ships operating in a proximity of each other's in restricted water depths. Development of the theoretical model was based on the potential fluid flow slender body far-field theory approach [3] extended with the shallow/finite water effects. In particular, the behavior of the added mass in sway in the shallow/finite water depth and its effects upon the hydrodynamic interaction loads has been investigated in detail.

	KCS	KVLCC2
Hull particulars		
Length between perpendiculars, L_{PP}	230.0 m	320.0 m
Breadth, B	32.2 m	58.0 m
Draft (even keel), T	10.8 m	20.8 m
Block coefficient, C_B	0.6505	0.8098
Displacement, $\tilde{N}$	52030.0 m^3	312621.0 m^3
Wetted surface area, S	9498.0 m^2	27194.0 m^2

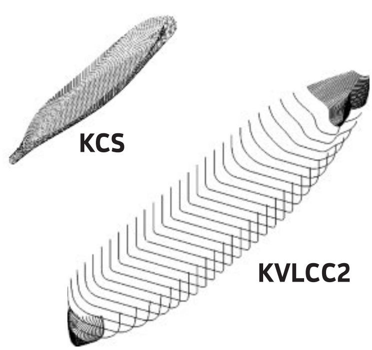


Figure 1. Principal characteristics and cross-sectional distribution of the KCS and KVLCC2 ships

The model was applied to study the overtaking (passing) and side by side maneuvers of two modern types of vessels (tanker KVLCC2 and container KCS ship) operating at the design drafts at even keel condition, see Figure 1.

2. APPLICABILITY OF HYDRODYNAMIC INTERACTION MODEL

The overtaking maneuver in calm water between the KCS and KVLCC2 ships in shallow/finite water depth condition is analyzed and the results are shown in Figure 2. Both ships follow the straight-line course with the different forward speeds. The ship B (KCS ship) approaches ship A (KVLCC2 ship) from behind where the nondimensional longitudinal distance between the ship's centers of gravity s_A is confined within the closed interval [– 3.0, 3.0]. Transverse distance e_A is preselected as a constant value and set equal to $e_A = -[12.5 + 0.5(B_A + B_B)]$ m. Here, L and B are the ships lengths and beams, respectively. The water depth is set equal to $|h| = 23.25$ m. At the beginning of maneuver, both ships experience the repulsion phase where the interaction sway forces on both ships tend to push them apart. At the same time, the the attraction surge interaction forces are present while, the interaction yaw moments are swinging the bow of ship B towards the stern of ship A and vice versa. Next, the ship's abeam position follows, where the interaction surge forces are zero, sway forces have peak values, and the yaw moments tend to swing the bow of each ship from each other. Finally, the repulsion phase repeats itself but, with the reversed roles of the interaction surge force and yaw moments, while the behavior of the sway forces remains the same.

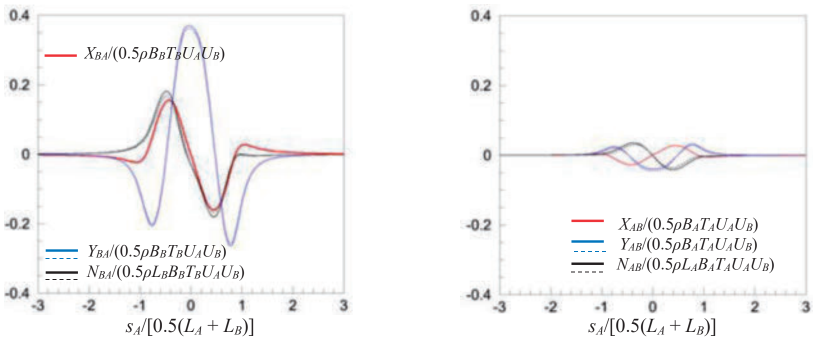


Figure 2. Overtaking maneuver between the KCS and KVLCC2 ships in shallow/finite water depth. The forward speeds: $U_A = 9.0$ kn and $U_B = 7.0$ kn, respectively

3. CONCLUDING REMARKS

Current work present estimation of the hydrodynamic interaction loads in calm water by the improved slender body [3] with the shallow/finite water depth effects.

Based on the obtained results, it has been concluded that the mentioned loads cannot be neglected when two ships are involved in the close proximity maneuver(s). This is particularly true when the presence of the shallow/finite water depth effects are encountered due to fact that the interaction effects and ship's collision risks are further intensified in comparison to the calm and deep water situation.

References:

[1] Yeung, R. W., 1978.On the interactions of slender ships in shallow water. Journal of Fluid Mechanics, 85, pp. 143-159.

[2] Kijima, K., 1987. Manoeuvrability of ships in confined water. International Conference on Ship Manoeuvrability-Prediction and Achievement, London, UK.

[3] Tuck, E. O. and Newman, J. N., 'Hydrodynamic Interaction Between Ships' In Proceedings of the 10th Symposium on Naval Hydrodynamics, Cambridge, MA, USA, pp. 35–70, 1974. 2.

Partially Rotating Grid Method for Prediction of Self-Propulsion Characteristics

Sanijo Đurasević *[1], Inno Gatin [2], Hrvoje Jasak [3]

[1, 2, 3] University of Zagreb,
Faculty of Mechanical Engineering and Naval Architecture, CROATIA.
(E-mail: sdurasevic@fsb.hr, inno.gatin@fsb.hr, hrvoje.jasak@fsb.hr)

Keywords: *Double-Body, Multiple Reference Frames, Self-Propulsion, Overset Grid*

Abstract: Computational Fluid Dynamics (CFD) simulations based on the Finite Volume Method are often used to predict self-propulsion characteristics and to describe ship-propeller interaction. Only recently, this kind of simulations has become feasible, as it requires substantial computing resources and a complete set of solver capabilities. Accurate representation of the rotating propellers and capturing of the free surface results in complexity and cost, which are still limitations for wider adoption in a preliminary design stage. Therefore, to reduce overall computational time while achieving reasonably accurate integral and local characteristics, a method using double- body model and a partially rotating grid is proposed.

1. INTRODUCTION

Due to increasing availability of computational resources and new regulations regarding lower greenhouse emissions, accurate prediction of self-propulsion characteristics has significant role in the field of numerical marine hydrodynamics. Different time scales, i.e. flow around the propeller and near the hull, that need to be solved simultaneously affect the computational time since the time step is determined by the more demanding of the two time scales. Reliable prediction of self-propulsion characteristics requires accurate modelling of the propeller. Several propeller model approaches exist including fully-discretized propeller [1] and body-force methods [2,3,4]. In order to be able to increase simulation time step, a hybrid method based on double-body model and local partially rotating grid [5] is introduced. Proposed method overcomes some of the limitations for wider adoption in a preliminary design stage.

2. METHODOLOGY

An incompressible, single-phase, viscous numerical model is applied in case of the double-body model. Turbulence is taken into account with the k-omega Shear Stress Transport (SST) model. Overset grid approach is used to handle relative motion between the propeller and the ship. Local non-inertial system is implemented for the appendage grid.

3. RESULTS AND DISCUSSION

Proposed method provided a good agreement for both integral and local characteristics with experimental data. Integral values such as thrust and torque were not significantly influenced by the locally introduced non-inertial frame, while the local flow characteristics are more affected.

4. CONCLUSION

Developed numerical method is able to predict integral and local flow characteristics, while being adequate for wider adoption in a preliminary design stage.

Acknowledgment: The authors are thankful for the financial support from the CEKOM project from the European regional development fund, referent number KK.01.2.2.03., sub–projects IRI 2 and IRI 6, in the scope of which this study is conducted.

References:

[1] A. M. Castro, P. M. Carrica, and F. Stern, "Full scale self-propulsion computations using discretized propeller for the KRISO container ship KCS," *Comput. Fluids*, vol. 51, no. 1, pp. 35–47, 2011, doi: 10.1016/j.compfluid.2011.07.005.

[2] C. Guo, X. Wang, C. Wang, Q. Zhao, and H. Zhang, "Research on calculation methods of ship model self-propulsion prediction," *Ocean Eng.*, vol. 203, 2020, doi: 10.1016/j.oceaneng.2020.107232.

[3] D. Villa, S. Gaggero, T. Gaggero, G. Tani, G. Vernengo, and M. Viviani, "An efficient and robust approach to predict ship self-propulsion coefficients," *Appl. Ocean Res.*, vol. 92, no. March, p. 101862, 2019, doi: 10.1016/j.apor.2019.101862.

[4] H. Jasak, V. Vukčević, I. Gatin, and I. Lalović, "CFD validation and grid sensitivity studies of full scale ship self propulsion," *Int. J. Nav. Archit. Ocean Eng.*, vol. 11, no. 1, pp. 33–43, 2019, doi: 10.1016/j.ijnaoe.2017.12.004.

[5] P. M. Carrica, A. Mofidi, and E. Martin, "Progress toward direct CFD simulation of manoeuvres in waves," *Mar. 2015 – Comput. Methods Mar. Eng. VI*, pp. 327–338, 2015.

Multibody Dynamics Model for Wave Motions of Floating Photovoltaics

Ivan Ćatipović *[1], Luka Ilić [1], Antonio Mikulić [1], Darko Smoljan [1]

[1] University of Zagreb,
Faculty of Mechanical Engineering and Naval Architecture, Croatia
(E-mail: ivan.catipovic@fsb.hr, li207352@stud.fsb.hr, amikulic@fsb.hr, dsmoljan@fsb.hr)

Keywords: *Connected floating bodies, Floating photovoltaics, Wave motions*

Abstract: Today, floating photovoltaic (FPV) systems are installed at freshwater surfaces and are designed to produce electricity for general purpose use. Recently, these systems are being developed so that they can be installed at sea. At these sites, FPV plants are exposed to sea waves. This study is focused on movements of a FPV system induced by the waves. FPV is considered as a set of multiple floating bodies that are interconnected. Applied approach is based on boundary element method (BEM). Hydrodynamic coupling between floating bodies is considered. Special attention is given to the model of connections between the bodies. Proposed model is solved in the frequency domain.

1. INTRODUCTION

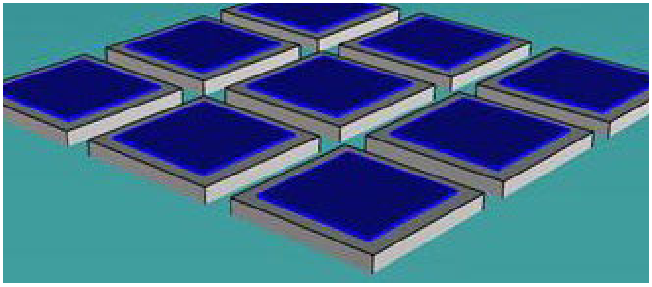
PV technology has proven to be reliable and low maintenance, and costs have fallen sharply in recent years. One of the limitations that can be found is in the use of land due to the low relative efficiency of PV panels. FPV technology solves this limitation since PV plants can be installed on freshwater surfaces and existing water basins. Recently, research has focused on FPV installations at sea. In 2021, Det Norske Veritas released the world's first recommended practice (RP) for floating solar energy projects following a joint industrial project involving 24 industry participants, [1]. The RP is intended for FPV systems located in protected and inland water bodies with significant wave heights up to 2 or 3 m. So, this study is concerned with the assessment of the wave motions of FPVs.

2. MATHEMATICAL MODEL

FPV installations are usually composed of floating bodies that are interconnected. A mathematical model used for this purpose incorporates hydrodynamics of multiple bodies where BEM can be used for the fluid flow. The connections, between the bodies, are incorporated as well. So, special attention is given to the model of connections between the bodies. The global connection stiffness matrix is derived and included into the motion equation, [2]. The equation is solved in the frequency domain and response amplitude operators (RAO) are obtained for the body motions. Afterwards, for a given sea state the response spectrums and significant values are calculated.

3. CASE STUDY

The case study is based on a set of generic floating pontoons that carry PV panels, see Figure 1. The individual pontoon has a width and length of 2.5 m. The pontoon height is 0.4 m, while the draft is 0.13 m. Nine pontoons are observed, spaced apart 0.7 m. The pontoons are interconnected with ball joints, see Figure 2. HydroStar (Bureau Veritas) is used for the analyses with roll viscous damping set at 5% of critical damping. Irregular waves modelled by JONSWAP spectrum are assumed (in various directions). A part of obtained numerical results is presented in Table 1 related to significant wave height Hs.



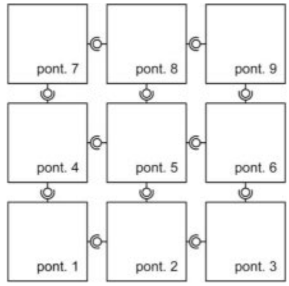


Figure 1. Generic floating pontoons with PV panels

Figure 2. Connection scheme

Table 1. The significant roll values (in degrees) for interconnected floating pontoons

H_s, m	Ponton No.								
	1	2	3	4	5	6	7	8	9
1.0	6.8	6.6	6.7	6.1	5.7	5.9	3.5	3.1	3.1
2.0	9.7	9.5	9.6	9.4	9.2	9.3	5.7	5.5	5.5
2.5	10.5	10.3	10.4	10.4	10.2	10.3	6.4	6.2	6.3
3.0	11.1	11.0	11.1	11.2	11.0	11.1	7.0	6.8	6.9

4. CONCLUSION

The paper presented the numerical approach for FPVs when installed at sea and moved by waves. The connections between pontoons are especially observed in the numerical model, so the connection matrix is successfully derived and applied in this study. There was no additional computational time due to the model of connections.

Acknowledgment: The Croatian Science Foundation HRZZ-IP-2019-04-5402 (DARS) support is gratefully acknowledged.

References:

[1] Det Norske Veritas 2021. Design development and operation of floating solar photovoltaic systems. DNV-RP-0584.

[2] Luka, I. Procjena ukupnog sunčevog zračenja za pomorske solarne sustave. Završni rad. Sveučilište u Zagrebu, Fakultet strojarstva i brodogradnje. 2021.

Numerical Assessment of Appended Hull Resistance of a RoPax Ship

Dević Matej *[1], Blagojević Branko [1], Raič Filip [1], Bašić Josip [1], Bašić Martina [1]

[1] University of Split,
Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Croatia
(E-mail: mdevic00@fesb.hr, bblag@fesb.hr)

Keywords: *appended hull, CFD, Resistance, RoPax*

Abstract: The article presents resistance assessment of a hull with appendages for a built RoPax ship. The Finite-Volume Method solver was used for numerical prediction. The solver is based on Reynolds-Averaged Navier-Stokes equations and the Volume of Fluid scheme for the free surface capturing. The resistance of the hull with appendages was calculated for a various ship speed to obtain resistance curve in calm water. Three grids sizes were used for RoPax ship in order to assess the grid refinement sensitivity. Numerical results were compared to available experimental data for a considered RoPax ship. Used CFD solver is capable to deliver results very close to experiments using relatively small computing power.

1. INTRODUCTION

The main RoPax data in this investigation: length overall 180 m, breadth 30.5 m, draught 6.7 m, displacement 21500 t, power MCR 38400 kW, service speed 21 kn, maximum speed 24 kn. The following appendages were included in the calculations: two bow thruster tunnels, two shaft arrangements, two rudders and trim wedge.

2. METHODOLOGY

The CFD procedure was verified and validated in previous studies [1]. The ship originates at x, $y = 0$ (no-slip boundary condition). Hexahedral domain size was defined according to ITTC recommendations [2]: 1.5 Lpp in front, 1 Lpp above the model, 3 Lpp behind, 1.5 Lpp below and 1.5-2 Lpp on the sides. The entrance area was modeled with inflow boundary condition. The hydrostatic pressure is set for the upper and lower surfaces and the fluid flows freely through these two surfaces. For all surfaces that had the boundary condition SOL (solids) and are in contact with water the wall-function type of the boundary condition was selected. At the other outer edges of the domain a far field boundary condition is set that moves in the x-axis direction. Gradient discretization schemes were used in the paper [3]. The turbulence model used was k-ω i.e., SST – Menter [4].

Multi-fluid options were defined same as in the experiment: water temperature 16 ^oC, density 1025.7967 kg/m3 and kin. viscosity 1.159×10^{-6} m^2/s. Air viscosity 1.85×10^{-5} m^2/s and density 1.2 kg/m^3 were used. In simulations the ship moves exclusively translationally in the x-axis direction. The ship accelerates for 55 seconds from 0 to the speed selected for the calculation. The greatest influence on the accuracy of the calculation had the modeling of the grid on the free surface [5]. In this case, the cells along the z axis had a threshold of a minimum size of 0.01 m, while the cells along the x and y axes have a threshold set at 1 m. The sailing time of the ship was calculated by multiplying the number of time steps and value of the time step. The two parameters were selected based on Numeca recommendations. Mesh densities used: coarse 1.75 M cells, medium 3.35 M cells and fine 4.75 M cells. Coarse grid had 21, medium 23 and fine 24 viscous layers. Viscous layers were placed on all parts of the geometry equally.

3. RESULTS AND CONCLUSION

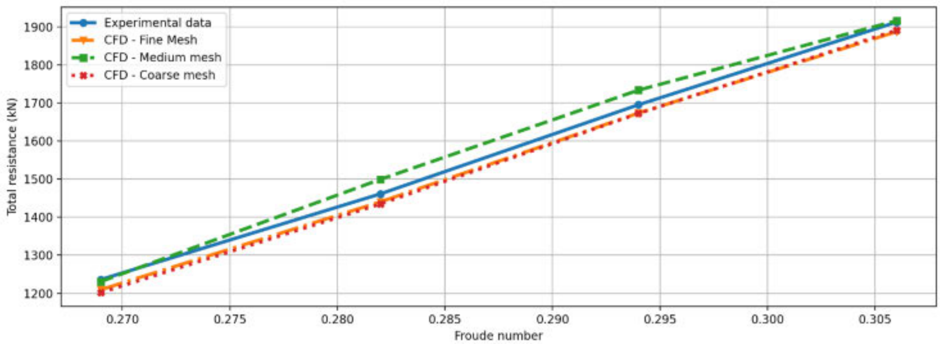


Figure 1. Comparison of calculated resistance curves

The sensitivity of the results with respect to the turbulence model has not been further investigated. The differences between the SST, EASTM and KSKL should not be significant for this application [6]. The results showed an excellent agreement between experiment data and the CFD simulations. Even coarse grid showed a minimal deviation from experiment with correct matching to experiment data trendline.

Acknowledgment: The research is part of the project "Innovative solution of waterjet propulsor" on CEKOM, IRA3. Contract number: KK.01.2.2.03.002.

References:

[1] Dević, M, Bašić, J, Bašić M, Blagojević, B. Validation of the CFD procedure for RoPax resistance assessment. Winkler 2021, Rijeka, Croatia, 2021, pp. 50–64.

[2] ITTC – Recommended Procedures and Guidelines. Practical Guidelines for Ship CFD Applications. 2011.

[3] Andrun, M, Blagojević, B, Bašić, J. The influence of numerical parameters in the finite-volume method on the Wigley hull resistance. Journal of Engineering for the Maritime Environment, vol. 233, 2018.

[4] Schot, J, Vaz, G, Toxopeus S. A Verification and Validation Study of CFD Simulations for the Flow Around a Tug. NuTTS, Wageningen, Netherlands 2017.

[5] Ozdemir, YH, Barlas, B. Free surface flow simulation around an appended ship hull. Brodogradnja, 69, 3, 2018.

[6] Deng, G, Duvigneau, R, Queutey P, Visonneau, M. Assessment of turbulence models for ship flow at full scale. APCOM, Beijing, China, September 2004.

Multi-Mode Variable Pitch Propeller and the Efficiency of Its Operation as a Part of Coaxial Rotation Propellers

L. Vishnevskii [1], A. Togujac [2], M. Popov [3]

[1] Krylov State Research Center, SPb, Russia
(E-mail: Vishli@yandex.ru)

[2] Marine-Technique company, SPb Russia
(E-mail: togunjac.branko@yandex.ru)

[3] Scientific assistance of Marine-Technique company, SPb Russia
(E-mail:org.energo@yandex.ru)

Keywords: *Multi-mode variable-pitch propeller, Operating mode with increased and moderate load on the propeller, Propeller efficiency*

Abstract: The features of multi-mode variable-pitch propellers (MVPP) were earlier pointed out, which, unlike control pitch propellers (CPP), the position of the blades on the hub is not controlled by power drive, but as a result of the action of hydrodynamic and inertial forces, fig. 1, [1,2,3,4]. In particular preliminary computational estimates showed that they can be quite promising propellers for ships with different modes of sailing, caused by factors: sea waves, operating at forced moving, increasing of resistance of the ship due to roughness of its hull, etc.

Figure 1. MVPP model in cavitation tunnel when it is tested at various modes

It was the reason to consider in more detail the using of MVPP when it is operating as part of coaxial propellers, in which the back propeller depends on the load of the front propeller and the incoming flow from it. The modes of back propeller can be changed in wide range, where the fixed pitch propeller (FPP) can operate with relatively low efficiency. At the same time, due to their high efficiency, coaxial propellers are very widely used on some samples of marine equipment.

The design and hydrodynamic calculation of coaxial FPP, as well as coaxial FPP and MVPP of opposite rotations, which make up the propulsion complex, was presented in this paper. The main results were obtained as follows.

MVPP can be effective in the development of coaxial sets of counter-rotating propulsion devices in order to increase their efficiency. The obtained positive result in order to increase the efficiency of coaxial propulsion devices with the using of MVPP refers to the area of increased loads on the propulsion unit.

As for coaxial propellers, consisting of FPP, their efficiency is significantly higher compared with single propellers, even if they are designed optimally for the selected conditions, at all other things being equal. In the given design case, this increase in the increase in efficiency is about 15%. This is due to the fact that in the case of coaxial propellers, power is distributed in the axial direction, and not processed in a concentrated place, as it takes the case with a single FPP.

Further studies of coaxial propellers with using MVPP should be continued in order to determine the influence of individual parameters on the propulsion, for example, in order to obtain data on the effect on the ratio of processing power between the first and second propeller, their relative position in the axial direction, etc.

References:

[1] Vishnevsky L.I. Multi-mode variable-pitch propeller and prospects for its use on ships with different driving modes // Proceedings of the KSRC named after acad. A. N. Krylov, vol. 4(398), 2021, pp.53-61

[2] Vishnevsky L.I., Togunjats A.R. Ship propellers, new technical solutions, research results, Shipbuilding, St. Petersburg, 2012.

[3] Morgan W.B. The Design of Counter rotating Propellers Using Lerbs Theory.– TSNAME, 1960 vol.68.

[4] Van Manen J.D., Oosterveld. Model tests on contra-rotating propellers. International Shipbuilding Progress, vol.15, no.172, pp.401-417, 1968.

Estimation of Drag Coefficient of a Bare Hull of a Submarine Moving in Different Directions

Hassan Saghi *[1, 2], Antonio Mikulić [1]

[1] University of Zagreb,
Faculty of Mechanical Engineering and Naval Architecture, Croatia.
(E-mail: hsaghi@fsb.hr, antonio.mikulic@fsb.hr)

[2] Department of Civil Engineering,
Hakim Sabzevari University, Sabzevar, Iran.

Keywords: *Submarine, Drag coefficient, Computational Fluid Dynamics.*

Abstract: We developed a numerical model using Computational Fluid Dynamics to simulate the movement of a submarine with spherical heads moving in different directions and at different speeds in a viscous and incompressible fluid. Afterward, the drag coefficient of the submarine is estimated for different scenarios. Using the Nonlinear Least Squares Marquardt-Levenberg algorithm, we fit the best curve to the results of the drag coefficient based on length-to-diameter ratio of the bare hull and the Reynolds number. For different directions, regression equations are presented to estimate the drag coefficient.

1. INTRODUCTION

The complexity of flow around the hull has made numerical and experimental models indispensable for predicting submarine resistance. Paz and Tascon [1] optimized submarines for maximum speed and minimum axial resistance and cross-flow drag, where the main objective was to minimize resistance. Mackay [2] used empirical relations to evaluate the total resistance and semi-empirical relationships to compute the hydrodynamic derivatives of the bare hull, sail, and control surfaces. Vasudev et al. [3] developed a multi-objective optimization framework to determine the optimal hull form for an autonomous underwater vehicle. In this paper, we propose a nonlinear equation to estimate the drag and drag coefficient of the bare hull based on two dimensionless parameters, the length-to-diameter ratio, and the Reynolds number. Furthermore, different moving directions of the submarine are considered.

2. METHODOLOGY

The forward and lateral motions of a submerged bare hull of a submarine were modeled in a viscous and incompressible fluid using Computational Fluid Dynamics (CFD) in OpenFOAM. Accordingly, Reynolds Averaged Navier Stokes (RANS) equations are used as the governing equations. In addition, the *K-Epsilon* two-equation model was used to account for turbulence. Next, the Nonlinear Least Squares (NLLS) Marquardt-Levenberg algorithm was applied to fit a relation to the generated data to estimate the drag coefficient using two dimensions-less parameters, including the length-to-diameter ratio of the bare hull and the Reynolds number (Re). The drag coefficient of the cube against the fluid flow was estimated for different mesh sizes, and the numerical results showed that uniform mesh sizes ($dx = dy = dz$) smaller than 0.04 m did not significantly affect the total drag. Additionally, the average of 1.12 was found to be very close to the amount suggested by other researchers [4], which is between 1.05 and 1.20.

3. RESULTS

The drag coefficient of the submarine with different length-to-diameter ratios and velocities were estimated. The NLLS algorithm was applied to fit the best curve to the results and find a nonlinear equation to estimate the drag coefficient of the bare hull, based on L/DS and Re.

4. CONCLUSIONS

The drag coefficient of the submarine's bare hull is calculated using CFD and equations are fitted to enable rapid estimation. According to the results of the comparison between the numerical model and the suggested equations, the estimated drag coefficient has an error of around 0-5%.

Acknowledgment: The project is co-financed by the European Union from the European Regional Development Fund within the Operational Program "Competitiveness and Cohesion 2014-2020", project KK.01.2.1.02.0339 – Development of the multipurpose luxury touristic and research submarine. The content of the publication is the sole responsibility of the project partner University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture. This research was performed using the resources of computer cluster Isabella based in SRCE – University of Zagreb University Computing Centre.

References:

[1] Paz, M.J.D., Tascon, O.D., Multiobjective optimization of a submarine hull design, Ship Sci Technol, Vol. 7, 2013, pp. 27–42.

[2] Mackay, M., The standard submarine model: a survey of static hydrodynamic experiments and semi-empirical predictions, Technical report DRDC Atlantic TR 2003-079, Ottawa, ON, Canada: Defence Research and Development Canada, 2003.

[3] Vasudev, K.L., Sharma, R. Bhattacharyya, S.K., A multi-objective optimization design framework integrated with CFD for the design of AUVs, Method Oceanograph, Vol. 10, 2014, pp. 138–165.

[4] Hassan Khan, M., Sooraj, P., Sharma, A. & Agrawal, A., Flow around a Cube for Reynolds numbers between 500 and 55000. Experimental thermal and fluid science, Vol. 93, 2018, pp. 257-271.

Procjena otpora trupa velikog jedrenjaka

Raič Filip *[1], Blagojević Branko [1], Bašić Josip [1], Bašić Martina [1]

[1] Sveučilište u Splitu,
Fakultet elektrotehnike, strojarstva i brodogradnje
(E-mail: fraic00@fesb.hr, bblag@fesb.hr)

Ključne riječi: *CFD, jedrenjak, otpor trupa, validacija*

Sažetak: Prikazan je numerički postupak (CFD) procjene otpora trupa izgrađenog velikog jedrenjaka. Primijenjena je metoda konačnih volumena temeljena na RANS jednadžbama i metodi udjela fluida u volumenu (VOF) za definiranje slobodne površine. Numerički rezultati su validirani prema dostupnim podacima o otporu od strane brodograditelja. Otpor trupa proračunat je za različite brzine broda. U simulacijama je korišteno više mreža različite gustoće. Postupak je pokazao vrlo dobro podudaranje numeričkih rezultata s eksperimentalnim podacima, te se može preporučiti za analizu modifikacija trupa već izgrađenog broda.

1. UVOD

Za postizanje kvalitetnih rezultata numeričkih simulacija za procjenu otpora broda, potrebno je uspostaviti vezu između numeričkih rezultata i stvarnog, fizikalnog, modela ili broda. To se postiže kroz validaciju [1] numeričke procedure. Validirane procedure mogu dati pouzdanije rezultate u simulacijama modifikacija osnovnih formi, bilo iz razloga razvoja nove forme ili adaptacije postojeće za drugu namjenu i performanse, a što je slučaj kod razmatranog broda u ovom radu. Podaci o brodu: duljina preko svega 166.38 m, širina 19.8 m, gaz 6.4 m, istisnina 10180 t, instalirana snaga pogona 6450 kW, brzina u službi 17 kn, maksimalna brzina 21 kn.

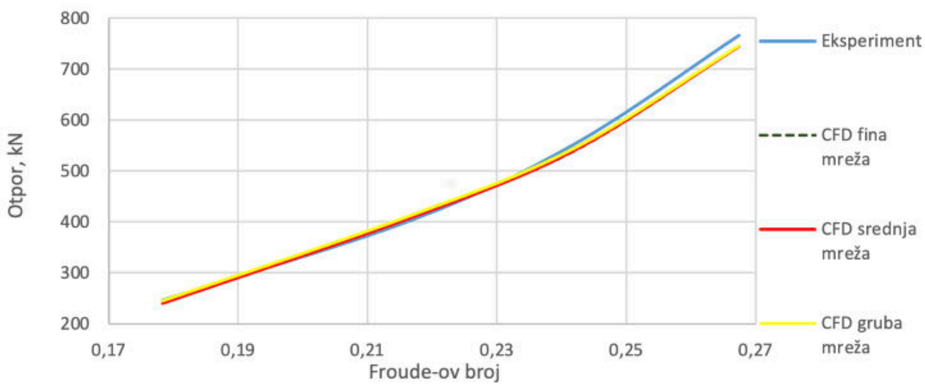
Slika 1. 3D model trupa jedrenjaka

2. POSTAVKE CFD SIMULACIJA I VERIFIKACIJA

CFD procedura definirana je u programu Numeca Fine/Marine. Simulacije su se izvodile u heksaedarskoj domeni i Kartezijevom koordinatnom sustavu. Brod je u ishodištu na $x,y = 0$. Površina vode je na $z = 6.4$ m. Rubni uvjeti postavljeni su u programu: ulazna površina kao inflow boundary condition, gornja i donja imaju zadan hidrostatski tlak. Fluid slobodno struji kroz ove dvije površine. Za sve površine koje imaju rubni uvjet kao čvrsta tijela odabran je wall-function uvjet. Kod ostalih vanjskih rubova postavljen je uvjet farfield. U simulacijama su korištene gradijentne diskretizacijske sheme za koje je poznato da nemaju većeg utjecaja na određivanje otpora pravilnih brodskih formi, sličnih razmatranoj [2]. Korišten je k-ω (SST – Menter) turbulencijski model. U simulacijama brod ubrzava 43.73 sekundi od 0 m/s do brzine odabrane za proračun, tako da brzina raste po pravilu pola sinusoide. Preciznost numeričkog proračuna određena je kontrolnim parametrima programa. Postavljen je maksimalni broj nelinearnih iteracija koji određuje broj izračuna u jednom vremenskom koraku. Numeca preporuča korištenje vremenskog koraka vrijednosti $T = 0.005$ (L_{oa}/V) što se i koristilo u proceduri. CFD simulacije rađene su za brzine broda 14 kn, 17 kn, 19 kn i 21 kn. Primijenjene su tri gustoće mreže: gruba s 2.25 M ćelija, srednja s 3.78 M i fina mreža s 5.28 M ćelija. Važno je naglasiti da se povećanjem broja ćelija ne garantira značajno povećanje točnosti [3]. Glavni kriterij za verifikaciju je kriterij konvergencije GCI [4]. Preporučeno je da konvergencijski indeks bude ispod 5% [5], što i je ostvareno.

3. VALIDACIJA I REZULTATI

Na temelju opisanog postupka verifikacije i validacija je uspješno provedena te je ovdje dobiveni indeks GCI bio u okvirima preporučenih vrijednosti. Krivulje otpora za sve korištene gustoće mreža pokazuju izvrsno poklapanje s eksperimentalnim podacima o otporu trupa.



Slika 2. Usporedba krivulja otpora dobivenih CFD postupkom

Reference:

[1] Oberkampfa, WL, Trucano, TG. Verification and validation in computational fluid dynamics. Progress in Aerospace Sciences 38, 2002.

[2] Andrun, M, Blagojević, B, Bašić, J .The influence of numerical parameters in the finite-volume method on the Wigley hull resistance. Journal of Engineering for the Maritime Environment, 233, 2018.

[3] Andrun, M, Blagojević, B, Bašić, J, Klarin, B. Impact of CFD Simulation Parameters in Prediction of Ventilated Flow on a Surface–Piercing Hydrofoil. Ship Technology Research, 68, 2020.

[4] Perez, CA, Tan, GM, Wilson, PA. Validation and verification of hull resistance components using a commercial CFD code. 11th Numerical Towing Tank Symposium, Brest, France, 2008.

[5] NUMECA FineMarine Documentation, 2020.

25th SYMPOSIUM ON THE THEORY AND PRACTICE OF SHIPBUILDING 2022

07 – 10 September 2022, Malinska – Croatia

Construction, Strength and Vibration of Vessels and Offshore Structures

Reliability Analysis of Secondary Hull Component

Siri Kolle Kleivane *[1], Bernt Johan Leira [1], Sverre Steen [1]

[1] Department of Marine Technology,
Norwegian University of Science and Technology, NORWAY.
(E-mail: siri.k.kleivane@ntnu.no, bernt.leira@ntnu.no, sverre.steen@ntnu.no)

Keywords: *Fatigue crack growth, FORM/SORM, Main eigne excitation, Monte Carlo simulation, Structural reliability analysis*

Abstract: A stochastic model of vibration response is developed for probabilistic formulation of the failure probability of crack propagation. A generic cargo hold model is analyzed with engine speed and placement as stochastic variables. A fitted polynomial of the vibration response is used for probabilistic analysis by Monte Carlo (MC/DSPS) and FORM/SORM methods. The limit state is formulated as the possibility of fatigue crack growth based on a threshold stress intensity factor. The failure probability estimated by Monte Carlo simulations and SORM indicate a satisfying integrity of the structural component under consideration. The adequacy of the fitted polynomial is also assessed. A main observation from the analysis is that reliability-based design of secondary structural component may help to improve the vibration characteristics of the structure.

1. INTRODUCTION

Ship hull vibration is a main contributor to fatigue crack growth and the main engine is identified as an important vibration source [1]. The complexity by which the vibration response is governed at both global and local level makes vibration calculation and fatigue analysis of a ship structure challenging. Influence of several parameters describing the physics of vibration and fatigue must be properly considered [2], and many of these are often only known at an approximate level. Hence, a general method to solve any vibration problem arising onboard a ship does not exist. This emphasizes a need for reliability formulations of ship vibration. A substantial number of studies have manly focused on hull vibration on a global scale, e.g., [3][4], while the interaction of global and local vibration and how it may influence local structural components have not been studied to the same extent.

2. METHODOLOGY

A generic cargo hold model is analyzed in Ansys with placement (X) and engine speed (Y) as stochastic variables. Submodelling is utilized to transfer the global response of the hold model onto submodels of the pipe stack supports. The excitation loading is taken as force emanating from the main engine at different speeds. The critical stress is evaluated at a weld for the pipe stack support [5]. The probabilistic formulation is based on polynomial regression by fitting a surface polynomial to data points from the vibration analysis. For simplicity, the stochastic variables are assumed to have uniform distribution. The failure probability is estimated by Monte Carlo and FORM/SORM simulations using Proban. The limit state is formulated as the possibility of fatigue crack growth based on a threshold stress intensity factor for crack growth of steel [6].

3. RESULT AND DISCUSSION

Table 1 gives the goodness of fit for the 2nd order polynomial fitted from the vibration analysis. The distribution of the X-variable is between 69 m and 82 m, with mean of 75.5 and standard deviation of 3.8. The distribution of the Y-variable is between 79 rpm and 120 rpm, with mean of 99.5 and standard deviation of 11.8. Table 2 gives the failure probabilities.

Table 1. Goodness of fit (MATLAB)

Parameter	X-variable	Y-variable
SEE	0.0028	3.640
R-square	0.9411	0.8207
RMSE	0.0306	1.102

SSE: sum of squares due to error
RSME: root mean squared error

Table 2. Estimated failure probability

Method	Failure probability [%]
MC	0.122
DSPS	0.122
FORM	0.251
SORM	0.119

The failure probability estimated by MC, DSPS and SORM indicate a satisfying integrity of the component under consideration. However, FORM deviates from the other methods. This may indicate a response surface which is curved and displaying nonlinear characteristics. The assumption of uniform distribution is to some extent reasonable for the X-variable as it is evaluated in the longitudinal direction only. However, it is more questionable for the Y- variable as this will depend on the ship's operational condition and voyage. The polynomial is also badly conditioned. Another functional representation may therefore be more suitable.

4. CONCLUSION

The agreement between SORM and MC/DSPS give a validity of the results, however, it cannot be concluded based on this that the structure is safe. It is seen that reliability-based design of secondary structural components, and looking at their interaction with the global structure, may help to improve the vibration characteristics of the structure.

References:

[1] American Bureau of Shipping, Guidance note on Ship Vibration, Texas, USA, 2018.

[2] Soares, C. G., Garbatov, Y., Rudan, S., Gaspar, B., Fatigue assessment of marine structures, Marine Technology and Engineering, Vol. 2, 2011, pp. 865-888.

[3] Jensen, J. J., Dogliani, M., Wave-induced ship hull vibrations in stochastic sea ways, Marine Structures, Vol. 9, No. 3-4, 1996, pp. 353–387

[4] Zilj, C., Soal, K., Volkmar, R., Govers, Y., Böswald, M., Brekker, A., The use of operational modal analysis and mode tracing for insight into polar vessel operations, Marine Structures, Vol. 79, 2021.

[5] Berge, S., Basic fatigue properties of welded joints, in A. Almar-Næss (Ed.), Fatigue Handbook: offshore steel structures, Tapir, 1985, pp. 175-236.

[6] British Standard, Guide to methods for assessing the acceptability of flaws in metallic structures, BS 7910:2005.

FEA of Hyperelastic Structures: A Case From the Submarine Design

Marin Palaversa *[1], Joško Parunov [2]

[1, 2] Faculty of Mechanical Engineering and Naval Architecture,
University of Zagreb, CROATIA
(E-mail: marin.palaversa@fsb.hr, josko.parunov@fsb.hr)

Keywords: *hyperelastic material, material model, O-ring, submarine design*

Abstract: The paper deals with FEA of seals made of a hyperelastic material. The seals are used in a novel design of a tourist submarine and undergo large deformations and strains. Thus, the analysis includes geometrical and material nonlinearity, finite strains and contact conditions. The whole process of analysis from selecting a suitable set of experiments used to calibrate the hyperelastic material model to determining mesh characteristics and interpreting the results is presented. It is shown that the required number of experiments can be minimised by a simple comparison of deformation gradient tensors of the experiments and the problem at hand.

1. INTRODUCTION

Submarines have traditionally been built out of steel and other metallic materials, usually without any windows on the hull. Such solutions obstruct a direct view from the interior of the submarine, which is not desirable if the submarine is intended for scientific or tourist purposes. A great research and engineering effort were invested to find a viable alternative to the metals [1]. The alternative was found in acrylic plastics that enables construction of fully transparent submarine hull segments. However, constructing the hull by many separate segments means that a special attention must be paid to proper sealing at the joints where the segments meet.

Seals of circular shape (commonly known as O-rings) have been used for principally similar purposes. If we confine ourselves to literature concerned with submarine design, there are papers on O-rings similar in diameter to the ones analysed here but used in much smaller one- or two-men submersibles [2] and o-rings of a much smaller diameter [3] used for conical frustum windows on submarine hulls [4].

In this paper we present a procedure for deriving a material model to represent the hyperelastic material of the O-ring seal used in the finite element analysis (FEA) of a simplified model of the real joint between the acrylic hull segment and the supporting steel ring.

2. METHODOLOGY, RESULTS AND DISCUSSION, CONCLUSION

Based on the uniaxial, planar and equibiaxial tension tests, the engineering stress – engineering strain curves are obtained [5] and a neo-hookean and a Mooney-Rivlin material models are derived for the nitirile-butadyene rubber of hardness of 70 according to the Shore A scale (NBR70). An additional neo-hookean material model is derived based on the planar tension test alone because, as demonstrated, the problem at hand is, in terms of deformation, similar to that test. After that, a series of simplified FE models of the joint between the acrylic segment, the supporting steel ring and the NBR70 seal are built: one FE model is built with an initial mesh size and with each of the aforementioned material models (3 models in total) and an additional model for the neo-hookean material model based on the planar tension only with a two times denser mesh in order to verify the quality of the initial mesh.

The stress results of the final FE model differ for less than 5% from the results of the model with approximately two times finer mesh, which is considered acceptable in this study meaning that the results obtained by the model can be considered as reliable for the study. Maximum stresses in the seal obtained by the final FE model are well below the tensile strength of the material.

The paper has dealt with the FEA of seals used in a novel submarine design. Due to the deformation state imposed on the seal considered in the paper, the material model of the final FE model has been derived based on the stress – strain data from the planar tension experiment. Additionally, the neo-hookean material model has been used in the final FE model due to an almost linear relationship between strains and stresses in the stress-strain range of interest. It has been demonstrated that the structural response of the analysed seal is acceptable at the considered load conditions and that the total number of experiments needed for material model derivation can be minimised by a simple analysis of the deformation state of the problem at hand.

Acknowledgment: The project is co-financed by the EU from the ERDF within the Operational Program "Competitiveness and Cohesion 2014-2020", project KK.01.2.1.02.0339 – Development of the multipurpose luxury tourist and research submarine. The content of the publication is the sole responsibility of the project partner University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture.

References:

[1] Stachiw, J.D. Handbook of Acrylics for Submersibles, Hyperbaric Chambers and Aquaria, Best Publishing Company, Flagstaff, AZ, USA, 2003.

[2] Song, W., Cui, W., Finite element analysis of large-sized O-rings used in deep-ocean pressure chambers, Advances in Mechanical Engineering, Vol. 13, No. 8, 2021, pp. 1–13.

[3] Li, J.X., Liu, P.F., Wang, S.B., Leng, J.X., Finite Element Analysis of O-Ring Sealing Performance of Manned Submersible Viewports, Journal of Failure Analysis and Prevention, Vol. 20, 2020, pp. 1628–1637.

[4] Pranesh, S.B., Deepak Kumar, D., Subramanian, V.A., Sathianarayanan, D., Ramadass, G.A., Numerical and experimental study on the safety of viewport window in a deep-sea manned submersible, Ships and Offshore Structures, Vol. 15, No. 7, 2020, 769-779.

[5] Szabo, G., Varadi, K., Failure Mechanism of O-Ring Seals Under Extreme Operating Conditions, Modern Mechanical Engineering, Vol. 8, 2018, 11-30.

Structural Design by Analysis of Touristic Submarine with Acrylic Hull

Maro Ćorak [1], Zdenko Šperanda [2], Juvel Čokić [2], Joško Parunov *[3]

[1] Maritime Department, University of Dubrovnik, CROATIA
(E-mail: mcorak@unidu.hr)

[2] MES-DIV, CROATIA
(E-mail: zdenko.speranda@divgroup.eu; juvel.cokic@divgroup.eu)

[3] Faculty of Mechanical Engineering and Naval Architecture,
University of Zagreb, CROATIA
(E-mail: jparunov@fsb.hr)

Keywords: *Acrylic hull, Finite element analysis, Touristic submarine*

Abstract: Structural design of touristic submarine with acrylic hull is presented using "design by analysis" concept proposed by ASME code for pressure vessels. Yielding, buckling and fatigue failure modes of the steel structural members are investigated. The analysis is performed of individual components as well as for the structural assembly. The most important loading conditions studied are submerged condition at the design depth of 65 m and the lifting condition.

1. INTRODUCTION

The touristic submarine with transparent acrylic hull is designed to enable panoramic view of the submerged sea environment to the passengers on board [1]. Although the concept of such submarine is known [2], structural design procedure is not available yet. Thus, the aim of this presentation is to give an overview of the structural analyses performed during development of the innovative design of such submarine. The approach used in the study is "design by analysis" method prescribed in ASME code for pressure vessels [3]. Finite element method using FEMAP with NX Nastran software is employed. The procedure consists in investigation of the yielding, buckling and fatigue failure modes for the main steel structural elements of the submarine both separately for individual components and considering assembled structure. The main particulars of the submarine are given in Table 1.

Table 1. The particulars of the submarine

Design depth, m	50.0	Forward speed (max.), knots	2.50
Length overall, m	25.085	Cruise speed, knots	0.5
Beam, m	4.75	Cruise duration, hours	12@1 knot
Height to deck, m	4.19	Dry weight, tons	142
Draft, m	3.42	Passengers	48
Hull (acrylic) outer diameter, m	2.64	Crew members	2

2. STRUCTURAL ANALYSIS

The structure of the touristic submarine consists of the pressure hull and the external chassis. Pressure hull is composed of the steel spherical heads and steel transverse rings that support acrylic cylindrical sections. As the mechanical properties of the acryl are poor and sensitive to the axial stresses and temperature variation, cylinders do not contribute to the structural strength. The chassis is designed to bear longitudinal forces produced by hydrostatic pressure, preventing thus load transfer to the acrylic cylinders. External chassis is screwed to the heads and rings to enable replacement of the cylinders. The global buckling failure mode of the assembled structure is shown in Figure 1, where adequate buckling load factor of 4.23 is achieved.

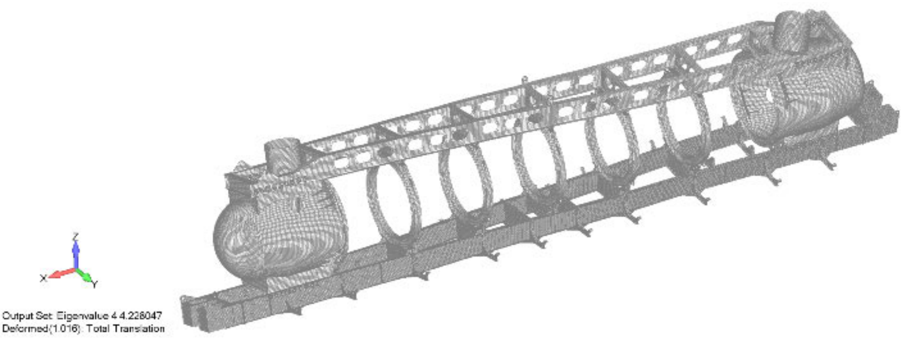


Figure 1. Global buckling failure mode of the touristic submarine

3. CONCLUSION

Structural analysis of the touristic submarine with the acrylic hull is performed using “design by analysis” approach, commonly employed for pressure vessel. Structural improvements are proposed to achieve satisfactory safety factors for different failure modes.

Acknowledgment: The project is co-financed by the European Union from the European Regional Development Fund within the Operational Program “Competitiveness and Cohesion 2014-2020”, project KK.01.2.1.02.0339 – Development of the multipurpose luxury touristic and research submarine. The content of the publication is the sole responsibility of the project partner Faculty of Mechanical Engineering and Naval Architecture.

References:

[1] https://tritonsubs.com/subs/deepview/

[2] https://lescompagnonsdusaga.files.wordpress.com/2021/04/claude-roubeau.pdf (in French)

[3] ASME Boiler and Pressure Vessel Code, Section VIII, Division 2, 2019.

Current State of Development of OOFEM, an Open-Source Tool for FEA of Ship Structures

Marin Palaversa *[1], Pero Prebeg [2], Jerolim Andrić [3], Stanislav Kitarović [4]

[1, 2, 3] University of Zagreb,
Faculty of Mechanical Engineering and Naval Architecture, CROATIA.
(E-mail: marin.palavera@fsb.hr)

[4] Bonum ltd., CROATIA.

Keywords: *FEM software, finite element analysis, ship structural analysis*

Abstract: Ship structural analysis is usually carried out using commercial FEA software. Besides the many benefits that they bring, there are also limits to the extent a user can alter their functionalities, thus limiting the testing of new ideas in science. In this paper, we present the current state of development and capabilities of open-source software called OOFEM (Object-Oriented Finite Element Method), which has recently been upgraded to enable a linear static analysis of real-world ship structures. We briefly summarise the latest upgrade and demonstrate its workings on a series of test cases including typical ship substructures and structures. We also provide a comparison with NX Nastran, an industry-standard FEA program, and classification societies' requirements and show that the upgraded version of OOFEM can solve problems that occur in typical linear static analysis of ship structures.

1. INTRODUCTION

Rational ship structural analysis and design is based on commercial finite element analysis (FEA) tools [1]. For example, in a survey conducted by ISSC [2] not a single structural designer reported that he was using open-source software (OSS) in his work. One of the possible reasons for this situation might be the fact that, to the best knowledge of the authors, OSS for FEA of ship structures that fulfils all the expectations of ship structural designers did not exist until recently. Since then, OSS called OOFEM (Object-Oriented Finite Element Method) has been upgraded to fulfil all the requirements that classification societies impose on ship structural analysis based on the finite element method (FEM) [3]. Moreover, its properties are comparable with that of NX Nastran [1], one of the most widely used programs for FEA of engineering structures. In this paper we sum the results gathered from all contributions on OOFEM in ship structural analysis ([1], [4]) and derive a critical assessment of its current capabilities.

2. METHODOLOGY

In a recent upgrade of OOFEM [1], a series of new quadrilateral and triangular shell finite elements were added. It is now important to validate their results and compare their performance with an industry standard program, as suggested by [5]. A series of tests is conducted ranging from relatively simple standard benchmark examples used for validation of general-purpose FEA programs to the tests specific to ship structural analysis. As elaborated in [1], this is a very important step due to some distinct characteristics of the ship structural design process, such as the requirements of classification societies on the FEA.

3. RESULTS AND DISCUSSION

The tests that have been carried out show that the newly implemented finite elements of OOFEM give results comparable to those of NX Nastran and within the acceptable limits given in the literature. However, there are three tests where the OOFEM elements still perform significantly inferior to the NX Nastran elements. Two of these tests are related with in-plane bending and the third one is related with FEA when warped finite elements are used.

It is important to emphasize that the aforementioned remarks hold for the set of generic tests. When it comes to ship structure specific tests, the difference between the OOFEM and NX Nastran results is within a few percent both for the displacements and stresses.

4. CONSLUSION

This paper is concerned with validation and critical assessment of the latest update of OOFEM. It shows that OOFEM produces results very similar to those of NX Nastran, especially when mesh is refined as required by classification societies. The paper also uncovers the remaining defects of the implemented elements that must be addressed in the future (in case of in-plane bending and warping).

Acknowledgment: This research was partially funded by the European Regional Development Fund (ERDF), under the project: KK.01.2.1.01.0124 – REMAKE.

References:

[1] Prebeg, P., Palaversa, M., Andric, J., Tomicic, M., Adaptation of FEM-based open-source software for ship structural analysis, Ships and Offshore Structures, 2022, pp. 1–12.

[2] ISSC Committee IV.2, Design methods, ISSC 2018, Amsterdam, Netherlands, 2018, pp.

[3] DNVGL-CG-0127 Finite element analysis, DNVGL, Hovik, 2015.

[4] Palaversa, M., Prebeg, P., Andric, J., Opportunities of using open-source FEA software in ship structural design, COMPIT '20, Pontignano, Italy, 2020, pp. 178-198.

[5] Basu, R.I., Kirkhope, K.J., Srinivasan, J., Guidelines for evaluation of ship structural finite element analysis, SSC, Washington DC, 1995.

Structural Analysis of RO-RO Ship According to Lloyd's Register Rules for Direct Calculation

Jerolim Andrić *[1], Karlo Pirić [2], Suzana Pavletić [3], Pero Prebeg [4], Aleksandar Dmitrašinović [5], Mateja Tomičić [6]

[1, 4, 6] University of Zagreb,
Faculty of Mechanical Engineering and Naval Architecture, Zagreb, CROATIA
(E-mail: jerolim.andric@fsb.hr , pero.prebeg@fsb.hr, mateja.tomicic@fsb.hr)

[2] BONUM d.o.o, Zagreb, CROATIA
(E-mail: karlo_piric@yahoo.com)

[3] ULJANIK, Pula, CROATIA
(E-mail: spavleti@gmail.com)

[5] Lloyd's Register, Trieste, ITALY
(E-mail: aleksandar.dmitrasinovic@lr.org)

Keywords: *Full ship FEM, Lloyd Register, RO-RO ship, SDA rules, Structural analysis*

Abstract: The paper discusses and highlights the basic challenges and the most important aspects in the structural design and analysis of large RO-RO ship using ULJANIK shipyard Newbuilding 531-532 as an example. Two main structural problems have been evaluated in detail: (1) hull girder longitudinal strength, due to large openings in the in upper part of side shell; (2) transverse/racking strength, due to absence of transverse bulkheads in the upper hull part.

1. INTRODUCTION

The direct strength calculation has been carried out according to Lloyd Register (LR) SDA Rules for direct structural analysis of Ro-Ro [1] ships using full ship FEM model in preliminary and detail design phases.

2. METHODOLOGY

To fully realize all benefits of the structural design procedure based on the direct strength calculation, in-house structural design system OCTOPUS_LR was developed and used for both design phases. It combines several in-house developed modules containing LR SDA requirements (definition of load components/load cases, stress correction/superposition procedure, feasibility/stress and buckling criteria), MAESTRO design system [2] as a FE modeler and response solver and in-house developed interactive GUI shell, View3D, for data manipulation and post-processing of results.

3. RESULTS

In the preliminary design phase full-ship 3D FE model was used to provide results for global deformations, distribution of all component stresses, as well as the boundary conditions for the fine mesh analysis of the critical details, see Fig.1. Determination of the structural feasibility (based on yield and buckling criteria) was done according to LR acceptance criteria and was base for efficient structural redesign.

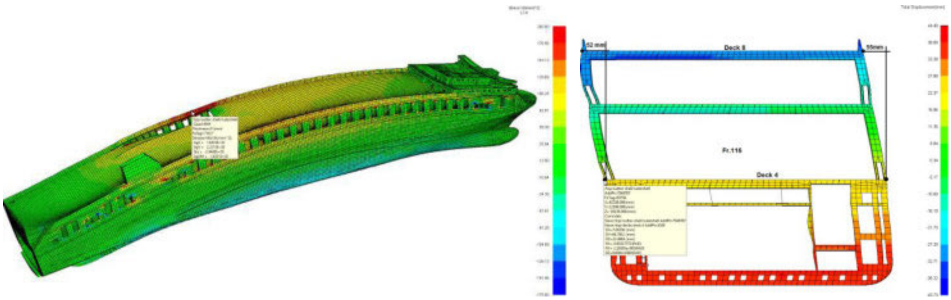


Figure 1. Distribution of σx stresses and deformation plot for racking case

In detail design phase several critical structural details have been evaluated using a very fine mesh FE models (*t* x *t*) as specified by the of LR SDA requirements, see Fig.2.

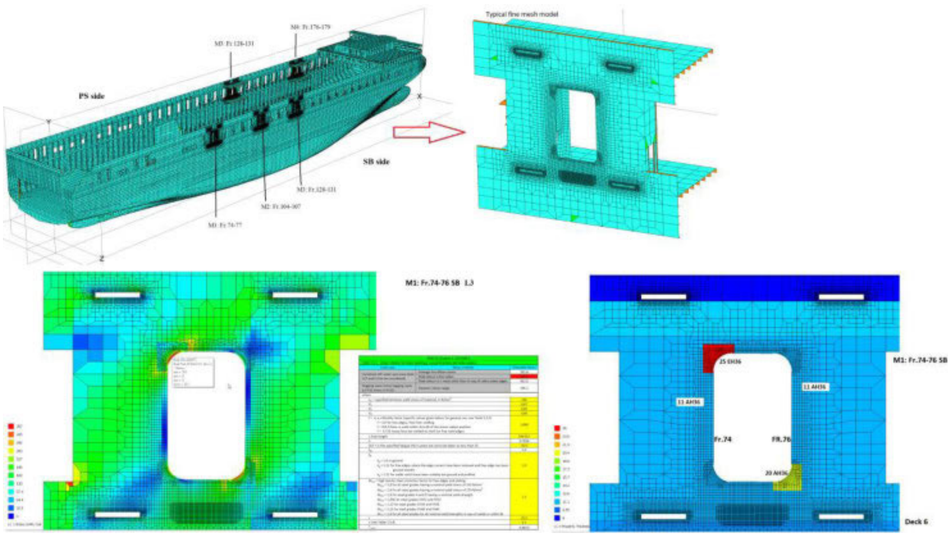


Figure 2. LR SDA Part B – Details of side shell openings between Deck 6 and Deck 8

4. CONCLUSIONS

The implemented methodology and developed structural design tools enable efficient structural analysis and redesign of complex RO-RO ship structure. Performed task served as a basis for the final scantling determination and finalization of classification drawings.

References:

[1] LR. 2012. ShipRight, Structural Design Assessment-SDA: Primary Structure of Ro-Ro Ships, March 2012.

[2] MAESTRO Version 11.5. 2018. Program Documentation.

Marine Engineering, Automation and Equipment of Vessels and Offshore Structures

Reduced Order Model of Airflow in a Room with Multiple Swirl Diffusers

Dario Pupić *[1], Darko Smoljan [2]

[1, 2] University of Zagreb,
Faculty of Mechanical Engineering and Naval Architecture,
Ivana Lučića 5. 10000 Zagreb, Croatia
(E-mail: dario.pupic@fsb.hr, darko.smoljan@fsb.hr)

Keywords: *Reduced order model (ROM), computational fluid dynamics (CFD), swirl diffuser*

Abstract: As part of a broader study on optimal control of ventilation systems based on ROMs for ventilation effectiveness and thermal comfort assessment, a linear ROM was constructed to reproduce the airflow described by the numerical model in a shorter time period. The simulations were performed on the example of a room with two swirl air diffusers. The accuracy of the ROM was assessed in comparison with the CFD results.

INTRODUCTION

Nowadays, CFD has become an inevitable tool for airflow estimation in a room with a ventilation system [1]. Many studies have shown that CFD can reliably describe airflow inside a room [2]. However, the biggest disadvantage of this method is the time required to conduct simulations [3]. Simulation time can be reduced with ROMs which determine the dominant airflow modes based on several numerical simulations [4]. However, the question arises as to the accuracy of ROM [5].

METHODOLOGY

Linear ROM was used to reproduce the velocity field determined by CFD in the example of a room with two swirl diffusers at a distance of 3.6 m. A polyhedral numerical mesh of 5500000 elements was used in all conducted simulations. The airflow is described as isothermal. Residuals of the order of 10^{-5} were adopted as the convergence criterion. Kω-SST turbulence model was used. A total of 12 CFD simulations were performed with different velocities at the diffuser inlet ranging from 1 to 4 m/s. Eight simulations were used for snapshot generation and 4 for ROM testing. Singular value decomposition was used to determine POD modes from previously generated snapshots. Reduced order model was obtained with Galerkin projection of the original system in space spanned by the 8 dominant modes.

RESULTS AND DISCUSSION

Once the data was generated with CFD, the ROM training and testing period lasted only a few minutes. The computation time was reduced from 2 h (CFD) to 2 s (ROM). From contours of velocity (Figure 1) it can be seen that the ROM accurately describes airflow between two swirl diffusers. Velocity profiles were also compared at 4 distances (a) from the ceiling in the middle between two air diffusers (Figure 2).

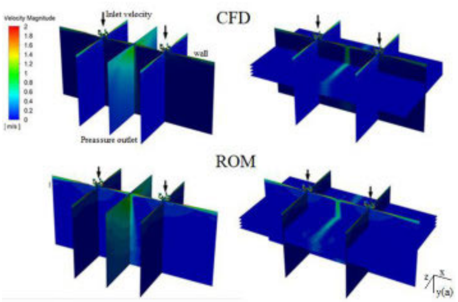


Figure 1. Velocity contours (0-2 m/s)

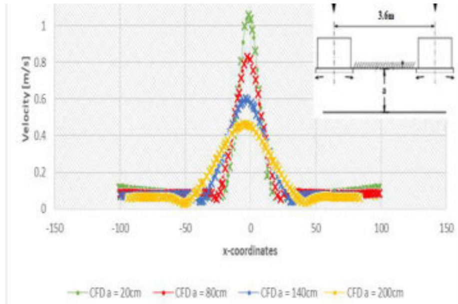


Figure 2. Velocity profiles for 3.342 m/s inlet velocity

The maximum velocity error calculated with ROM compared to CFD (within the whole domain) was found to be 0.17%.

CONCLUSIONS

Linear ROM can accurately reproduce results of a three-dimensional isothermal flow in a room with swirl diffusers for a wide range of flow rate at the diffuser inlet. The study will be continued on a model with a larger number of input parameters on the example of multicomponent non-isothermal flow.

References:

[1] X. Shan and W. Z. Lu, "An integrated approach to evaluate thermal comfort in air conditioned large-space office," *Sci. Technol. Built Environ.*, vol. 27, no. 4, pp. 436–450, 2020, doi: 10.1080/23744731.2020.1796420.

[2] M. A. Aziz, I. A. M. Gad, E. S. F. A. Mohammed, and R. H. Mohammed, "Experimental and numerical study of influence of air ceiling diffusers on room air flow characteristics," *Energy Build.*, vol. 55, pp. 738–746, 2012, doi: 10.1016/j.enbuild.2012.09.027.

[3] N. Morozova, F. X. Trias, R. Capdevila, C. D. Pérez-Segarra, and A. Oliva, "On the feasibility of affordable high-fidelity CFD simulations for indoor environment design and control," *Build. Environ.*, vol. 184, no. August, 2020, doi: 10.1016/j.buildenv.2020.107144.

[4] S. J. Cao and J. Meyers, "On the construction and use of linear low-dimensional ventilation models," *Indoor Air*, vol. 22, no. 5, pp. 427–441, 2012, doi: 10.1111/j.1600-0668.2012.00771.x.

[5] Z. Feng, C. W. Yu, and S. J. Cao, "Fast prediction for indoor environment: Models assessment," *Indoor and Built Environment*, vol. 28, no. 6. SAGE Publications Ltd, pp. 727–730, Jul. 01, 2019. doi: 10.1177/1420326X19852450.

Test Rig for Validating of the Marine Sliding Bearings Properties

Nenad Vulić*, Liane Roldo

Faculty of Maritime Studies,
University of Split, CROATIA.
(e-mail: nenad.vulic@pfst.hr, lroldo@pfst.hr)

Keywords: *Marine Shafting, Oil or Water Lubricant, Metallic Bearings, Polymer Bearings*

Abstract: This study presents the newly established laboratory at the Faculty of Maritime Studies in Split called TEMPOLab – Laboratory for Testing of Engineering Materials and Products. At present, TEMPOLab consists mainly of a machine facility for validating the mechanical properties of radial and thrust plain bearings for ship shafts. The central component is the instrumented test rig. Measurable quantities, i.e. pressures, displacements, temperatures, power, rotational speed, flow, particles class comprise the necessary information to validate lubricant and other properties of the test bearing.

1. INTRODUCTION

Static and dynamic mechanical responses of marine propulsion shafting highly depend upon the elastic properties of its sliding bearings, as well as their type of lubrication and lubricant. Shaft journal, lubricant layer and the sliding bearing itself express significantly nonlinear behavior. Consequently, the related research based upon modern numerical methods necessary to model hydrodynamic or elasto-hydrodynamic bearing properties is very comprehensive and demanding, requiring proper and reliable experimental validation [1]. This need for exhaustive validation explains the rationale for entering the project with the aim to develop and build up the test rig for sliding bearings of radial and axial type implemented in marine shafting.

The sliding bearings test rig has been developed as the prototype by the local design engineering office in Split, Croatia, on the basis of technical specification requirements imposed by the Faculty of Maritime Studies. The rig parts and components have been produced by several domestic and foreign manufacturers. The aim of this extended abstract is to briefly describe the rig itself and its capabilities, with a very short reflection to its configurational layout.

2. MATERIAL, METHODS AND RESULTS

The concept of the test rig has been developed in modular form, implementing principles of methodical design. The most important modules are: bed plate, driving module, transmission module, support module, loading module and test bearing module. The rig is primarily intended for testing of radial plain bearings supported as intermediate shaft bearings (simple beam concept) or stern tube bearings (overhang concept). Test bearings are either metallic (Babbit metal with oil) or polymer (water or sea water lubrication). The basic quantities it is capable to measure have been shown in Table 1.

Table 1. Basic measurement quantities of the sliding bearings test rig.

Measurement quantity	Measurement means	Measurement precision
Lubricant pressure	Pressure sensors	Precision class 1
Journal position	Capacitive sensors	±2 μm
Bearing temperature	Temperature sensors	±0.5ºC
Lubricant flow	Flow meter	Precision class max. 1
Frictional torque	Force probe	Precision class max. 2
Power loss	From torque and speed	Precision class max. 0.4

The results are presented just in form of the photo of the actual test rig (Figure 1) after its successful assembly and testing in every configuration and layout of the rig modules.

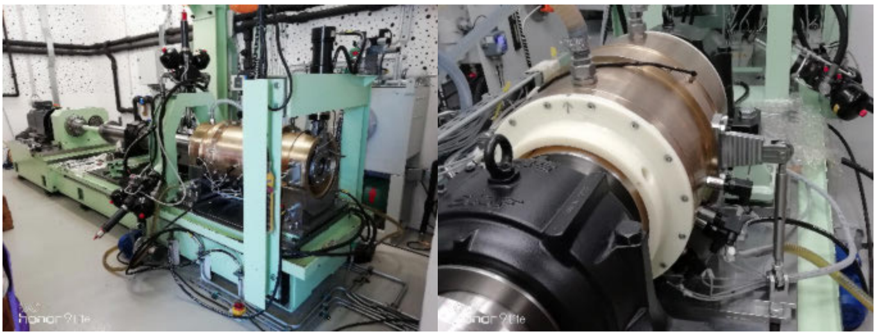


Figure 1. Test rig overhang layout and the test module details in the simple beam layout

3. CONCLUSION

The test rig for sliding bearings is intended for the laboratory validation of the properties of marine propulsion shafting journal bearings in several layouts, bearing materials and lubrication concepts [2-4]. After successful commissioning of the rig, the TEMPOLab will apply to obtain the status of service supplier by an IACS class society.

Acknowledgment: The authors are grateful for the financial support of the EU through the funding of the project KK.01.1.1.02.00182.2.

References:

[1] ISO 6281:2020Plain bearings – Testing under conditions of hydrodynamic and mixed lubrication in test rigs, International Organization for Standardization, Geneva, 2020

[2] Vulić, N., Komar, I., Design specification background for the sliding bearings instrumented test rig, 19th ICTS 2022, May 23rd-24th 2022, Portorož.

[3] Roldo, L., Vulić, N., Instrumented test rig: Analysis of the procedure to test radial bearings and related components, 19th ICTS 2022, May 23rd-24th 2022, Portorož.

[4] Pavlović, I., Roldo, L., Dobrota, Đ., Selection of proper theoretical numerical model to describe the behavior in lubricant layer of radial plain bearings, 19th ICTS 2022, May 23rd-24th 2022, Portorož.

Thermodynamic Analysis of Liquified Natural Gas Supply for Dual Fuel Engines

Damjan Bator *, Danijel Zadravec, Nenad Ferdelji

Faculty of Mechanical Engineering and Naval Architecture,
University of Zagreb, Croatia.
(E-mail: damjan.bator@fsb.hr, danijel.zadravec@fsb.hr, nenad.ferdelji@fsb.hr)

Keywords: *Dual fuel engines, Fuel gas supply system, Liquefied natural gas, Thermodynamic analysis*

Abstract: Liquefied natural gas has recently become a desirable fuel in the maritime industry due to its lower emissions of pollutants compared to the other commonly used marine fuels. Dual fuel engines and steam boilers have been developed to utilize LNG stored on a ship. To meet their requirements, a fuel gas supply system is used to evaporate liquified gas and to achieve suitable gas flow, pressure and temperature. Main parts of the gas supply system are LNG tanks, heat exchangers, turbomachinery and piping. Multiple configurations of the gas supply systems are possible and different equipment can be used to obtain the required gas state. The goal of this work is to perform a thermodynamic analysis of several fuel gas supply system configurations.

1. INTRODUCTION

Liquefied natural gas (LNG) is increasingly used in the maritime industry to reduce the harmful pollutant emissions [1]. LNG is consumed on a ship in boilers and in dual fuel engines which can also use alternative fuel, if needed. The function of the LNG fuel gas supply system (FGSS) is to provide needed flow rate of gaseous fuel in the acceptable temperature and pressure range for the consumers [2]. Heat exchangers – evaporators, superheaters and pressure building units (PBU) are used for fuel regasification, temperature and pressure control [3]. Valves or rotary equipment – liquid pumps and gas compressors are used for the control of flow and pressure [4]. Some of the mentioned equipment can be combined or completely omitted [5], resulting in different system characteristics, which are compared in this work.

2. METHODOLOGY

Required fuel flow rates are calculated for different ship exploitation conditions. FGSS configurations using PBU or pump for LNG pressurization and gas valve or compressor for boil-off gas (BOG) handling are examined. Balance equations and thermodynamic models are used to model analyzed equipment. Characteristics of examined FGSS configurations are compared and evaluated.

3. RESULTS

Three FGSS configurations which can satisfy ship fuel demands are examined, as shown on Fig. 1. Use of PBU and gas valve leads to high tank pressures and temperatures, while a pump with a compressor can limit tank pressure rise. Combination of pump and gas valve results in gradual tank pressure rise. Benefits and disadvantages of analyzed FGSS depend on the expected ship exploitation conditions.

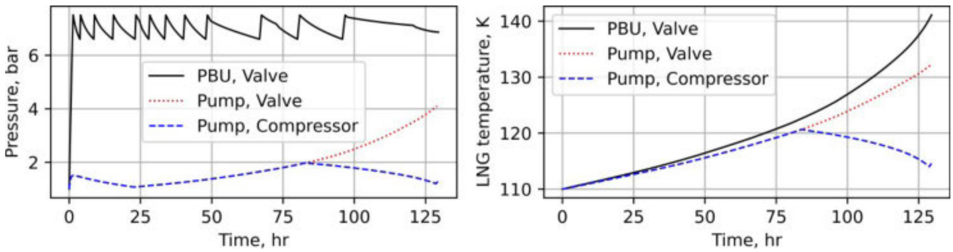


Figure 1. Simulation results for 3 FGSS configurations

4. CONCLUSIONS

Conducted thermodynamic analysis is a useful tool for the selection of ship FGSS configuration. Suitable configuration can be selected based on the expected ship parameters and external conditions, e. g. tank design pressure, BOG utilization capacity and voyage duration. Research can be extended to the variety of possible systems, conditions and ship configurations.

Acknowledgement: This research is supported by the Project "Competence Center for Advanced Mobility" DIV GROUP d.o.o. – Development of LNG system for ships powered by dual fuel engines.

References:

[1] Thomson H., Corbett J. J., Winebrake J. J., Natural gas as a marine fuel, Energy Policy. Vol 87, 2015, pp. 153–167

[2] Wang C., Ju Y., Fu Y., Comparative life cycle cost analysis of low pressure fuel gas supply systems for LNG fueled ships. Energy, Vol. 218, 2021, 119541.

[3] Wang Z., Cai W., Han F., Ji Y., Li W., Sundén B., Feasibility study on a novel heat exchanger network for cryogenic liquid regasification with cooling capacity recovery: Theoretical and experimental assessments. Energy. Vol. 181, 2019, pp. 771–781.

[4] Seo S., Chu B., Noh Y., Jang W., Lee S., Seo Y., Chang D., An economic evaluation of operating expenditures for LNG fuel gas supply systems onboard ocean-going ships considering availability. Ships Offshore Struct., Vol. 11, No. 2, 2016, pp. 213– 223

[5] Chorowski M., Duda P., Polinski J., Skrzypacz J.. LNG systems for natural gas propelled ships, IOP Conf Ser Mater Sci Eng. Vol. 101, No. 1, 2015

An Overview of Maintenance Procedures for Ship Machinery

Ivana Jovanović *[1], Nikola Vladimir [1], Maja Perčić [1], Marija Koričan [1]

[1] University of Zagreb,
Faculty of Mechanical Engineering and Naval Architecture, CROATIA.
(E-mail: ivana.jovanovic@fsb.hr, nikola.vladimir@fsb.hr, maja.percic@fsb.hr, marija.korican@fsb.hr)

Keywords: *Ship maintenance; reliability; preventive maintenance; predictive maintenance; condition based maintenance*

Abstract: In recent years, the ship maintenance has significantly evolved to increase both the safety and environmental protection. Bearing in mind that the number of crew and engineers on board has been reduced drastically and that maintenance requires significant effort (manpower, time, money, etc.) the development of a maintenance plan came to be useful. Ship maintenance accounts for 20-30% of a ship's operational costs and is related to unexpected breakdowns, repairs, loss of operational availability, and consequently revenue. Generally, maintenance procedures can be divided into corrective, preventive, condition based, and reliability centred maintenance. Preventive and condition based maintenance procedures are under continuous development by employing various tools and technological advancements aiming to detect upcoming failures before they occur thus increasing reliability and reducing costs. This paper brings out an overview of recent developments in maintenance procedures and outlines their advantages and drawbacks.

1. INTRODUCTION

According to the British Standards (BS) maintenance is defined as "the combination of all technical and administrative actions, including supervision actions, intended to retain an item in, or restore it to, a state in which it can perform a required action". Main objectives of maintenance are prevention of breakdowns, production improvement, downtime reduction, safety improvement, total costs reduction, extension of equipment lifetime, and prevention of environmental pollution [1]. Currently maintenance is rapidly advancing and adopting practices from data analytics and artificial intelligence (AI).

2. AN OVERVIEW OF MAINTENANCE PROCEDURES

There are three basic types of maintenance procedures: i) Corrective Maintenance (CM), ii) Preventive Maintenance (PM), iii) Predictive Maintenance (PdM). CM as oldest and simplest maintenance concept, known as run-to-fail, nowadays can only be used on non-critical auxiliary systems, where the risk of failure is low [2]. Aim of PM, as task-oriented and structured concept, is to minimise failure and can include visual inspections, testing, servicing and replacements [3]. PdM, most recent concept, aims to minimise failures with pre-scheduling the maintenance based on equipment state determined with data collection and non-destructive testing [3]. Comparison of basic concepts is illustrated on Figure 1.

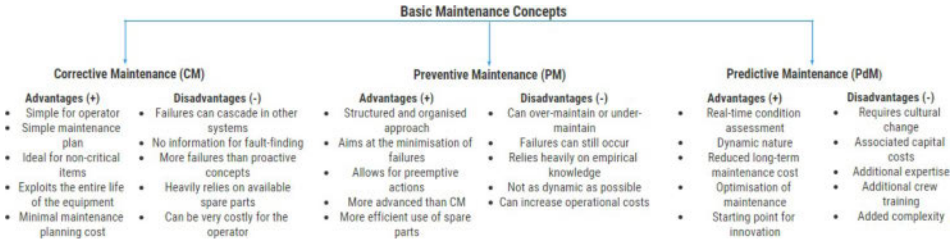


Figure 1. Basic maintenance concepts advantages and disadvantages

Several different maintenance frameworks are applied in maritime industry, however Condition Based Maintenance (CBM), Reliability Centered Maintenance (RCM), Total Productive Maintenance (TPM), and Business Centered Maintenance (BCM) are the most popular in terms of application. CBM integrates data collection techniques with fault detection, diagnostic and prognostic modules, to obtain relevant real-time condition-describing parameters. CBM can reduce maintenance costs for up to 30% and reduce unexpected failures by up to 70% [4]. RCM is focused on the reliability of components as function of their condition meaning that by increasing safety and reliability maintenance costs are minimised [5].

3. CONCLUIDNG REMARKS

Maintenance and reliability are interlinked. High-quality maintenance improves the operational reliability and high reliability results in low maintenance cost. Considering advantages and disadvantages of maintenance concepts, PM is the best approach closely followed by PdM, thus leaving outdated CM approach and increasing overall ship system reliability and safety. When considering maintenance frameworks, CBM outperforms the remaining frameworks.

Acknowledgment: This research was funded by the Croatian Science Foundation under the project Green Modular Passenger Vessel for Mediterranean (GRiMM), (Project No. UIP-2017-05-1253).

References:

1. Kobbacy, Khairy A.H (2008). Complex System Maintenance Handbook. 1st. New Jersey: Springer. isbn: 9781848000100.
2. Fang, Liu and Huang Zhaodong (2015). "System Dynamics Based Simulation Approach on Corrective Maintenance Cost of Aviation Equipments". In: Procedia Engineering. Vol. 99. Elsevier Ltd, pp. 150–155. doi: 10.1016/j.proeng.2014.12.519.
3. Garg, Amik and S. G. Deshmukh (2006). "Maintenance management: Literature review and directions". In: Journal of Quality in Maintenance Engineering 12.3, pp. 205–238. issn: 13552511. doi: 10.1108/13552510610685075.
4. Prajapati, Ashok, James Bechtel, and Subramaniam Ganesan (2012). "Condition based maintenance: A survey". In: Journal of Quality in Maintenance Engineering 18.4, pp. 384– 400. issn: 13552511. doi: 10.1108/13552511211281552.
5. Selvik, J. T. and T. Aven (Feb. 2011). "A framework for reliability and risk centered maintenance". In: Reliability Engineering and System Safety 96.2, pp. 324–331. issn: 09518320. doi: 10.1016/j.ress.2010.08.001.

SORTA

25th SYMPOSIUM ON THE THEORY AND PRACTICE OF SHIPBUILDING 2022

07 – 10 September 2022, Malinska – Croatia

Design of Vessels and Offshore Structures, Safety and Offshore Engineering

Site Condition Assessment and Design Basis – Getting the Basics Right for a Successful Offshore Wind Project

Neil Morgan [1], Ivan Bubic [2], Gianpaolo Dalla *[3]

[1] Technical Support Office, Lloyd's Register EMEA, United Kingdom.
(E-mail: neil.morgan@lr.org)

[2] Marine and Offshore, Lloyd's Register EMEA, Croatia.
(E-mail: Ivan.Bubic@lr.org)

[3] Marine and Offshore, Lloyd's Register EMEA, Italy.
(E-mail: Gianpaolo.DallaVedova@lr.org)

Keywords: *certification; design basis; offshore wind; site conditions*

Abstract: Effective site condition assessment and definition of a design basis are key to the successful execution of an offshore wind project (fixed or floating). The presentation/paper will look at what is needed for a site condition assessment and how that data is then used through the design process and into service life of the assets. It will describe the requirements of site condition assessment in relation to industry project certification requirements (e.g. IEC/IECRE). The presentation will then look at the design basis stage, which uses the site condition data, to select suitable engineering concepts for the identified project site and define the methodology to be used in the subsequent design phases. The presentation will look at the different stakeholders who have an interest in offshore wind projects and how their requirements should be considered at the definition stage of a project. The input of different engineering disciplines is considered including geotechnical, metocean, wind, structures and materials and real examples are used to illustrate why these initial stages of a wind farm project are vital to all subsequent phases of wind farm development and service life.

1. INTRODUCTION

This presentation looks at the key steps of performing site condition assessment and developing a design basis. It considers different stakeholders who may have an interest in the project and uses real examples to illustrate the points raised.

2. PROJECT DEFINITION

To perform site condition assessment and to develop design basis effectively, it is important to define the project and to understand the project stakeholders at the outset and to consider them throughout the process. A project stakeholder may be considered as any organisation or person that has an interest in may assert a claim on the value of a project or have an interest in the project. In the context of an offshore wind projectthere are the developer and contractors as stakeholders, but also other external parties such as the fishing industry and wildlife concerns. An initial understanding of the project may be made from basic information about where the project is and what local experience there is. The requirements of the development through the lifecycle should be considered including during design, transport & installation, commissioning, operation and maintenance and end-of-life.

Once some assessment of project definition is concluded then this may guide the concepts that may be adopted for future engineering and what type and detail of site condition data is required. The project definition should be reconsidered throughout the development process to make sure it remains valid.

3. COLLECTION AND USE OF SITE CONDITION DATA

A required part of offshore wind development and certification is to collect site condition data including metocean, scour and marine conditions, earthquake conditions, geotechnical and geophysical information. Throughout future phases it is important that the available data is used effectively and it is ensured that the engineering concepts under consideration remain suitable given the knowledge of the site. The presentation looks at examples where site condition data was available but had not been used effectively within projects and this lead to project delays and increased costs.

4. DESIGN BASIS

The design basis should outline all of the parameters and methodology required for future design phases. It is important to define key assumptions that could have a big impact on the project if not properly defined at an early stage. Typically design basis part A contains the site condition data and employer requirements, design basis part B is provider by the wind turbine provider and design basis part C is developed by the support structure designer. Design Basis part C should interpret the site condition data for design and should recognize any hazards or particular issues on the site that require to be accounted for. The design basis should consider all lifecycle phases and the engineering concepts. Examples of design basis definition include scour, the use of jack-ups for installation, operation and maintenance and definition of design life.

5. CONCLUSIONS

The presentation will look at the importance of the early phases of offshore wind project development including project definition, site condition data collection and development of project design basis. It will provide some real-life examples to reinforce the points discussed.

Adriatic Blue-Green Oil Tanker Class

Dario Ban *[1]

[1] FESB, University of Split, CROATIA
(E-mail: darioban@fesb.hr)

Keywords: *oil tanker, green fuels, increased safety, environmental protection, Adriatic Sea*

Abstract: In the next period of time, the increase of the environmental stress in Adriatic Sea can be expected due to increase of traffic of oil and gas tankers with possible negative impacts on environment. Therefore, new class of Adriatic Blue-Green Oil Tanker is proposed in this paper with green fuels used for ship propulsion, and increased safety obtained by denser hull subdivision for improved Adriatic Sea environmental protection.

1. INTRODUCTION

The Adriatic Sea is becoming new fossil fuel hub for the Europe with increased traffic of oil and gas tankers. Nevertheless, this change is not followed by corresponding new regulations for the sea, with neglecting existing ones such as MARPOL and Barcelona Convention, with example of it shown in Figure 1 with illicit oil spills detected in European waters in the period from 2000 to 2004, [1].

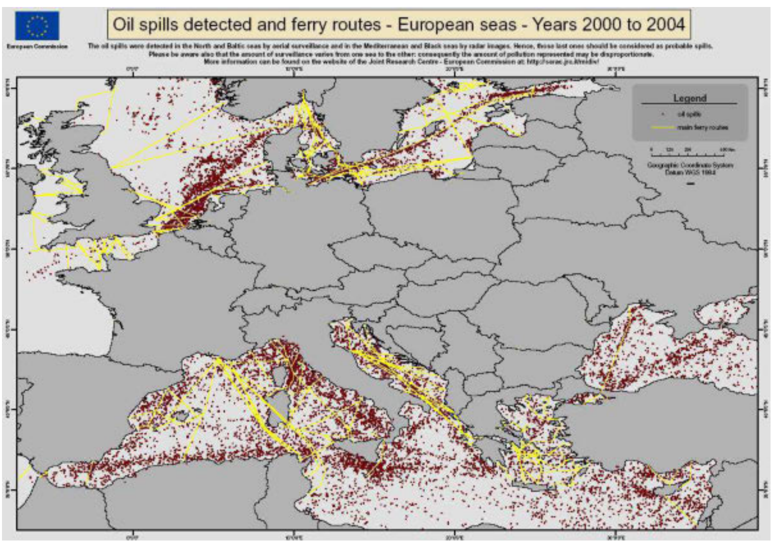


Figure 1. Detected Oil Spills in European Seas, [1]

The absence of concrete policies for environmental protection of the Adriatic Sea in the new political situation in the world could lower of safety levels that must be prevented by introducing new measures of sea protection, [2]. Therefore, new policy for environmental sea protection in Adriatic Sea should be established leaning on new agreement on exclusive economic zone between Republic of Croatia and Italy, [3], including new types of oil tanker ships for Adriatic Sea.

2. New Oil Tanker Class

The concept of new class of Adriatic Blue-Green Oil Tankers is given in this paper with deadweights from 10000 to 50000 tons and powered with green fuels. To increase maritime safety, the ship will have larger double skin for 1(m) then existing ships and twin propeller propulsion system with central bulkhead in the engine room, as shown in Figure 2.

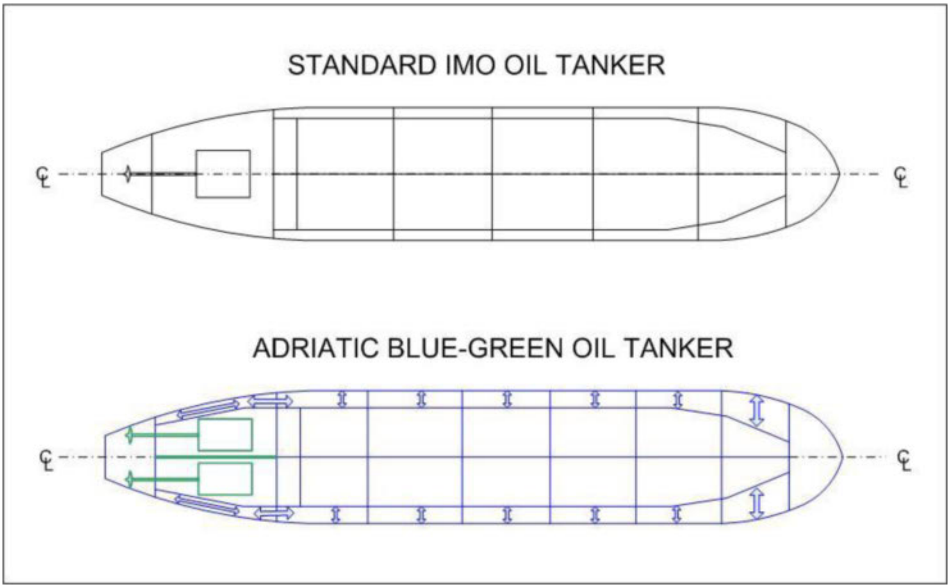


Figure 2. The comparison of standard IMO and Adriatic Blue-Green Oil Tanker

3. CONCLUSION

New blue-green oil tanker class for Adriatic Sea is proposed in this paper in order to increase maritime traffic safety as well as environmental sea protection with denser hull subdivision and usage of green fuels for ship propulsion.

References:

[1] European Commission, Joint Research Centre, 2009.

[2] Ban, D. Blue Book for Adriatic Sea: Croatian Shipbuilding Research Projects for Adriatic Sea until 2050, 2019.

[3] Agreement between Republic of Croatia and Italian Republic on Delimitation of Exclusive Economic Zones, 2022.

General and Structural Design of Floating Garage

Iva Klara Lajtner, Josip Luka Erhardt, Vedran Slapničar, Jerolim Andrić *

University of Zagreb,
Faculty of Mechanical Engineering and Naval Architecture, Zagreb, CROATIA.
(E-mail: jerolim.andric@fsb.hr , vedran.slapnicar@fsb.hr)

Keywords: *floating garage, conceptual general design, structural design, FEM analysis*

Abstract: To tackle the ever-growing need for parking of personal vehicles, a conceptual general design and structural design of a floating garage (for about 450 cars) has been presented. Structural design has been made in accordance with the rules of Det Norske Veritas classification society (DNV).

1. INTRODUCTION

Based on conceptual solution and calculations of the mass, vertical center of gravity and intact and damage stability was performed. A preliminary technical description was defined, from which the sprinkler system, the preliminary mooring and the energy calculation of the photovoltaic modules were analyzed in more detail. Garage planning includes determining the number of floors, layout and position of parking spaces, width of road lanes, organization of traffic flow with internal ramps for movement between floors and defining the outer ramp. To determine the optimal usability of the available parking space and ease of driving in the garage, several possible versions were considered, see Fig.1.

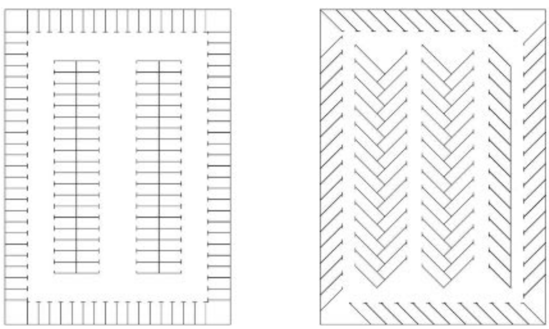


Figure 1. Parking lots with vertical and oblique arrangement of parking spaces

2. METHODOLOGY

Based on a brief study of garage optimal planning, regarding the maximum utilization of parking space a general arrangement plan of the garage was made on which the topological positions of primary supporting members, bulkheads and pillars was developed. For the proposed topology, the calculation of structural elements of cargo decks, pontoons and ramps considering local scantlings, was performed following DNV Rules [1] and [2]. Direct calculation based on global full ship FEM of the floating garage, has been performed using MAESTRO software, see Fig.2. It was basic for lightship mass calculation and more precise VCG determination.

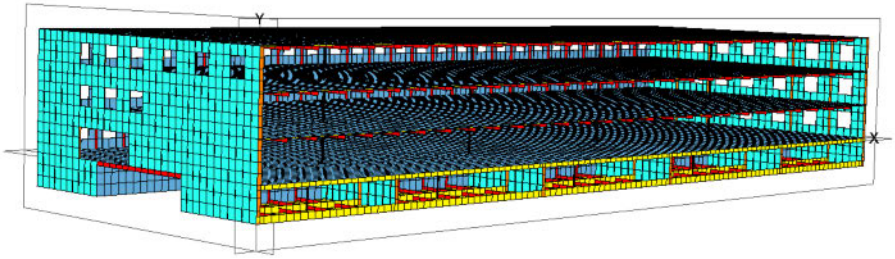


Figure 2. Full ship FE model, PS side

3. RESULTS

Several critical loading conditions has been used to formulate eight load cases used for the calculation of the structural response and final determination of all structural scantlings. Full-ship 3D FE model was used to provide results for global deformations and distribution of all component stresses. Determination of the structural feasibility (based on yield and buckling criteria) was done according to DNV safety factors and acceptance criteria in built in MAESTRO, see Fig.3.

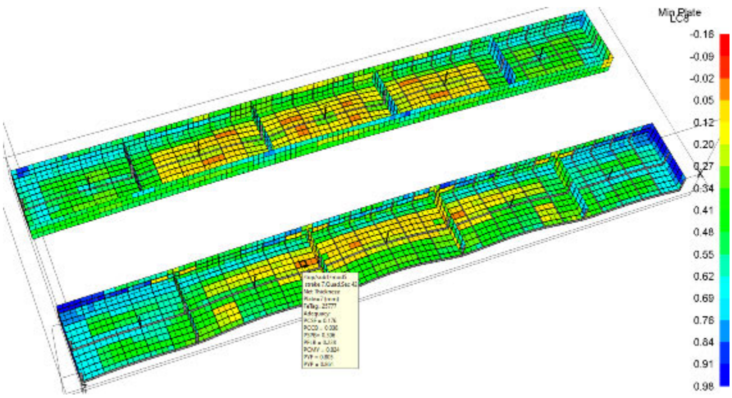


Figure 3. Wort of all adequacy criteria for bottom plating in LC8

4. CONCLUSIONS

Conceptual design of floating garage project has been shortly presented together with detail structural design based on direct FE calculation.

References:

[1] Det Norske Veritas: Rules for Classification of Ships, Part 3 Ch.1 Sec.12 Direct strength calculation, 2016.

[2] Det Norske Veritas: Class guideline, DNV-CG-0128, 2021.

[3] MAESTRO Version 11.5. 2018. Program Documentation.

Design of LNG Tank Type C

Helena Galić *, Vedran Slapničar, Smiljko Rudan

Faculty of Mechanical Engineering and Naval Architecture,
University of Zagreb, Croatia.
(E-mail: helena.galic@fsb.hr, vedran.slapnicar@fsb.hr, smiljko.rudan@fsb.hr)

Key words: *Classification rules; Dished end; Finite element analysis; Stiffening and vacuum rings; Tank type C*

Abstract: Cylindrical tank-type C is designed for cruise passenger ships trying to adopt hull space and to meet the requirements of propulsion. Tank must be a double shell with the vacuum space in between, which is also fulfilled with the perlite as insulation. The main input for the design was tank capacity of 430 m3, vapor pressure, and hull structure. Trying to satisfy volume capacity different dished end of tank was observed. According to classification rules, DNV and IGC rules tank thickness, supports, stiffening and vacuum rings are determined to satisfy bending and buckling requirements. Finite element analysis was used to verify the given results. According to the given results space for improvements of tank-type C was observed.

1. INTRODUCTION

International Maritime organization is requiring low emission of carbon dioxide, and due to that liquified natural gas is increasingly used in the maritime industry used as dual fuel. Tank type C is designed with the internal shell which must resist high internal pressure and the outer shell which has to satisfy buckling criteria. As today the price of the steel is increasing it is important to consider where cost reduction could be applied.

2. METHODOLOGY

According to DNV [1] and IGC [2] rules, analytical calculations were applied. FEM analysis was used to check primary and secondary stress during the pressure impact. Tank material properties are given in DNV rules and austenitic stainless steel 304L is used for the inside and outer shell. Annular insulation space with vacuum and perlite insulation is determined by satisfying of holding period of the Boil-off gas.

Step calculations procedures for the structure of Tank type C:

1. Pressure determination for inside and outside shell
2. Determination of thickness and vacuum rings for the outside shell
3. Section division of inner shell and combined internal liquid pressure calculations
4. Calculations of thickness segments of the internal shell
5. Determination of stiffener rings and supports for the internal shell.

Procedure for bending and buckling stress assessment:

1. Evaluation of the designed stress in the tank
2. Longitudinal, circumferential, and shear stress for inside tank
3. Calculation of critical buckling pressure.

3. CASE STUDY

To achieve maximum available volume for inside and outside shell torispherical dished end is used. In attendance to use the maximum with and length of shell plate, the tank is divided into segments shown in Figure 1. Each segment gives a different thickness. The smallest value of thickness is used for the outer shell and according to satisfied buckling criteria it is accepted, otherwise it should be increased also as a number of vacuum rings. One ring in the center of each saddle-support satisfied longitudinal and hoop stresses, and therefore it is accepted as that.

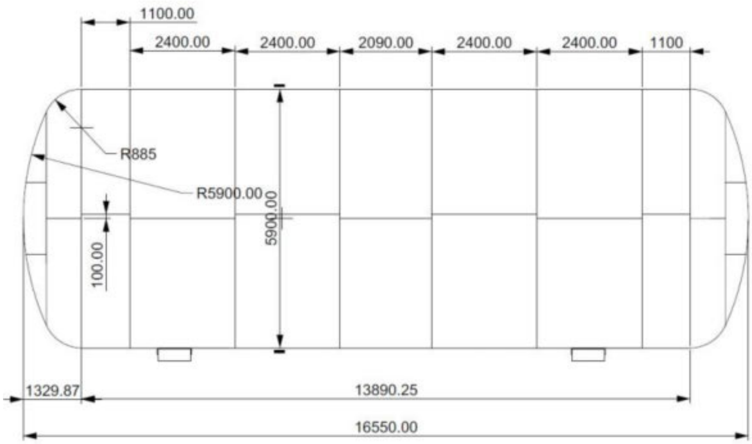


Figure 1. LNG tank type C segments for inner shell

4. CONCLUSIONS

Understanding of design procedure of LNG tank type C is important to reduce the cost material of structure by reducing the thickness of the tank shell. Another option to decrease the thickness for the same volume is changing the following parameters: diameter, length of the tank, and reducing demand for internal pressure which will satisfy the Boil-off gas.

Acknowledgment: The research is supported by ERDF, project IRI 5 – CEKOM DIV

References:

[1] DNV. 2016. Strength analysis of independent type C tanks

[2] IGC. 2016. The International Code of the Constructoin and Equipment of Ships Carrying Liquified Gasses in Bulk

Existing Floating Dock Part Extension to a Dewey Type 65000 t Floating Dock Initial Design

Luka Mudronja [1], Robert Grubiša [2], Marko Pirija *[3]

[1] Viktor Lenac Shipyard, CROATIA.
(E-mail: luka.mudronja@lenac.hr)

[2, 3] IHC Engineering Croatia d.o.o., CROATIA.
(E-mail: r.grubisa@royalihc.com, m.pirija@royalihc.com)

Keywords: *Dewey Type Floating Dock Extension, FE Analysis, Feasibility Study, Stability Analysis, Strength Analysis*

Abstract: In this paper, the initial design of a 65000 t design lifting capacity Dewey type [1] floating dock is presented. This envisioned extending the existing, 146.3 m long dock part, available to Viktor Lenac shipyard, by approximately 100 m in length. The project constraints are laid out as a starting point followed by the initial stability and strength calculations. This was done in terms of acquiring a solid base for a steel weight estimation that was found as a governing factor in the new floating dock cost estimation. The new floating dock also included a "self-docking" option and this was addressed in the design.

1. INTRODUCTION

The new dock is envisioned as a pontoon floating dock comprising of three separate parts with two parts connected with the overhanging wings to the central part. All of the dock parts needed to be designed in such a way that all of the dock parts could be "self-docked" for maintenance of the respective dock parts [1], [2]. The two newly added dock parts encompass the aft and forward section as shown in Figure 1.

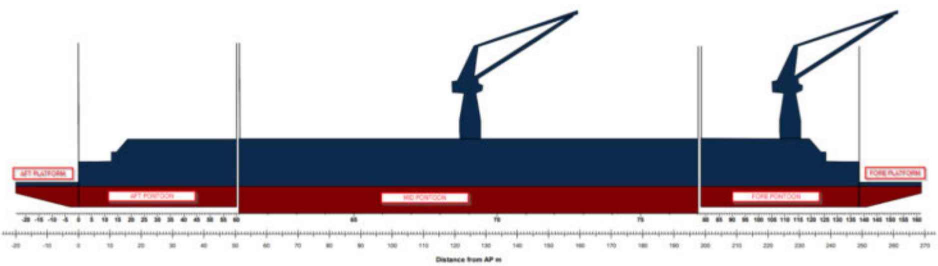


Figure 1. Floating Dock Characteristic Sub-division

The targeted assembled floating dock main particulars are given in the following table.

Table 1. Floating dock main dimensions and particulars

Particular	Dimension
Length overall	288.8 m
Length covered by docking blocks	270.0 m
Length over pontoons (between perpendiculars) Ld	248.8 m
Length of pontoons (aft / central / fore)	50.4 / 146.3 / 50.4 m
Breadth amidships	79.2 m
Max breadth (end pontoons)	90.0 m

2. METHODOLOGY

Given that the existing dock part is of American origin, built under ABS rules [3], these were referenced for the new dock design. DNV-GL rules [4] were referenced mostly for comparison purposes and introduction of longitudinal and transverse loading induced by the most severe loads transferred to the dock structure by the theoretical docked vessels. The environmental loadings were taken over from the longitudinal strength reports of one of shipyard's existing docks [5]. Local loadings for the central part were obtained from existing dock's operating manual while the operational loads indicated by Viktor Lenac Shipyard were cross checked versus these, as well as loadings on the added dock parts.

3. RESULTS AND DISCUSSION

The main results of this study were the confirmation of the intended, chosen Dewey type layout and the main particulars shown in Table 1. The preliminary weight estimation was also obtained as well as the conceptual layout of the assembled dock.

4. CONCLUSIONS

The study results lead to a conclusion that the existing dock part can withstand the introduced loading and that the newly designed parts shall also provide sufficient structural strength. Additional operational requirement, the "self-docking" of different dock parts was also assessed and found compliant.

References:

[1] Westmore, D., Types of Floating Dry-dock, Drydock Conference, San Diego, USA, 2011.

[2] Heger, R., Dockmaster's Training Manual, Heger Dry Dock Inc., 2018.

[3] American Bureau of Shipping, Rules for Building and Classification of Steel Floating Dry Docks, 2020.

[4] Det Norske Veritas, Rules for Classification of Floating Docks, 2015.

[5] Dok 11 – Proračun Uzdužne Čvrstoće na Valovima, Rijeka, Veljača 2002

Wave Measurement in the Adriatic Sea Using Floating Buoy

Tamara Petranović *[1], Ivana Gledić[2], Marko Katalinić[3], Petar Matić[3], Srđan Vujičić[2], Joško Parunov[1]

[1] Faculty of Mechanical Engineering and Naval Architecture,
University of Zagreb, CROATIA.
(E-mail: jparunov@fsb.hr, E-mail: igledic@fsb.hr, E-mail: tpetranovic@fsb.hr)

[2] Maritime Department,
University of Dubrovnik, CROATIA
(E-mail: srdjan.vujicic@unidu.hr)

[3] Faculty of Maritime Transportation,
University of Split, CROATIA
(E-mail: marko.katalinic@pfst.hr, E-mail: petar.matic@pfst.hr)

Keywords: *Adriatic Sea, waves, measurements, floating buoy, wave spectra*

Abstract: The paper describes two experimental campaigns of measurement of waves in the Adriatic Sea. Wave measurements are performed at two locations: one in the middle Adriatic Sea near Split and the other in the southern part of the Adriatic, near Dubrovnik. Measurements are performed using freely floating buoy in choppy seas. Measured wave elevation is subjected to spectral analysis to derive wave energy spectra. STRUREL software is used for that purpose. The aim of the study is to provide data for the future verification of the accuracy of the existing theoretical wave spectra for seakeeping calculations of marine structures in the Adriatic Sea.

1. INTRODUCTION

Estimating sea condition characteristics near a moving ship is a tough task that has recently been the focus of various studies. Mak and Düz (2019) used a ship as a wave buoy and applied machine learning to evaluate sea condition features from time series of 6-DOF ship motions. Piscopo et al. (2020) created a wave spectrum quasi approach for detecting sea condition parameters using onboard data of heave and pitch motion time series. Katalinić et al. (2022) took full-scale measurements of ship motion near Split to compare with seakeeping calculations to evaluate modeling uncertainties in ship response predictions. Since marine structures operate in the stochastic wave environment, the accurate modelling of the waves is challenging and of great interest of the international shipbuilding research community.

2. MEASUREMENTS

Measurements were performed at two different locations in the Adriatic Sea. The first measurement campaign was performed on February 10th, 2021 offshore Split, and the second one on November 5th, 2021 near Dubrovnik. Solar-powered floating buoy Sofar Ocean – Spotter is used for wave recording in real-time. The highest measured amplitudes of waves were 1.48 m near Split, and 1.32 m near Dubrovnik, which correspond to the moderate sea state 4 on the Douglas scale. Time series of recorded wave elevations are subjected to statistical analysis using the software STATREL, and the wave energy spectra are derived. Those wave energy spectra are compared to theoretical wave spectra and wave spectra calculated by the signal processing tool built on the floating buoy. An example of the comparison is given in Figure 1.

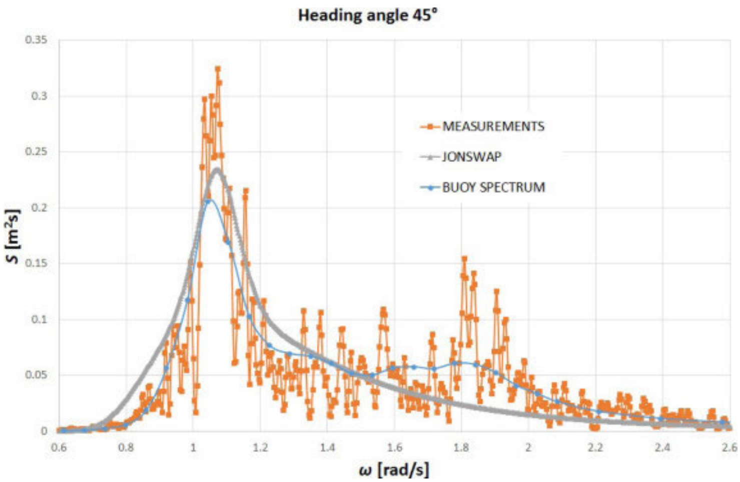


Figure 1. Example of derived wave spectra

3. CONCLUSION

Wave elevations were measured at the two locations in the Adriatic Sea, near Split and Dubrovnik. For wave recording, the floating buoy Sofar Ocean – Spotter was used. Software STATREL was used for statistical analysis of the time series of measured wave amplitudes. Wave energy spectra obtained through STATREL are compared to theoretical spectra and wave spectra from the floating buoy.

Acknowledgment: This work has been fully supported by Croatian Science Foundation under the project IP-2019-04-2085.

References:

[1] Mak, B. & Düz, B. 2019. Ship as a wave buoy – estimating relative wave direction from in-service ship motion measurements using machine learning. *Proceedings of the ASME 2019 38th International Conference on Ocean, Offshore & Arctic Engineering (OMAE 2019) June 9-14, Glasgow, Scotland, OMAE 2019-96201*

[2] Piscopo, V., Scamardella, A. & Gaglione, S. 2020. A new wave spectrum resembling procedure based on ship motion analysis. *Ocean Engineering* 201: 107137

[3] Katalinić M., Matić P., Petranović T. & Parunov J. 2022. Full-scale measurements of ship motion in rough seas in the Adriatic Sea. *Proceedings of the 6th International Conference on Maritime Technology and Engineering (MARTECH 2022, Lisbon, Portugal, 24-26 May 2022). CRC Press.* 10.1201/9781003320272

Reverse Engineering Methods in Deviation Measurements of Golden Horizon Masts

Ivana Željković [1], Ratko Mimica *[2], Ante Katić [3], Tina Celić [4]

[1] Brodosplit Institut , Put Supavla 21/B, 21000 Split, Croatia

[2] Brodosplit R&D ltd. , Put Supavla 21/B, 21000 Split, Croatia
(E-mail: ratko.mimica@brodosplit.hr)

[3] Brodosplit Interijeri, Put Supavla 21/B, 21000 Split, Croatia

[4] Brodosplit SPIK, Put Supavla 21/B, 21000 Split, Croatia

Keywords: *laser scanning, reverse engineering, mast deviation*

Abstract: Five masts and sundeck were scanned with laser. Scans were assembled and registered. 3d model of masts was reconstructed from a point cloud, aligned and compared with original 3d model provided by Brodosplit Project office.

1. INTRODUCTION

Reverse engineering methods formed and revised by Brodosplit during last year proved to be useful for different purposes, such as yacht hull reconstruction from laser scanning of its composite mold [1], procedure development for measuring ship's hull deviation from welding [2], CNC machining of anchor cradle based on anchor laser scans [3] and CNC machining of a sport boat supports based on its scans [4].

Recently Reverse engineering office was contacted by Brodosplit Plovidba regarding a problem with possible deviation of Golden Horizon masts (***Figure 1***).

Figure 1. Golden Horizon

2. METHODOLOGY

2.1 Laser scanning

For scanning process **FARO Focus 3D X130** was used, along with its tripod and reference spheres. Registration and data processing of a point cloud was made in **Faro SCENE** software. Reference model was provided by Brodosplit Project office (SPIK). After processing, point cloud was exported to **Rhinoceros 6** software.

3. RESULTS AND DISCUSSION

Main problem was proper alignment of point cloud, either in longitudinal (Center line) or transverse direction (starboard-portside). If alignment of point cloud in accordance to 3d model was not done properly there is a possibility that results would not be adequate.

Results suggest that the misalignment is rather significant for all masts except Mizzen. Middle mast shows significant deviation in portside direction, in addition with deviation in stern direction. Main mast deviates almost linearly in stern direction, while Jigger mast also deviates almost linearly but in bow direction. Interesting result is shown for Fore mast, which forms a C shape which could be seen by naked eye in ***Figure 1.***

4. CONCLUSION

Ship deck and masts were successfully scanned and registered.

Reverse engineering methods were proven useful in this kind of dimensional control, especially when no other alternative procedure was available at the time.

References:

[1] I. Željković et. al., Report: Laser scanning of composite yacht mold, scan editing and 3d model reconstruction, Brodosplit, July 2021.

[1] I. Željković et. al., Report: Measurement of ship hull deformations using 3D laser scanning, Brodosplit, August 2021.

[2] R. Mimica et. al., Report: Reverse engineering of an anchor cradle for ship Janssonius, Brodosplit, October 2021.

[3] R. Mimica et. al., Report: Reverse engineering in building supports for sport boat on Golden Horizon, Brodosplit, October 2021.

Measurement of Ship Hull Deformations Using 3D Laser Scanning

Ivana Željković *[1], Ratko Mimica [2], Ante Katić [3], Tina Celić [4]

[1] Brodosplit Institut , Put Supavla 21/B, 21000 Split, Croatia
(E-mail: ivana.zeljkovic@brodosplit.hr)

[2] Brodosplit R&D ltd. , Put Supavla 21/B, 21000 Split, Croatia

[3] Brodosplit Interijeri, Put Supavla 21/B, 21000 Split, Croatia

[4] Brodosplit SPIK, Put Supavla 21/B, 21000 Split, Croatia

Keywords: *laser scanning, reverse engineering, welding deformation,*

Abstract: This paper presents the methodology of reviewing ship's hull deformations using laser scanner recording and 3D model in three different ways. The optimal procedure for future tasks is established. Potential problems are detected and guidelines for setting up working procedure were recorded, all in interest to make Standard Operative Procedure (SOP) for measurement report with 3D laser scan.

1. INTRODUCTION

After latest scanning of ship's hull mold and reconstruction of its form [1], the question was raised, could it be possible to measure real deformations and compare it to the ''ideal'' 3D model and, if so, how to represent the results and make it usable in dimension control. Something similar was tried for pipe dimension control, as shown in paper [2], but the procedure wasn't developed any further. Ability of detecting deformations and correcting them on time is one of necessary pre-requirements in this kind of work contracting.

Hence, this paper will describe the methodology of scanning and comparing ideal vs. scanned object on ongoing Brodosplit project with the goal of making most use of available equipment for dimension control.

2. EQUIPMENT AND METHODS

Location of the object is 3rd loggia of NPH hall in the Brodosplit yard. The scanning object is scaffolded which later made difficulties when trying to create continuous surface.

Equipment required for scanning was **FARO Focus 3D X130** laser with its own tripod and reference balls.

Registration and data processing of a point cloud was made in **Faro SCENE** software. 3D model was exported from **Navisworks** program as **.fbx** file and also from **AVEVA Marine** module as **.stp** file. Model translation and rough point cloud alignment was done with **Rhinoceros 6**, while final alignment and comparison was made with **Cloud Compare** software.

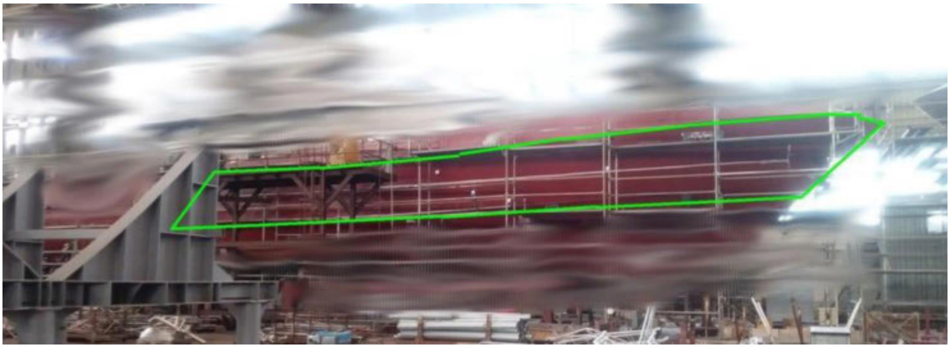


Figure 1. The object of scanning – the possibility of achieving continuous surface is inside green boundary

3. RESSULTS AND DISCUSSION

The part is composed of 2 rows of sheet metals in the upper levels of the hull. Crepe tape was glued in the middle of the scanned area. A part of the surface was sprayed. After surface preparation, 6 scans were made.

Deformation visualization of a scanned object is not possible without adequate 3D model. If 3D model is not available, the one most be ''raised up'' from 2D drafts or reconstructed from laser scan.

Before comparison, the recording is aligned, first roughly, afterwards with fine tuning. Rough alignment can be achieved in **Cloud Compare** with *Translate/Rotate* function till point cloud and model are in line.

Meeting was organized with the **SPIK** department to find a potential solution without reconstructing the surface in 3D modeling software.

4. CONCLUSIONS AND FURTHER ACTIONS

The paper investigates methodology for reviewing ship's hull deviations using terrestrial laser scanning and 3D model.

Comparison is performed with three different references: using refined **.fbx** format from **Navisworks,** comparing with reconstructed surface from **Rhino** and lastly with cleaned **.stp** format from **AVEVA Marine** module.

References:

[1] Ivana Željković et.al. Report: laser scanning of a composite mold for making yachts, image processing and 3D model making , Brodosplit 2021, internal document

[2] Ratko Mimica et.al. Record: Testing the capabilities of current equipment in order to generate virtual (VR) and augmented (AR) reality for the needs of Brodosplit shipyard, Brodosplit 2021, internal document

[3] Ante Katić, Ratko Mimica, Standard Operating Procedure: Scanned images to a point cloud registration, Brodosplit 2021, internal document

[4] Ratko Mimica, Ante Katić, Standard Operating Procedure: Converting refined point cloud to mesh in Cloud Compare, Brodosplit 2021, internal document

Innovative Developments in the Croatian Mariculture Within the Intel-Maric Project

Tena Bujas *[1], Nikola Vladimir [1], Marija Koričan [1], Vladimir Soldo [1], Zdenko Tonković [1], Manuela Vukić [1]

[1] University of Zagreb,
Faculty of Mechanical Engineering and Naval Architecture
(UNIZAG FSB), CROATIA
(E-mail: tena.bujas@fsb.hr)

Keywords: *INTEL-MARIC, Mariculture, Sustainability, Technology foresight*

Abstract: The rapid development of aquaculture production at the global level is the result of higher demand, modernization, and innovation. Simultaneously, the demand for more food production has a big impact on the environmental footprint. The design environment for aquaculture plants becomes ever complex since it is necessary to consider technical, economic, environmental, and social issues. This paper introduces the research background and activities of the INTEL-MARIC (The research center for INTELligent, innovative, environmentally friendly, and sustainable MARICulture) project, that is being implemented at UNIZAG FSB. Within the project, an advanced multidisciplinary research center has been founded, where important problems inherent to the sustainable development of Croatian mariculture are dealt with. The research background of the center associated with the state-of-the-art in the Croatian aquaculture related to energy needs, production, revenue, and environmental impact is elaborated and predictions for future development are discussed. Consequently, a set of technical solutions and methods which should meet future requirements is reviewed.

1. INTRODUCTION

The aquaculture industry has become one of the world's fastest-growing industries. It produces aquatic animals such as fish, crustaceans, molluscs, and aquatic plants [1]. According to [2], aquaculture in the world has reached 85 million t in 2019. In Croatia, the most common species in mariculture are Atlantic blue tuna, sea bream, sea bass, mussels, and ostriches [3]. Significant improvements have been made with this biotechnological approach, but it is primarily related to the quality of breeding of existing species, the introduction of new breeding species, and the interaction of ecosystems and organisms. In [4], the authors used a model called DEXi Aqua for the assessment of sustainable aquaculture production and directly expressed the need for its further application as well as a need for future sustainability studies of aquaculture farms.

2. INTEL-MARIC ACTIVITIES

Organizational activities are aimed at establishing a research center that would serve to exchange knowledge and experiences in mariculture production. Through communication with stakeholders from the mariculture, data on technical problems are collected and discussions are held on possible solutions for the best possible production, with the lowest possible environmental impact. Technical activities include analysis of potential sites that are not currently exploited, analysis of energy potential and temperature profile in the Adriatic, and analysis of regulations. Determining mariculture zones by mapping relevant environmental data, allows the testing of highly sophisticated systems and the impact on the quality of cultivation. With data from sensors for water quality processed by mobile application, the producers will have a real time insight into critical parameters and will be able to perform preventive and corrective activities in a timely fashion. The analysis of greenhouse gas emissions, seawater quality, and total life costs will offer a pathway for mariculture in Croatia to be sustainable, considering three pillars of sustainability (social, economic, environmental). Preliminary analyses of implementation of Renewable Energy Sources (RES) in the mariculture farms indicate an emission reduction of about 20% and an increase in capital costs by only 0.61% [5]. However, within INTEL-MARIC, more detailed studies will be conducted, bearing in might high fluctuations in energy prices.

3. CONCLUSIONS

The aquaculture industry has a big opportunity for its development in Croatia. To become more competitive and sustainable, extensive interaction between all involved stakeholders is needed. This will be strengthened by recently established INTEL-MARIC research center, through a set of administrative and technical steps, based on the top-level research findings by the INTEL-MARIC team.

Acknowledgment: This research is funded by the European Maritime and Fisheries Fund of the European Union within the project "INTEL-MARIC", granted by the Ministry of Agriculture, Directorate of Fisheries, Republic of Croatia [Award No. 324-01/21-01/385].

References:

[1] Food and Agriculture Organization, https://www.fao.org/3/x6941e/x6941e04.htm (Accessed: 7th of July 2022).

[2] Food and Agriculture Organization, 2021. *FAO Yearbook. Fishery and Aquaculture Statistics 2019*, Rome, Italy

[3] Volarić, H., Kolanović, I., Poletan Jugović, T. Current situation and development prospects for mariculture in the Republic of Croatia, International Scientific Journal "Science. Business. Society", Vol 4, Issue 4, P.P. 127-130, 2019.

[4] Le Féon, S., Dubois, T., Jaeger, C., Wilfart, A., Akkal-Corfini, N., Bacenetti, J., Costantini, M., Aubin, J., DEXiAqua, a Model to Assess the Sustainability of Aquaculture Systems: Methodological Development and Application to a French Salmon Farm, Sustainability 13, 7779, 2021.

[5] Koričan, M., Perčić, M., Vladimir, N., Soldo, V., Jovanović, I. Environmental and economic assessment of mariculture systems using a high share of renewable energy sources, *Journal of Cleaner Production*, 333, 130072, 2022.

Power Output Estimation of Oscillating Surge Wave Energy Converter

Ivan Ćatipović *[1], Robert Orlović [1], Neven Alujević [1], Vedran Slapničar [1]

[1] University of Zagreb,
Faculty of Mechanical Engineering and Naval Architecture, Croatia
(E-mail: ivan.catipovic@fsb.hr, ro205961@stud.fsb.hr, nalujevic@fsb.hr, vslapnic@fsb.hr)

Keywords: *Boundary element method, Power output, Wave energy converter*

Abstract: This study focuses on estimating the power output of an oscillating surge wave energy converter (WEC) for a given sea state. The central part of the converter is a flap plate that is connected to a power take-off (PTO) system. The hydrodynamic of the plate is solved in the frequency domain with boundary element method (BEM). The estimation of the power output is based on the plate's obtained velocities i.e. on response amplitude operators (RAO) of the oscillating velocity.

1. INTRODUCTION

The energy of the waves varies between 30 and 70 kW/m in the most energy-rich areas. The highest amount of 100 kW/m can be found in the Atlantic. Therefore, due to the natural potential of waves, the production of electricity from sea waves has found its use today. This paper is concerned with an oscillating surge WEC also known as a flap type WEC. The central part of the converter is a plate that is moved by waves back and forth, i.e. the palate is oscillating in a surge direction, [1]. The plate is usually connected with the seabed by a hinge joint. This study provides an approach for estimating the WEC movements and the power transferred to the associated PTO.

2. MATHEMATICAL MODEL

BEM and the potential flow theory model the fluid flow. The motion equation of the WEC is solved in the frequency domain. The special stiffness matrix is introduced to the equation to model the hinge joint, so the plate has only one degree of freedom, i.e. a rotation around the joint, [2]. For the rotation velocity, an RAO is obtained, and the velocity response spectrum is calculated for a given sea state. The damping coefficient in the model considers the PTO and should be set to maximize the power output, [1]. Finally, the power output is approximated based on the damping, the response spectrum area, and the efficiency of the PTO, [2].

3. CASE STUDY

The case study is based on the WEC that has been researched in [1]. HydroStar (Bureau Veritas) is used for the motion analysis under irregular waves described by JONSWAP spectrum. The oscillating plate is modeled as a cuboid with dimensions 25 × 17.5 × 1 m. The BEM model is presented in Figure 1. The damping is set to 1.36×10^8 kg m/s and PTO efficiency is assumed as 82.5%. A part of obtained numerical results are presented in Table 1 related to significant wave height Hs and wave directions β. The table gives the power capture P estimated on the motions of the WEC and the effective power output Pe of the PTO.

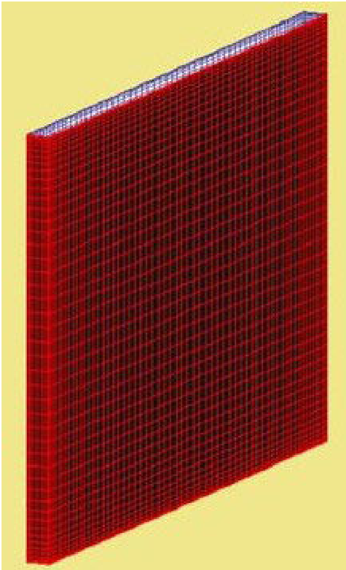


Figure 1. BEM model of WEC

Table 1. Power output the WEC

Hs, m	*β*, O	*P*, kW	P_e, kW
1.5	30	27.2	22.5
	40	29.9	24.7
	50	32.7	26.9
	60	35.6	29.3
	70	38.6	31.8
	80	41.8	34.4
	90	45.0	37.1
2.5	30	94.1	77.7
	40	103.3	85.3
	50	112.9	93.2
	60	122.9	101.5
	70	133.4	110.1
	80	144.3	119.1
	90	155.6	128.4

The obtained values of P_e are compared with the ones presented in [1] where the more advanced but more time-consuming methodology is used since being solved in the time domain. A fair agreement of the corresponding results was established, the relative devations are approximately 25%.

4. CONCLUSION

This study presented a power output estimation of oscillating surge wave energy converter based on BEM solved in the frequency domain. The presented approach provides a fast and efficient estimation of the power output that can be used in the preliminary design.

Acknowledgment: The Croatian Science Foundation HRZZ-IP-2019-04-5402 (DARS) support is gratefully acknowledged.

References:

[1] Yu, Y.-H., Jenne, D.S., Thresher, R., Copping, A., Geerlofs, S., Hanna, L.A. Reference Model 5 (RM5): Oscillating Surge Wave Energy Converter. National Renewable Energy Laboratory. Technical Report. NREL/TP-5000-62861. 2015.

[2] Orlović, R. Procjena izlazne snage kod proizvodnje električne energije iz morskih valova. Završni rad. Sveučilište u Zagrebu, Fakultet strojarstva i brodogradnje. 2021.

Virtual Ship Simulation and Commissioning

Rodrigo Pérez Fernández [1], Mirko Toman Fernández *[2]

[1] Universidad Politécnica de Madrid, Spain
(rodrigo.perez.fernandez@upm.es)

[2] SIEMENS DI SW, Madrid, Spain
(mirko.toman@siemens.com)

Keywords: *Digitalization, Simulation, Shipbuilding, Virtual Commissioning, Virtual Ship.*

Abstract: This paper is focuses on how Shipbuilders would implement the "Virtual Ship Simulation and Commissioning" with the objective to improve the quality and to reduce the delivery time for highly complex ships. We will review the importance of adopting and integrating virtual ship simulation and commissioning into the manufacturing process.

1. INTRODUCTION

Developing advanced ships is a formidable challenge, primarily because it requires managing immense amounts of information. Traditionally, shipbuilding teams needed to repeatedly sort through a single, hierarchical and vast data repository to access the required information, a painfully laborious and inefficient process. It has become apparent that shipbuilding teams must have the ability to create and manage the portion of the design and associated data such as requirements that is relevant to their specific task and responsibilities.

2. METHODOLOGY

Composites engineering and fastener management solutions for addressing the complex challenge of advanced composites engineering and fastener management. Software for composites engineering enables engineers to efficiently develop optimal designs by striking the appropriate balance between lighter weight, cost and performance. Using this tool provides rapid producibility assessments early in design to alleviate manufacturing issues and rework. As well as enables shipbuilders to reduce weight, tailor structural and multifunctional properties, and streamline and consolidate parts and assemblies, all of which has proved to reduce lifecycle costs while improving the performance of vessels.

3. RESULTS AND DISCUSSIONS

The integrated end-to-end process for structures leverages simulation throughout the product lifecycle to deliver innovative products on time and with predictable performance, such as: Reduce model preparation time by 70 percent, shorten design-analysis iterations, evaluate different structural design tradeoffs (number of frames, number of longitudinals, stringers...), Improve the quality of nonrecurring charges.

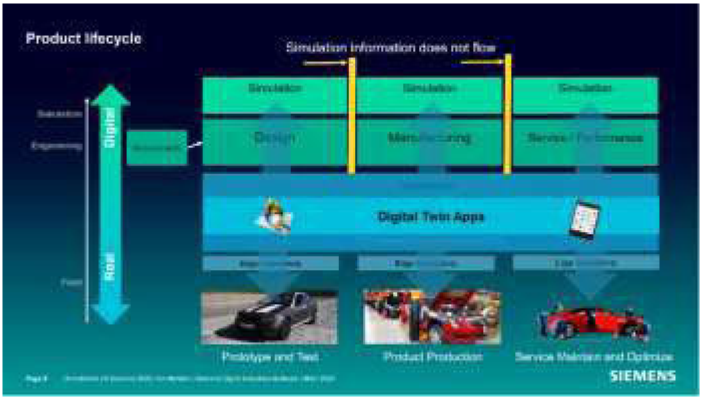


Figure 1. Product Lifecycle and Simulation flow

Most importantly, this shipbuilding technology can sync all designs and changes to every supplier and builder involved in the project, so no time is lost, and no inconsistencies find their way on board.

Shipbuilders can create digital models to simulate the entire fabrication process step-by-step until they reach an optimal process. The 3D modeling capabilities allow production teams to virtually inspect every component and every system on the ship to optimize material flow through shipyard, assembly and out to sea.

4. CONCLUSIONS

- Digitalization is key for sustainable shipping success
- Improvement focus: cost, speed and certainty
- Faster commitments with digital simulation
- Building a sustainable shipping business
- First-to-market breakthroughs
- Traceability and visibility
- More efficient and sustainable shipyards
- Digitalizing the shipping industry

Acknowledgment: The authors would like to express appreciation for the support of the sponsors: Jan Van Os and Viktor Braun.

References:

[1] Jan van Os, Digitalization is key for sustainable shipping success,

[2] Viktor Braun, SIEMENS Virtual commissioning for machine builders

[3] Alonso, V., Valderrama, A., & Matson, J. C. (2017). Innovative 3D Approach for the Basic/Class Design in a Remote Engineering Environment. SNAME

Lasersko skeniranje kompozitnog kalupa za izradu jahti, obrada snimki i izrada 3D modela

Ivana Željković [1], Ratko Mimica [2], Ante Katić [3], Tina Celić *[4]

[1] Brodosplit Institut , Put Supavla 21/B, 21000 Split, Croatia
(E-mail: tina.celic@brodosplit.hr)

[2] Brodosplit R&D ltd. , Put Supavla 21/B, 21000 Split, Croatia

[3] Brodosplit Interijeri, Put Supavla 21/B, 21000 Split, Croatia

[4] Brodosplit SPIK, Put Supavla 21/B, 21000 Split, Croatia

Ključne riječi: *povratno inženjerstvo, lasersko skeniranje, 3d rekonstruiranje,*

Sažetak: U ovom radu opisani su postupci od izvida terena do izrade modela broda na osnovi laserske snimke kompozitnog kalupa. Osim lasera za skeniranje, korišteni su i laseri za niveliranje te za kontrolu udaljenosti. Nakon skeniranja brod je obrađen u računalnom programu te je takav izvezen u drugi program u kojem su rekonstruirane nove linije broda. Obrađen je i dio najčešćih grešaka koje su primjećene, mogući razlozi nastanka istih i načini ispravljanja.

1. UVOD

Početkom godine od strane Fakulteta strojarstva i brodogradnje je poslan upit za potencijalnim skeniranjem kalupa broda. Brod je okvirne dužine oko 20tak metara, kalup je sastavljen od 4 dijela, dva dijela su bočne stranice trupa i dodatna dva dijela koja kompletiraju nadgrađe.

Cilj ovog rada je opisati korake skeniranja i obrade snimke, zabilježiti vremensko trajanje, pogreške i nedostatke pojedinih koraka koji će se kasnije koristiti za izradu SOP procesa laserskog skeniranja, te evidentirati potrebne radnje kod naknadne obrade snimke i modeliranja 3D objekta u software-u Rhinoceros.

2. IZVID TERENA

Cilj izvida je potvrda mogućnosti skeniranja, i u pogledu materijala skeniranja i mikrolokacijski.

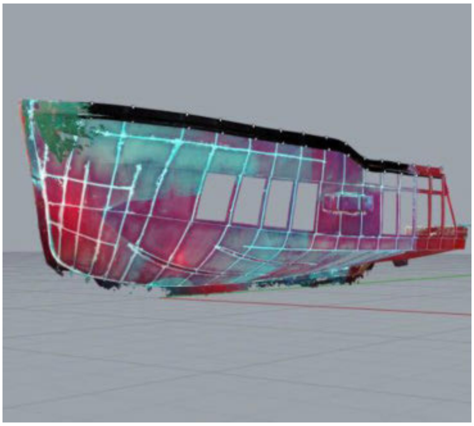
Osim samog skeniranja potrebno je sklopiti skenirane dijelove kalupa u jednu cjelinu te je kao takvu exportirati u formatu koji je primjeren CFD programima. Po zahtjevu naručetelja(FSB) osgovaraju formati *.3dm ili *.iges.

3. PRIPREMA I PROCES SKENIRANJA

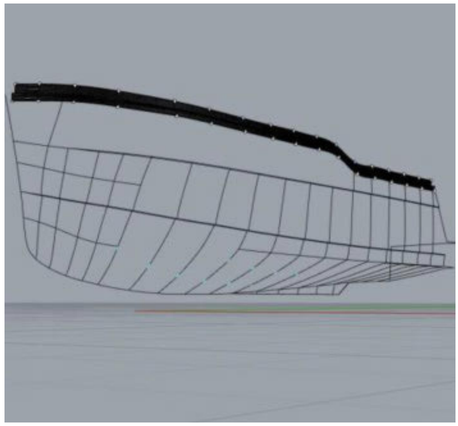
Na mjestu skeniranja – brodogradilište jahti Eastern Mediterranean u Vranjicu – lijevi i desni dio kalupa bili su razmaknuti i poravnati prema prijašnjim zahtjevima. Ostali dijelovi kalupa – nadgrađe i zadnji dio – nisu bili pripremljeni za skeniranje.

4. OBRADA SNIMKI

Svaka od snimki imala je cca od 17 do 20 milijuna registriranih točaka a ukupna veličina datoteka bila je 700 MB. Napravljena je registrirana snimka pune rezolucije sa oba kalupa za ogledni primjerak a zatim dvije datoteke lijevog i desnog kalupa, svaki veličine oko 50 MB tj. oko 2.5 milijuna točaka.



Slika 1. Izvučene konture i point cloud



Slika 2. Konture kalupa broda

5. ZAKLJUČCI

U radu je opisano 3D skeniranje laserskim skenerom kalupa jahte od kompozitnih materijala sa prethodnim i naknadnim koracima pripreme i obrade. Prikazan je postupak obrade dobivene snimke po koracima uz opis funkcija koje su se koristile. Obrađen je i dio najčešćih grešaka koje su primjećene, mogući razlozi nastanka istih i načini ispravljanja.

References:

[1] R.Mimica, A. Katić, Standardna Operativna Procedura: Pripremne radnje i skeniranje kalupa broda, standardna operativna procedura, srpanj 2021.

[1A] R.Mimica, A. Katić, I. Željković Standardna Operativna Procedura: Pripremne radnje i skeniranje kalupa broda – Check up lista, Prilog standardne operativne procedure, srpanj 2021.

[2] Zakrivljenost površina i Gaussova zakrivljenost: https://www.britannica.com/science/differential-geometry/Curvature-of- surfaces#ref235557 , 26.7.2021.

[3] Rhinoceros upute za korištenje: http://docs.mcneel.com/rhino/5/help/en- us/index.htm#commands/gumball.htm%3FTocPath%3DCommands%7CAlphabetical%7CG%7C____9 26.7.2021.

[4] Kreiranje solid-a u program Rhino-vodonepropusnost: https://digitalmedia.architecture.yale.edu/manual-model-repair-rhino, 26.7.2021.

Primjena programa otvorenog koda d3v za vizualizaciju i utvrđivanje karakteristika analitički zadane forme

Pero Prebeg *[1], Ivan Ćatipović [1] , Ivan Munić [1], Gordan Šikić [2], Luka J. Erhardt [1], Tomislav Pavlović [1], Ivan Oreč [1]

[1, 3, 4, 5] Sveučilište u Zagrebu,
Fakultet strojarstva i brodogradnje,
REPUBLIKA HRVATSKA.
(E-mail:pero.prebeg@fsb.hr)

[2] LINA ET AL,
REPUBLIKA HRVATSKA.
(E-mail: gordan.sikic@linaetal.eu)

Ključne riječi: *3D vizualizacija, analitički zadana forma, program otvorenog koda*

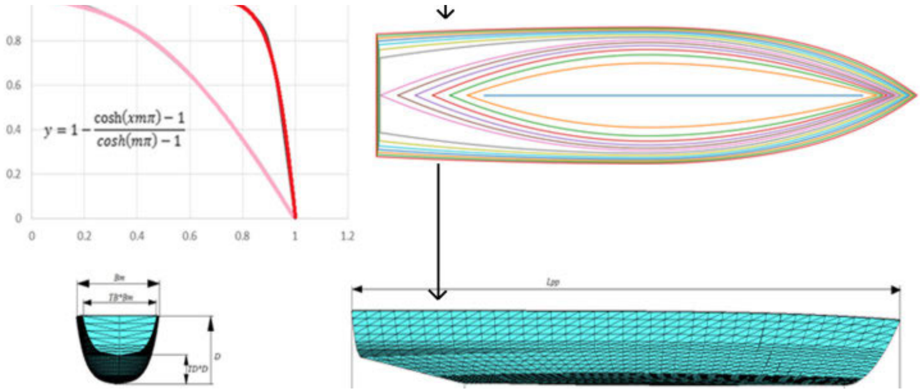
Sažetak: U ovome radu, proširenjem funkcionalnosti programa otvorenog koda d3v, omogućena je automatizirana promjena brodske forme, određivanje hidrostatičkih karakteristika, priprema mreže za proračun pomorstvenosti u programu HydroSTAR za analitički zadanu formu te vizualizacija projektnih građevnih blokova pri projektiranju.

1. UVOD

Analitičko zadavanje forme broda primjenjuje se u ranim fazama projektiranja broda jer omogućuje jednostavno modificiranje forme broda putem promjene manjeg broja parametara. Program otvorenog koda linaetal-fsb/d3v [1], omogućuje 3D vizualizaciju geometrijskih entiteta te jednostavno definiranje grafičkog sučelja za pojedina namjene, a napisan je u programskom jeziku Python. Povezivanjem analitički zadane forme i programa otvorenog koda d3v realiziran je program *d3v-gsd* (*Design visualizer for General Ship Design*) [2] koji omogućuje modificiranje i vizualizaciju forme te jednostavne izračune karakteristika analitički zadane forme broda s točnošću prikladnom za rane faze projektiranja broda.

2. METODOLOGIJA

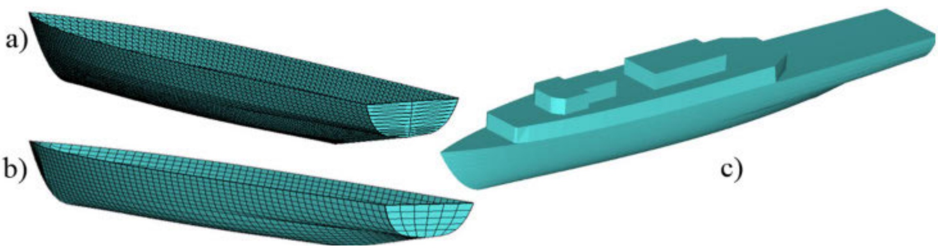
Analitička forma, zadana prema [3] i [4], definirana je tako da su vodne linije, opisane složenom izrazom koja sadrži kosinus hiperbolne funkcije, pri čemu je vodne linije moguće mijenjati promjenom glavnih dimenzija te koeficijentima koji utječu na punoću pojedinog dijela forme, Slika 1. Mreža za hidrostatičke kalkulacije generira se izradom trokuta čiji vrhovi se nalaze na svije susjedne vodne linije, pri čemu se izmjenjuju trokuti koji imaju dva vrha na gornjoj, a jedan na donjoj liniji i obrnuto. Mreža za proračun pomorstvenosti programom HydroSTAR [5] određena je nizom četverokutnih panela s preddefiniranim brojem rebara, od kojih svako rebro mora imati jednak broj točaka koje su jednoliko distribuirane po duljini (konturi) rebra. Mreža za vizualizacija projektnih građevnih blokova DBB (*Design Building Blocks*) metode rezultat je presjecišta jednostavne mreže prizmatičnih DBB blokova i mreže forme broda.



Slika 1. Prikaz načina generiranja trodimenzijske forme broda iz analitičkog modela

3. REZULTATI I ZAKLJUČAK

Na Slici 2., za primjer fregate, prikazani su modeli tri glavna modula programa d3v-gsd čije su mreže osim za vizualizaciju korištene i za proračun hidrostatičkih karakteristika i izradu dijagramnog lista, proračun pomorstvenosti primjenom programa HydroSTAR, čiji moduli su integrirani unutar d3v-gsd sučelja te za vizualizaciju, interaktivnu modifikaciju i određivanje karakteristika projektnih blokova DBB metode. Za izračun hidrostatičkih karakteristika direktno se koriste volumeni prizmi koje nastaju projiciranjem trokuta triangualizirane forme ispod vodne linije na ravninu vodne linije. Budući razvoj programa d3v-gsd uključuje povezivanje s bibliotekama za optimizaciju što će omogućiti određivanje optimalnih vrijednosti parametara analitički zadane forme s obzirom na odabrane kriterije vezane za hidrostatiku i pomorstvenost.



Slika 2. Generirana mreža za trodimenzijsku vizualizaciju i proračun a) hidrostatičkih karakteristika, b) pomorstvenosti i c) projektnih građevnih blokova

Reference:

[1] https://github.com/linaetal-fsb/d3v

[2] https://github.com/pprebeg/d3v-gsd

[3] http://dbb.ucl.im/

[4] Calleya, John, R Pawling and Alistair Greig. "A Data Driven Holistic Early Stage Design Process to Design Profitable Low Emission Cargo Ships." (2015).

[5] Bureau Veritas, "HydroSTAR User manual," Bureau Veritas, Paris, 1991-2016.

25th SYMPOSIUM ON THE THEORY AND PRACTICE OF SHIPBUILDING 2022

07 – 10 September 2022, Malinska – Croatia

Production and Maintenance of Vessels and Offshore Structures

The Performance of Surface Treatments and the Use of Duplex Stainless Steel to Avoid Galvanic Corrosion Between Shaft Casing and Shutter

M. Victoria Biezma-Moraleda *[1], Paul Linhardt [2], Carlos Berlanga [3], Pablo Colve [4], Alberto Porras [4], David Arenal [4]

[1] Departmento de Ciencia e Ingeniería del Terreno y de los Materiales,
Universidad de Cantabria, SPAIN
(E-mail: biezmav@unican.es)

[2] Insitute for Chemical Technologies and Analytics,
Technische Universität Wien, AUSTRIA
(E-mail: Paul.Linhardt@tuwien.ac.at)

[3] Materials and Manufacturing Engineering,
Public University of Navarra, SPAIN
(E-mail:carlos.berlanga@upnavarra.es)

[4] Astander, SPAIN.
(E-mails: pablo.colve@astander.es; alberto.porras@astander.es; david.arenal@astander.es)

Keywords: *antifouling paint, duplex stainless steel (DSS), galvanic corrosion, nickel- aluminium bronze (NAB)*

Abstract: This study is related to premature corrosion that appeared repeatedly in some vessels at the contact between the main shaft casing and the main shaft shutter due to galvanic interaction. Two preventive strategies were found feasible: application of a silicone based coating, and alternatively plating with duplex stainless steel. These potential solutions were evaluated by classical corrosion tests in a salt spray chamber, and by electrochemical corrosion tests addressing the galvanic effect. It was concluded that the option involving the coating provides high performance against the current problem.

1. INTRODUCTION

Premature corrosion failure of a ship's main shaft casing manufactured of carbon steel was observed repetitively (Figure 1). From investigation in the dry dock it was concluded that galvanic corrosion was driven by the main shaft shutter made of NAB, i.e. a high corrosion resistance copper based alloy. The aim of this work was to evaluate two potential remedies considered feasible in this case: (1) extending a silicone based antifouling paint up to the critical area, or (2) plating the affected area with a duplex stainless steel (DSS).

2. METHODOLOGY

In order to test the corrosion behaviour of materials, there were designed coupons of carbon steel S355JR, with the coating JOTUN [1], DSS 2205 (UNS S31803) and NAB UNS C96500. There were selected two types of corrosion test: a), a Neutral Salt Spray test (NSS) (192 h, 35 °C, 5% NaCl), and b) electrochemical potentiostatic test using Octopoti device [2] with Zero Resistance Ammeter conditions to test galvanic corrosion between the couples S355JR steel-NAB and DSS-NAB using natural sea water as electrolyte.

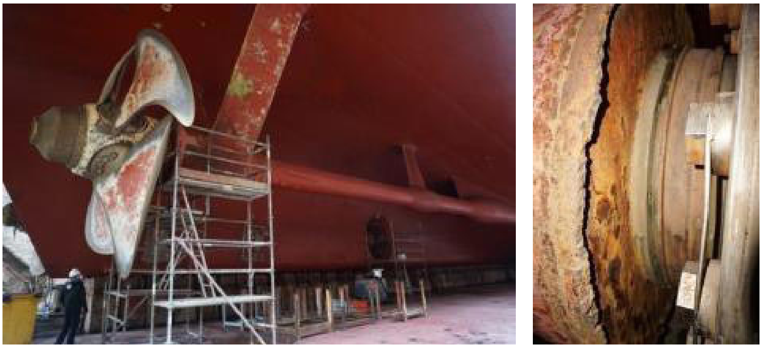


Figure 1. View of the main drive shaft (left); corroded area on the main casing (right)

3. RESULTS AND DISCUSION

NSS results show a significative anticorrosion effect of JONTUN system since only appears few corroded area on mechanically damaged S355JR meanwhile do not offer any attack on galvanic couple DSS-NAB. Electrochemical test show a clear important current density in S355JR-NAB couple affecting to S355JR (more active material,; meanwhile the couple DSS-NAB is has been resulted in a notorious damage on NAB since lead to an ennoblement as have been observed previously [3]. Figure 2 details the more significative results of both defined options.

Figure 2. S355JR-NAB couple after NSS test (right) and DSS-NAB after electrochemical test detailing the DSS corroded (right)

4. CONCLUSIONS

The first proposal is effective and viable to solve the current problem meanwhile the DSS steel, is ruled out due to its acting as a cathode against NAB, leading to the corrosion of the latter.

References:

[1] https://www.jotun.com/us/en/b2b/. [visited December 2021]

[2] Linhardt, P., Kührer, S., G. Ball, G., Biezma, M.V., Design of a multichannel potentiostat and its application to corrosion testing of a nickel-aluminum bronze, Materials and Corrosion. Vol. 69, No. 3, 2018, pp. 358–364.

[3] Linhardt, P., Unusual corrosion of nickel-aluminium bronze in a hydroelectric power plant, Materials and Corrosion, Vol. 66, No. 12, 2015, pp. 1536–1541.

Usporedba metoda predmontaže zakrivljenih sekcija u brodograđevnom procesu

Ivan Maslov [1], Karmela Prlac [2], Goran Kovačević [3], Boris Ljubenkov [4]

[1, 2, 3] Brodosplit d.d., Put Supavla 21, 21000 Split
(e-mail: ivan.maslov@brodosplit.hr,karmela.prlac@brodosplit.hr,goran.kovacevic@brodosplit.hr)

[4] Sveučilište u Splitu, FESB, Ruđera Boškovića 32, 21000 Split
(e-mail: boris.ljubenkov@fesb.hr)

Keywords: *predmontaža; zakrivljena sekcija; podesiva upora*

Sažetak: Proizvodni program brodogradilišta usmjeren je na putničke brodove duljine do 150m. Dimenzije i forma brodova su takve da se u strukturi nalazi veći broj zakrivljenih sekcija, pa je potrebno analizirati metode predmontaže. Članak prikazuje pregled broja i masa zakrivljenih sekcija karakterističnog broda iz proizvodnog programa brodogradilišta. Za karakteristične zakrivljene sekcije prikazane su metode sastavljanja koje se koriste u te su definirane njihove prednosti i nedostaci. U članku je prikazan prijedlog efikasnije metode sastavljanja zakrivljenih dijelova sekcija sa istaknutim prednostima.

1. UVOD

Usmjerenje brodogradilišta prema proizvodnom programu u kojem su putnički brodovi do 150 m duljine utječe na podprocese brodograđevnog tehnološkog procesa. Mijenjaju se količine i geometrijske karakteristike limova i profila od kojih se grade sekcije i trup broda. U strukturi se nalazi veći broj zakrivljenih sekcija što će utjecati na fazu predmontaže. Zakrivljene sekcije se u brodogradilištu izrađuju na dva načina koji imaju svoje prednosti i nedostatke [1]. Postojeće metode izrade se u radu analiziraju kako bi se eliminirali uočeni nedostatci. Predlaže se novi način izrade zakrivljenih dijelova kojim bi se povećala jednostavnost izrade i proizvodnost te smanjila količina pomoćnih materijala [2]. Ravni dijelovi strukture mogu se raditi na adekvatnim proizvodnim linijama kao što su mikropanel i panel linija [3].

2. ANALIZA ZAKRIVLJENIH SEKCIJA KARAKTERISTIČNOG BRODA

Karakteristični brod koji će se promatrati u ovom radu je brod namijenjen za polarne ekspedicije koji može primiti 200 putnika. Ovakav tip broda ima vitkiju formu i relativno veći broj zakrivljenih sekcija. Analiza broja i masa zakrivljenih sekcija karakterističnog broda napravljena je prema podjeli broda na makroprostore, grupe i sekcije u brodogradilištu [4]. Od ukupno 210 sekcija brod ima 44 zakrivljene sekcije što je 20.95 % od ukupnog broja sekcija. Ukupna masa trupa broda 3820.36 t, dok je masa zakrivljenih sekcija trupa broda 1513.44 t, pa je ukupan postotak mase zakrivljenih sekcija 39.6 %.

3. USPOREDBA POSTUPAKA PREDMONTAŽE ZAKRIVLJENIH SEKCIJA

U brodogradilištu se koriste dvije metode za predmontažu zakrivljenih sekcija, a to su:

1. Predmontaža sekcije na ravnom dijelu strukture
2. Predmontaža sekcije u koljevci

U tablici 1. prikazane su prednosti i nedostaci metoda koje se koriste. Detaljna analiza prednosti i nedostataka metoda je napravljena za dvije karakteristične grupe dvodna broda za polarna krstarenja. Karakteristične grupe 211 i 311 se nalaze u makroprostorima strojarnice i teretnog prostora.

Tablica 1. Prednosti i nedostaci postojećih metoda predmontaže zakrivljenih sekcija

<table>
<tr><th></th><th>Metoda 1</th><th>Metoda 2</th></tr>
<tr><td rowspan="3">Prednosti</td><td>Predmontaža na ravnoj podlozi</td><td>Izrada zakrivljenih dijelova u prirodnom položaju</td></tr>
<tr><td rowspan="2">Jednostavan transport strukturnih elemenata sekcije</td><td>Točnost izrade, jer koljevka prati oblik zakrivljene oplate</td></tr>
<tr><td>Nema okretanja sekcije i nadglavnog zavarivanja</td></tr>
<tr><td rowspan="4">Nedostaci</td><td>Potrebno okretanje sekcije</td><td>Velik utrošak materijala za izradu koljevke</td></tr>
<tr><td>Montaža i demontaža uški za okretanje</td><td>Vrijeme potrebno za pripremu i izradu koljevke</td></tr>
<tr><td>Potrebno nadglavno zavarivanje</td><td rowspan="2">Koljevka se koristi samo za jednu određenu zakrivljenost oplate</td></tr>
<tr><td>Montaža i demontaža skele</td></tr>
</table>

Uočeni nedostatci mogu se izbjeći korištenjem podesivih upora. Zakrivljeni dijelovi strukture predmontiraju se u prirodnom položaju oslonjeni na podesive upore. Ovim fleksibilnim rješenjem moguće je predmontirati strukture različitih zakrivljenosti. Potrebno je definirati položaj limova zakrivljene oplate radi definiranja visina podesivih upora, radi položaja šavova i stikova limova te radi definiranja nosivosti postavljenih podesivih upora. Raspored i visina podesivih upora se određuje za određenu zakrivljenu strukturu pomoću računala.

4. ZAKLJUČAK

Nedostaci postojećih metoda predmontaže zakrivljenih dijelova strukture broda mogu se izbjeći korištenjem podesivih upora. Zakrivljeni dijelovi strukture će se predmontirati u prirodnom položaju. Svi ravni dijelovi strukture mogu se izraditi na adekvatnim proizvodnim linijama čime će se osigurati visoka proizvodnost. Prema rezultatima analize izrade karakterističnih sekcija predloženom metodom izrade zakrivljenih dijelova sekcija dvodna očekuje se 10 % uštede ukupno potrebnih radnih sati.

Literatura:

[1] Duboković, E., Izrada zakrivljenih sekcija u brodograđevnom procesu, diplomski rad, FSB, Zagreb, 2009.

[2] Maslov, I., Izrada zakrivljenih sekcija u brodograđevnom procesu, diplomski rad, FESB, Split, 2021.

[3] Ćurković, K., Linije sastavljanja sklopova strukture brodskog trupa, diplomski rad, FSB, Zagreb, 1995.

[4] Brodosplit d.d., Tehnička i tehnološka dokumentacija novogradnje 487, Split, 2019.

Additive Manufacturing for Marine and Offshore: Key Breakthroughs and Future Perspective

Tolga Berkay Şirin *[1], Arif Savaş [2]

[1, 2] Marine Engineering / Maritime Faculty
Bandirma Onyedi Eylül University, TURKEY.
(E-mail: tsirin@bandirma.edu.tr, asavas@bandirma.edu.tr)

Keywords: *Additive Manufacturing, Marine, Offshore, Rapid Production*

Abstract: The idea of additive manufacturing is the most creative thing the industry community has seen in the last century. The rapid production capability has paved the way for additive manufacturing methodologies to be popularized and used in almost every industry. On the other hand, the marine and offshore industry abstained from additive manufacturing and continued to maintain its minimum cost policy. However, contrary to popular belief, additive manufacturing has potentials that can be beneficial. This paper will evaluate the additive manufacturing applications and current developments in the marine industry and provide a perspective on the future.

1. INTRODUCTION

Additive manufacturing, in contrast to subtractive and formative manufacturing methodologies, is the process of combining materials, mostly layer upon layer, to make end-use parts from 3D model data [1]. Especially for the last ten years, it has been used in many areas of the industry due to all sorts of advantages such as cost savings, mass customization, one-off or short production runs, unlimited complexity, and high strength/weight ratio (stronger/lighter). Moreover, it is now possible to manufacture materials such as metals, ceramics, composites, graphene-embedded plastics, food, yarn, glass, concrete, paper, and bio-inks. Thus, in addition to classical industrial production, organs and soft tissues, which are vital in the field of medicine, will be created.

The applications of additive manufacturing in marine and offshore are limited compared to other industries. The decrease in the availability of additive manufacturing with the growth of the masses can be shown as the reason for this. Besides, high initial investment costs, limited build size, high surface roughness and mechanical defects are among the reasons. McLearen [2] brought the issue of "Logistics" to the agenda, stating that the naval forces are carrying out serious studies on this issue. It is mentioned that additive manufacturing has the potential to reduce or end its dependence on supply chains. Appleton et al. [3], on the other hand, argued that it has the potential to manufacture and repair near the point of use, reduce costs, improve asset availability, and increase combat effectiveness. In addition, the fact that the components in Class IX block are no longer perishable in the repair of obsolete ships reveals the necessity of using this technology. This paper takes a look at the state of additive manufacturing in the marine and offshore industry.

2. EVALUATION

Additive manufacturing has a wide range of capabilities in the marine and offshore industry, from spare parts production to ship production. Composite boat parts, wear parts, propeller (Figure 1), crane hook production and even the production of submarine hulls for the US Navy are complemented by these methods. Being environmental friendly in accordance with the climate decisions taken by both the European Union and the world will also cause the use of this group of additive methods to become widespread. On the other hand, the fact that not every piece can be produced leads to the fact that traditional methods cannot be shelved.

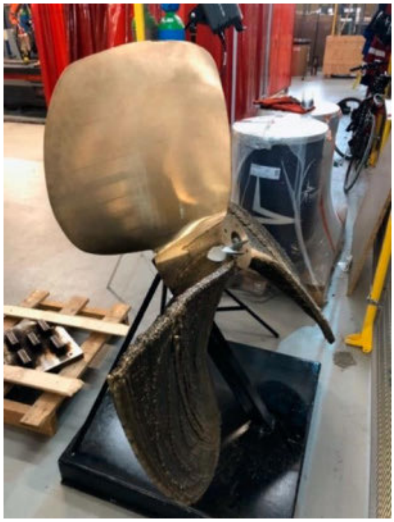


Figure 1. Propeller produced by WAAM (wire arc additive manufacturing).

3. CONCLUSIONS AND FUTURE PERSPECTIVE

Additive manufacturing, perhaps not now, but standardized and empowered in the future, will increase logistics responsiveness, reduce costs and processing times, facilitate Seabasing, strengthen the supply chain, help enable Naval Logistics Integration, and meet other challenges. It should be foreseen that the difficulties in these promising methods will be overcome in time, and therefore the marine and offshore industry should not give up on additive manufacturing.

References:

[1] Salmi, M., Paloheimo K.-S., Tuomi J., Wolff J., and Mäkitie A. Accuracy of medical models made by additive manufacturing (rapid manufacturing), Journal of Cranio-Maxillofacial Surgery, Vol. 41, No. 7, 2013, pp. 603-609.

[2] McLearen, L. J., Additive manufacturing in the Marine Corps, Naval Postgraduate School Monterey CA, 2015.

[3] Appleton, R. W., Additive manufacturing overview for the united states marine corps. RW Appleton and Company Inc, Sterling Heights, MI, Tech. Rep, 2014.

High Density Polyethylene (HDPE) as a Prominent Marine Small Craft Building Material: Opportunities and Obstacles.

Ayberk Sözen [1,2], Gökdeniz Neşer [2]

[1] Dokuz Eylul University,
The Graduate School of Natural and Applied Sciences,
Izmir, Turkey

[2] Dokuz Eylul University,
Institute of Marine Sciences and Technology,
Izmir, Turkey,
(E-mails: ayberk.sozen@deu.edu.tr, gokdeniz.neser@deu.edu.tr)

Keywords: *High Density Polyethylene (HDPE), marine small craft building, manufacturing methods for thermoplastic boat building.*

Abstract: The existing and potential uses of HDPE in marine industry have been introduced in detail, in this study. The methods of manufacturing with HDPE have been compared in terms of usage characteristics such as design approach, cost, time, and performance by experts and users opionions. Apart from these conventional methods, additive manufacturing methods (AMMs) has come into prominence today's small craft industry and HDPE has been considered as a potential material for this method in spite of its obstacles. The ways of improvement of HDPE for AMMs such as "reinforcements with glass or carbon fibres" has been also introduced based on early experimental results.

1. INTRODUCTION

HDPE, as the most used plastic material, with low moisture absorption, good resistance to chemicals, marine organisms and corrosions, sufficient mechanical performance, reasonable cost in structures pipes, cables, plates and geo-membranes has been attracted the attention of the marine industry for decades [1]. Chronologically, in 1970s HDPE small marine crafts with relatively complex forms up to 5 meters of length overall produced by means of rotation moulding method in which a heated mould rotates in a fixed orbit, plastic granules adhere to the mould under the influence of centrifugal force and are reshaped by cooling [2]. To reach larger boat with the same material, the plastic welding method were developed starting from 2010s. By using this method which does not allow designers to study complex form, patrol boats, passenger vessels and even fishing boats over 20 meters of length overall were produced. Another method emerged from 1980s, additive manufacturing, has been gained a popularity in marine small craft building from the late 2010s [3,4]. However, apart from the other thermoplastics, using HDPE in this method is still problematic due to thermal deformation and weak layer adhesion [5,6]. To solve these problems new glass and carbon fibre reinforced composite materials based on HDPE matrix have been investigated in today's naval architecture research field.

2. METHODOLOGY

The usage characteristics of HDPE due to the production method have been evaluated by the expert studied in small marine craft building area as designer, manufacturer, supplier and researcher. Their evaluations have been analysed by Analytical Hierarchical (AHP), which is a decision-making process included in the hierarchical analysis developed by Saaty in the early 1970s. This method helps decision makers to systematically prioritize many alternatives by effectively implementing a multi-criteria decision-making process, which includes the measurement criteria of various features and decision factors.

3. RESULTS AND DISCUSSION

AHP results have been given in in the Table 2. Efficient production method changes according to boat type, preference, and priority.

Table 1. AHP results and rank of the production methods

	Dinghy (n>=10)	Fishing Boat (n<10)	Passenger boat (n<10)	Patrol Boat (n<10)	USV (n<10)	Yacht (n<10)
Rotational moulding	1 (42%)	2 (29%)	3 (23%)	3 (19%)	3 (22%)	3 (18%)
Sheet welding	2 (30%)	1 (56%)	1 (50%)	1 (62%)	2 (38%)	2 (30%)
Additive manufacturing	3 (27%)	3 (15%)	2 (28%)	2 (%20)	1 (40%)	1 (%51)

4. CONCLUSIONS

HDPE is a quite prominent material in the whole marine industry. For its use in small craft building, it is advised that deciding a particular method should be on a case-by-case basis by considering above mentioned characteristics.

References:

[1] Siswandi, B., Aryawan, D., HDPE vessel of Pompong as a fishing vessel for Bengkalis Fisherma, IPTEK Journal of Proceeding Series, 2, 2017, pp. 108-113.

[2] Garces, J.M., Moll, D.J., Bicerano, J., Fibiger, R., McLeod, D., Polymeric nanocomposites for automotive applications, Adv Mater., 23, 2000, pp. 1835–1839.

[3] Aloyaydi, B., Sivasankaran, S., Mustafa, A., Investigation of infill-patterns on mechanical response of 3D printed polylactic-acid. Polymer Testing, 87. 2020

[4] Strickland, J., Strickland, D., Applications of Additive Manufacturing in the Marine Industry. Practical Design of Ships and Offshore Structures, 2016

[5] Ge, Q., Qi, H. J., Dunn, M., Active materials by four-dimension printing, Applied Physics Letters, 103, 2013,

[6] Ding, Z., Yuan, C., Peng, X., Wang, T., Qi, H. J., Dunn, M., Direct 4D printing via active composite materials, Science Advances, 34, 2017

Influence of Layer Thickness on Corrosion Protection Properties of Multilayer Coating System

Ivan Stojanović [1], Lovro Turkalj *[1], Ivan Cindrić [1], Ivan Juraga [1], Vesna Alar [1], Vinko Šimunović [1], Marin Kurtela [1], Hrvoje Franjić [2]

[1] Faculty of Mechanical Engineering and Naval Architecture,
University of Zagreb, Zagreb, Croatia;
(E-mail: ivan.stojanovic@fsb.hr, ivan.cindric@fsb.hr, ivan.juraga@fsb.hr, vesna.alar@fsb.hr, vinko.simunovic@fsb.hr, marin.kurtela@fsb.hr)

[2] Končar Steel Structures Inc.,
Zagreb 10000, Croatia
(E-mail: hrvoje.franjic@koncar-mk.hr)

Keywords: *corrosion, coating, salt chamber, IR curing, EIS, adhesion test*

Abstract: Most common method of corrosion protection in shipbuilding is the application of organic coatings, which in addition to the corrosion protection role can have various other requirements depending on the protected part of the structure. In this paper, a solvent-borne coating system dried by infrared (IR) radiation consisted of epoxy primer, epoxy intermediate coat, and polyurethane topcoat, with the difference in achieving recommended primer and topcoat thickness, was studied. Analysed coating system is used for coating ship decks, as well as other marine superstructures such as on offshore facilities and wind farms. The results point out better overall protective properties of coating system with thicker topcoat.

1. INTRODUCTION

A 3-layer solvent-borne coating system with differences in primer and topcoat layer thicknesses dried by IR radiation was observed. Studied coating system is used in shipbuilding for all above-sea parts of the ship. The aim of this study was to determine whether the difference in the thickness of primer and topcoat layer affects the protective coating system properties. Anti-corrosion properties were tested using a salt spray chamber and Pull-off adhesion test. Electrochemical analysis using electrochemical impedance spectroscopy was performed to evaluate coating resistance properties.

2. METHODOLOGY

After drying in the IR chamber, a non-destructive method of DFT measurement was performed in accordance with ISO 2808:2019. Aggressive marine atmosphere was simulated in salt spray chamber for a period of 720 hours (30 days) in accordance with ISO 9227:2012 [1]. Protective coating properties were examined by open circuit potential (OCP) and electrochemical impedance spectroscopy (EIS) [2]. Adhesive properties were assessed before and after exposure in the salt spray chamber.

Table 1. Number of layers and obtained thicknesses of the observed coating system

Coating	Number of layers		DFT [µm]	
Primer	1	2	93	143
Intermediate	1	1	102	105
Topcoat	2	1	139	57
Sample 1 (S1)		Sample 2 (S2)	ΣS1 = 334	ΣS2 = 305

3. RESULTS AND DISCUSSION

Both samples proved satisfactory adhesion properties before (S1=17,51 MPa, S2= 18,85 MPa) and after (S1=10,5 MPa, S2=8,6 MPa) exposure to salt spray chamber in accordance with ISO 4624 [1]. After 30 days, no signs of cracking, flaking, or rusting were visually noted. After 10 days of exposure in 3% NaCl, compared bode plots a notable difference between inspected coated samples. The results are shown in Figure 1.

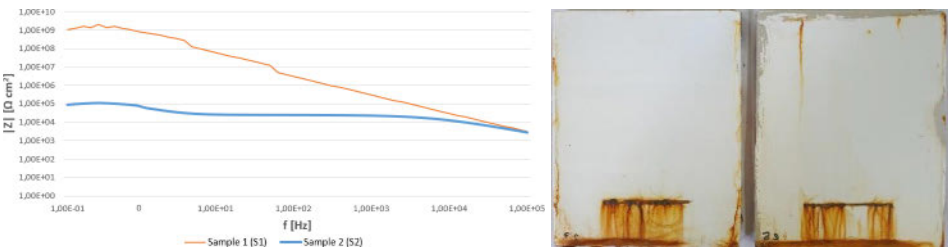


Figure 1. Bode plots after 10 days (240 h) in 3% NaCl solution (left), samples after 720 h exposure to salt spray chamber (right)

4. CONCLUSION

Results indicate better overall properties of coating system containing one primer and two topcoat layers (Sample 1) in oppose to applying two primer and one topcoat layer (Sample 2) to fulfill required thickness.

Acknowledgment: This study is part of the project "Smart plant for drying liquid coatings" which is co- financed within the Operational Programme Competitiveness and Cohesion from the European Regional Development Fund under reference number KK.01.2.1.02.0030. The content of the published materials is the sole responsibility of the Faculty of Mechanical Engineering and Naval Architecture.

References:

[1] Janković, L., Cindrić, I., Stojanović, I., Juraga, I., Rakela-Ristevski D., Waterborne coating protection properties dried with rapid and traditional drying techniques, Conference Proceedings, Croatian Society for Materials Protection, Zagreb, MTECH, 2021.

[2] Stojanović, I., Cindrić, I., Janković, L., Šimunović, V., Franjić, H., Performance Assessment of Differently Dried Coating Systems for Potential Application in the Power Transformer Industry, Coatings 2022, 12, 331.

A Simple Method to Estimate Key Performance Indicators of the Prefabrication and Fabrication Production Line in a Shipyard

Viktor Ložar *, Neven Hadžić, Tihomir Opetuk, Hrvoje Cajner

Faculty of Mechanical Engineering and Naval Architecture,
University of Zagreb, Croatia.
(E-mail: viktor.lozar@fsb.hr, neven.hadzic@fsb.hr, tihomir.opetuk@fsb.hr, hrvoje.cajner@fsb.hr)

Keywords: *Finite state method; Key performance indicators; Production lines; Splitting lines*

Abstract: The prefabrication and fabrication production line PFPL in a big shipyard is the place of processing steel plates and profiles into structural elements for vessel refits or newbuildings. Therefore, it is very important to determine the key performance indicators such as production rate, work in process, probabilities of blockade, and starvation and thruput. This can be efficiently retrieved using the fast and simple finite state method in the case of splitting lines that will be briefly presented here.

1. INTRODUCTION

Shipyards are exposed to a harsh economic competition. They are pushed to optimize their processes and to find savings in all sectors, including PFPL. Therefore, mathematical models can be very useful [1]. In this paper the finite state method will be briefly presented [2]. This semi-analytical approach is a fast method to formulate the transition matrix and to evaluate its eigenvector which is necessary to determine the key performance indicators.

2. METHODOLOGY

The PFPL consist out of flattening, drying, sand-blasting, preserving, marking, cutting and forming machines including buffers placed between them. For all these machines it is necessary to define the operational probability and the capacity of the buffers. Since these fabrication lines include splitting of the material flow, it is also necessary to define the associated splitting factors.

Figure 1 shows a general splitting line with one primary and two secondary flows.

The circles denote the machines while buffers are represented using squares.

Generally this method includes the following steps: 1.) Define the weakest machine in the main branch, 2.) Create a virtual machine probability by multiplication of these machine with the splitting factor, 3.) Compare the probability of the virtual machine with the probabilities of machines in the corresponding branch, 4.) Indicate in each branch the weakest machine, 5.) Create elements in each branch according to the weakest machine, 6.) Calculate the Eigenvector for each element, 7.) Calculate the Eigenvector for the whole line.

Once the Eigenvector for the complete line is defined, it is possible to determine the key performance indicators:

- The production rate as the expected number of pieces per cycle time produced by the last machine
- The work in process as the average number of semi-products at the ith buffer
- The blockade as the probability that the ith machine is not working because the subsequent buffer is full
- The parameter starvation as the probability that the ith machine can not work since the preceding buffer is empty.
- The thruput as the number of products which the line produces in a specific period.

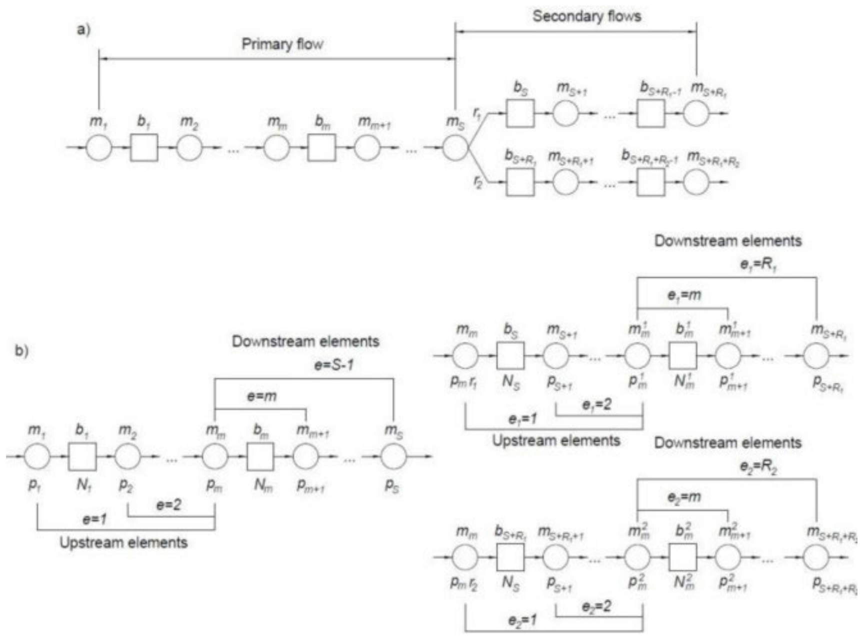


Figure 1. General splitting line composed of one primary and two secondary flows

3. CONCLUSIONS

The presented method is a simple and powerful tool to determine the key parameters of a PFPL. This is of key significance when considering maintenance, improvement of design of such production systems.

Acknowledgment: The research is supported by the Croatian Science Foundation, project UIP-2019-04-6573 ANTYARD (Advanced Methodologies for Cost Effective, Energy Efficient and Environmentally Friendly Ship Production Process Design).

References:

[1] Papandopulos CT, Li J, O'Kelly MEJ. A classification and review of timed Markov models of manufacturing. Computers & Industrial Engineering. 2019;128:219-244. doi 10.1016/j.cie.2018.12.019

[2] Hadžić N., Ložar V., Opetuk T., Andrić J., The Bernoulli splitting line: analytical and semi-analitical evaluation of the steady-state performance, International Journal of Production Research, 2021

Polylactic Acid (PLA) and Wood Composite as a Sustainable Material Alternative in Additive Boat Manufacturing and Its Degradation in Marine Environment

Selin Barış Çamlı [1], Gökdeniz Neşer [2], Ayberk Sözen [2]

[1] Dokuz Eylul University, The Graduate School of Natural and Applied Sciences, Izmir, Turkey
(E-mail: selin.baris@deu.edu.tr)

[2] Dokuz Eylul University, Institute of Marine Sciences and Technology, Izmir, Turkey
(E-mail: gokdeniz.neser@deu.edu.tr, ayberk.sozen@deu.edu.tr,)

Keywords: *Polylactic acid (PLA) and wood composite; Marine environmental degradation; Additive manufacturing*

Abstract: For the sustainable boat production, a new composite material consisting of PLA and wood was introduced in the study. Wood, yellow pine from the forests of the Mediterranean region of Turkey, was in two form in the study: (1) 8% in weight in the composite and (2) solid wood. From the both kind of the material, specimens were produced by additive manufacturing technique in two (parallel and cross) printing directions and after that, the specimens were subjected to accelerated aging processes representing long-term effects of marine environmental agents such as humidity, salt and temperature in four conditions namely: (1) without, (2) one-week, (3) two weeks and (4) four weeks aging. Tensile and compressive testing were performed for all the samples and the results were given comparatively. A scanning electron microscope (SEM) analysis and thermal analysis were also performed to appreciate the bonding performance of the materials and the environmental effects on the composite. According to the results, newly introduced PLA/wood composite material was found usable for the interior design elements whose the complex form and the limited exposure to the marine environment.

1. INTRODUCTION

From the first day that human used water for transportation until today, wood, as the most sustainable alternative, has been the main material used in small marine craft building by maintaining its competitiveness with the help of developed woodworking technologies and additives [1]. Considering today's efforts for the sustainable maritime industry, an alternative composite material consisting of a local wood (yellow pine micro particles) and Polylactic acid (PLA), a thermoplastic, was introduced in the study for the boat structural elements with complex form. These two materials in the composite were biodegradable and can be used in the replacements of petroleum-derived polymers [3].

2. METHODOLOGY

Since the structural elements with complex forms can be produced by additive manufacturing techniques, the fused filament fabrication (FFF) method with 3D printers was used to produced composite samples using the composite filament in an optimum mixture (8% wood in weight [4]). Two printing directions, cross and parallel, were also considered as the parameter of the performance of the introduced composite.

To understand the effects of marine environmental agents such as humidity, salt and temperature, specimens were subjected to accelerated aging in four conditions: (1) without, (2) one week, (3) two weeks, and (4) four weeks in an Ascott type cabin.

Tensile and compressive tests were also performed for all the samples (aged, non-aged). A scanning electron microscope (SEM) analysis and thermal analysis were also performed to appreciate the bonding performance of the materials and the environmental effects on the composite. Additionally thermal analysis was done for the samples.

3. RESULTS AND DISCUSSION

The degradations were seen clearly at a level of 10% in first week, 20% in second week and 30% in one month for PLA/wood composite as PLA is a biodegradable material. Solid wood shows a high resistance in the first two weeks. The degradation is less than 5%, but if the one-month data is analysed a 20% degradation can be seen. Tensile and compression tests showed similar degradation performance.

Newly introduced PLA/wood composite material was found usable for the interior design elements whose the complex form and the limited exposure to the marine environments.

References:

[1] Praharsi, Y., Jami, M., Suhardjito, G., Wee, M., Modeling a traditional fishing boat building in East Java, Indonesia. Ocean Engineering, 189., 2019.

[2] Heräjärvi, H. Static bending properties of Finnish birch wood. Wood Science and Technology, 37(6), 2004, pp. 523–530.

[3] Liu, J., Sun, L., Xu, W., et al., Current advances and future perspectives of 3D printing natural-derived biopolymers. Carbohydrate Polymers, 207, 2019, pp. 297–316.

[4] Kariz, M., Sernek, M., Obucina, M., et al., Effect of wood content in FDM filament on properties of 3D printed parts, 14, 2018, pp.135-140

Numerical Modeling of a Prefabrication and Fabrication Production Line in a Shipyard

Viktor Ložar *, Tihomir Opetuk, Neven Hadžić, Hrvoje Cajner

Faculty of Mechanical Engineering and Naval Architecture,
University of Zagreb, Croatia
(E-mail: viktor.lozar@fsb.hr, tihomir.opetuk@fsb.hr, neven.hadzic@fsb.hr, hrvoje.cajner@fsb.hr)

Keywords: *Enterprise Dynamics, Numerical modeling, Production lines, Shipbuilding industry*

Abstract: In this paper a brief overview of existing numerical models of the shipbuilding industry will be reviewed and the case of a prefabrication and fabrication production line (PFPL) will be presented. Therefore, the software tool Enterprise Dynamics will be employed to simulate the required production time for two virtual sections.

1. INTRODUCTION

Numerical modelling of production lines in a shipyard are not so common in the practice. There are solutions for the scheduling systems as for example in the Daewoo shipyard, but they don't analyze explicitly the production line [1]. Steel plate scheduling can be described by algorithms to optimize the time of lifting the target plate [2]. Micro-panel and robotic micro-panel assembly lines are analyzed using a value stream mapping method [3]. Efforts are made to simulate the handling of block sections in a dry dock using Integration Definition (IDEF0) and Unified Modelling Language (UML) methodologies [4]. An inverse regression method is used to solve a multivariate calibration problem and to calculate the various costs in a shipyard [5]. A raw example of a discrete simulation model of production lines can be found in the paper [6], where the authors describe the method on a virtual example. Another approach to modelling methodology based on the Product, Process, Resource and Schedule model (PPR-S) is explained in [7].

2. METHODOLOGY

For the numerical modelling of a PFPL the discreate event simulation software tool Enterprise Dynamics 10.3 [8] was employed and the layout of the production line from the shipyard "Brodosplit" was used. The model was built up by approximately 119 standard atoms and two virtual sections are used for the input.

3. RESULTS

The production time for two virtual sections was approximately 28 hours. The Figure 1 shows the process times for steel plates and profiles in the PFPL.

4. CONCLUSIONS

Simulation of a PFPL in a shipyard is a demanding task that requires a lot of experience and knowhow. However, these efforts are needed to achieve the level of industry 4.0. Once the model is created different scenarios can be simulated without affecting the regular production.

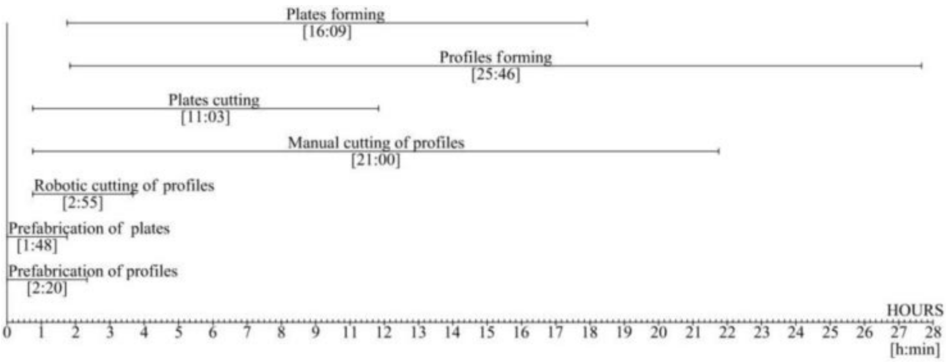


Figure 1. The process times in the production line for two virtual sections

Acknowledgment: The research is supported by the Croatian Science Foundation, project UIP-2019-04-6573 ANTYARD (Advanced Methodologies for Cost Effective, Energy Efficient and Environmentally Friendly Ship Production Process Design). We would also like to express our gratitude to Brodosplit, for granting us the layout and data.

References:

[1] Lee JK, Lee KJ, Park HK, Hong JS, Lee JS. Developing scheduling systems for Daewoo Shipbuilding: DAS project. European Journal of Operational Research. 1998;98:380-395.

[2] Liyun X, Zhongyu S, Liansheng Y. Steel plate scheduling optimization in shipbuilding based on storage area partition. Procedia CIRP. 2020;93:1001-1006.

[3] Kolich D, Yao YL, Fafandjel N, Hadjina M. Value stream mapping micropanel assembly with clustering to improve flow in a shipyard. International Conference on Innovative Technologies IN-TECH Leiria 2014; Leiria, Portugal 10-12.09.2014.

[4] Kim H, Lee S-S, Park JH, Lee J-G. A model for simulation-based shipbuilding system in a shipyard manufacturing process. International Journal of Computer Integrated Manufacturing. 2005;18(6):427-441.

[5] Dain O, Ginsberg M, Keenan E, Pyle J, Smith T, Stoneman A, Pardoe I. Stochastic shipyard simulation with SIMYARD. Proceedings of the 2006 Winter Simulation Conference Monterey 2006; Monterey, California, USA 3-6.12.2006.

[6] Williams DL, Finke DA, Medeiros DJ. Discrete simulation development for a proposed shipyard steel processing facility. Proceedings of the 2001 Winter Simulation Conference Monterey 2001; Arlington, Virginia, USA 9-12.12.2001.

[7] Lee KL, Kim Y, Hwang IH, Oh DK, Shin JG. Study on a process-centric modelling methodology for virtual manufacturing of ships and offshore structures in shipyards. International Journal of Advanced Manufacturing Technology. 2014;71:621-633.

[8] Enterprise Dynamics Tutorial, INCOTROL Simulation Solutions: Utrecht, The Netherlands, 2021

Analysis of Organizational Models of Shipbuilding Production in Selected Domestic and Foreign Shipyards

Rajko Rubeša [1], Tin Matulja *[2], Marko Hadjina [3], Jakov Rajić [4]

[1, 3] MAJ Brodogradilište d.d., CROATIA.
(E-mail: rajko.rubesa@gmail.com)

[2, 3, 4] Faculty of Engineering,
University of Rijeka, CROATIA.
(E-mail: tin.matulja@riteh.hr, hadjina@riteh.hr, jrajic@riteh.hr)

Keywords: *Organization; Outsourcing; Shipyards; Technological process.*

Abstract: In this paper, organizational models of shipbuilding production processes in several domestic and foreign shipyards are analyzed. The paper analyzes the domestic shipyards 3. MAJ Brodogradilište, before and after the restructuring, Brodosplit Shipyard, and foreign shipyards ASL Shipyard Singapore and Fincantieri Ancona. Organizational structures and management models of the shipbuilding process for selected shipyards are presented, which are further analyzed from the point of view of advantages and disadvantages. Based on the analysis, the assessment of the success of each individual organizational model was performed, and guidelines for the optimal organizational structure applicable to domestic shipyards are given.

1. INTRODUCTION

The organization of shipbuilding is a deliberate association of experts with main task of building the ship with appropriate resources and a disciplined process involving minimal effort and cost, optimizing the shipbuilding process and respecting the current technological limitations of selected shipyards. Every shipyard has a system of organizational structure, i.e. a hierarchical system. It is important to properly shape the organizational structure because without it, results in business segments will have a poor outcome. Therefore, it is necessary to set the choice of the correct organizational structure for each shipyard. [1, 2, 3, 4, 5, 6, 7]

2. METHODOLOGY

In this paper, organizational models of shipbuilding production processes in several domestic and foreign shipyards are presented and analyzed. Selected shipyards subjected to analysis are those in which the authors have developed the collaboration and access to detailed information. For example, on Figure 1. the Organizational model for ASL Shipyard Singapore is presented. The benchmarking method was used to compare analyzed organizational models of shipbuilding production process and advantages and disadvantages are presented for each model. Finally, using expert approach method the basic guidelines are presented for improving the organizational model of selected domestic shipyard.

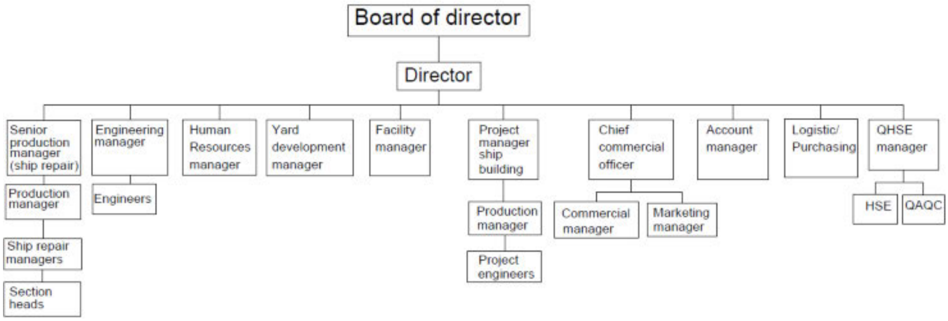


Figure 1. Example of organizational model for ASL Shipyard Singapore

3. CONCLUSION

Four shipyards, two domestic and two foreign, where the authors had detailed access to information's are analyzed regarding organizational model of shipbuilding production process. Furthermore, two analyses for 3.MAJ shipyard were performed, before and after joining the Uljanik Group. All models are schematically presented with emphasis on advantages and disadvantages. Finally, using expert approach, the basic guidelines are given for improving the organizational model of selected domestic shipyard.

Acknowledgment: This research is supported by funds from the support research at the University of Rijeka for the project "Development of Methodology for Ship Design and Production towards Industry 4.0. Concept", technic-18-159.

References:

[1] Kerzner, H.: Project management – a systems approach to planning, scheduling and controlling (10th edition), John Wiley & Sons Inc., New Jersey, 2009.

[2] Meredith, J.R., Mantel, S.J.: Project management, John Wiley & Sons, Inc., 2009

[3] Sikavica, P.: ORGANIZACIJA, Školska knjiga, Zagreb, 2011.

[4] Hauc, A.: Projektni menadžment i projektno poslovanje, M.E.P. Consult, Zagreb, 2007.

[5] Omazić, M. A., Baljkas, S.: Projektni menadžment, Sinergija nakladništvo, Zagreb, 2005.

[6] Wei, Y.: Automatic Generation of Assembly Sequence for the Planning of Outfitting Processes in Shipbuilding, Doctoral thesis, Technische Universiteit Delft, Netherland, ISBN 978-90-6562-295-2, 2012.

[7] Čagalj, A. Veža, I., Markovina, R.: Organizacijski model umreženog brodogradilišta, University of Split, 2008.

Unapređenje učinkovitosti procesa opremanja broda

Petar Lisičić [1], Rajko Rubeša *[2], Marko Hadjina *[3], Tin Matulja [4]

[1] MKM Yachts, HRVATSKA
(E-mail:plisicic@riteh.hr)

[2] Brodogradilište „3.MAJ", HRVATSKA
(E-mail: rajko.rubesa@gmail.com)

[3,4] Sveučilište u Rijeci – Tehnički fakultet, HRVATSKA
(E-mail: hadjina@riteh.hr; tmatulja@riteh.hr)

Ključne riječi: *opremanje broda, učinkovitost, unapređenje, troškovi*

Sažetak: Brod je složen proizvod koji zahtijeva interakciju između gradnje trupa, montaže opreme i bojenja. Radi podizanja konkurentnosti na tržištu brodogradilišta nastoje ubrzati gradnju broda, uz snižavanje troškova te podizanja efikasnosti i kvalitete. Pri tome, u okviru unapređenja učinkovitosti opremanja broda, prepoznat je značajan potencijal za snižavanje ukupnih troškova gradnje broda. Stoga, autori u ovom radu provode analizu i predlažu unapređenje metodologije opremanja odabrane sekcije broda sa ciljem povećanja učinkovitosti procesa i smanjenja ukupnih troškova. Pri tome posebnu pozornost usmjerena je na premještanje aktivnosti opremanja u ranije faze procesa gradnje broda vodeći računa o međuodnosima relevantnih aktivnosti te za to potrebne dokumentacije.

1. UVOD

U suvremenoj brodogradnji, pri gradnji sofisticiranih brodova više dodane vrijednosti, učinkovitosti opremanja broda iznimno je važna za unapređenje efikasnosti procesa i snižavanje ukupnih troškova gradnje broda [1]. Autori u ovom istraživanju provode analizu i predlažu unapređenje učinkovitosti procesa opremanja odabrane sekcije broda sa ciljem smanjenja utrošenih radnih sati. U prvom dijelu istraživanja analiziran je postojeći proces opremanja trupa broda. Definirani su norma sati, korištene pretpostavke te alati i tehnike. Nadalje, analizirani su različiti slučajevi uz definirane relevantne kriterije sa ciljem definiranja unapređene metodologije opremanja odabrane sekcije trupa broda. Za potrebe istraživanja autori su razvili poseban alat za analizu i izbor optimalnog modela opremanja promatrane sekcije u programskoj aplikaciji MS Project.

2. ANALIZA POSTOJEĆEG PROCESA OPREMANJA BRODA

U osnovi, metodologija opremnih radova dijeli se na [2]: opremanje prema zanimanjima; sistemsko opremanje i prostorno zonsko opremanje. Analiza postojećeg stanja provela se za odabranu sekcija dvodna broda za prijevoz kemikalija [3], te je za nju utvrđen redoslijed i sadržaj svih aktivnosti opremanja i utrošeni norma sati. Nadalje, pristupa se analizi slučajeva koristeći metodu mrežnog planiranja, mrežnog dijagrama i „gantograma", [4] sa ciljem unapređenja procesa opremanja odabrane sekcije broda.

3. ANALIZA I DEFINIRANJE OPTIMALNOG SLUČAJA

Analizirano je više slučajeva sa variranjem broja i odnosa radnika po zanimanjima, timovima, metodi opremanja (prostorno zonska ili sistemska), raspoloživost opreme i kvaliteta dokumentacije. Praćeni su parametri vrijeme trajanja radova, resursi, odnosi korištenih resursa i trajanja radova, broj aktivnosti, vremenska rezerva i dr. Na kraju, analizirani slučajevi su vrednovani te je slučaj 4 označen kao optimalni slučaj metodologije opremanja odabrane sekcije trupa broda (slika 1.).

	Bodovi	100	40	20	20	20	
	Slučaj	Vrijeme	Postotak rasta i smanjenja	Kritični put	Resursi	Ukupna vremenska rezerva	
OCJENA KRITERIJA	1	3,5	5	2	10	5	
	2	4	5	6	10	10	
	3	8	7	7,5	7	7	
	4	9	8	7,5	7	7,5	
	5	10	4	8	4	8	
	6	9	3	5	4	1	
OCJENA KRITERIJA × BODOVI	1	350	200	40	200	100	890
	2	400	200	120	200	200	1120
	3	800	280	150	140	140	1510
	4	900	320	150	140	150	1660
	5	1000	160	160	80	160	1560
	6	900	120	100	80	20	1220

Slika 1. Vrednovanje analiziranih slučajeva/Scenario validation

4. ZAKLJUČAK

Osnovni karakterizirajući elementi optimalnog slučaja jesu: opremanje prema mješovitoj prostorno zonsko i sistemskoj metodologiji opremanja; korištenje dva tima cjevara i samo jednog tima bravara; primjena koncepta uranjenog opremanja.

Priznanje: Ovo istraživanje podržano je sredstvima podrške istraživanjima Sveučilišta u Rijeci za projekt "Development of Methodology for Ship Design and Production towards Industry 4.0. Concept", UNIRI PROJEKT tehnic-18-159.

Literatura:

[1] Storch, R. L. i dr.: „Ship Production", Cornell Maritime Press, Centreville, 2007.

[2] Lamb, T. i dr.: „Ship Design and Construction", SNAME, 2003.

[3] Dokumentacija Brodogradilište „3.MAJ" d.d., Rijeka.

[4] Winston, W.L.: „Operations Research: Applications and Algorithms", Cengage Learning, 2003.

25th SYMPOSIUM ON THE THEORY AND PRACTICE OF SHIPBUILDING 2022

07 – 10 September 2022, Malinska – Croatia

Maritime Transport and Economics

Energy Efficiency of Inland Vessels: Current Status

Kalajdžić Milan [1], Vasilev Matija [2], Momčilović Nikola [1]

[1] Department of Naval Architecture,
Faculty of Mechanical Engineering,
University of Belgrade, Serbia.
(E-mail: mdkalajdzic@mas.bg.ac.rs, nmomcilovic@mas.bg.ac.rs)

[2] Ocean Pro Marine Engineers LTD, Serbia.
(E-mail: matija@oceanpro.eu)

Keywords: *EEDI, EEXI, energy efficiency of inland vessels, inland waterway vessels.*

Abstract: Inland waterway industry is far smaller than maritime and therefore, provides less environmental impact. However, its local effect is not negligible. Even though maritime practice has been addressing energy efficiency of ships for decade, no corresponding measures were delivered in inland waterway industry, considering the Green Deal goals. However, there are few proposals for addressing the energy efficiency of inland vessels. Hence, this work tries to gather such proposals and provide a review on their current status.

1. INTRODUCTION

Since 2011 IMO has been introducing resolutions and strengthening its criteria to address the energy efficiency of new ships (EEDI index), followed by the corresponding set of measures for existing ships (EEXI index) in later years. During that time and as of nowadays, no similar measures were delivered for inland waterway vessels (IWV). IVW industry is far smaller and have almost negligible global environmental impact compared to the maritime sector. However, local and regional effects could not be ignored taking into account that more than 15000 vessels are navigating in EU countries. As in case of IMO long term goals, Green Deal and Mobility Strategy of the European Union are aiming at significantly reduced emissions – zero from navigation sector until 2050. However, there are no mandatory measures with respect to energy efficiency measures for IWV. This work explores and critically reviews methods that are being proposed in that respect.

2. IWV ENERGY EFFICIENCY PROPOSALS

For the evaluation of energy efficiency of EU IWV two methods are proposed so far and both based on IMO's EEDI approach. One is developed at the Department of Naval Architecture in Belgrade (Modified EEDI) [1, 2] and the other in the Development Centre for Ship Technology and Transport Systems from Duisburg (DST EEDI) [2, 3]. The comparison of both method is summarized in the Table 1.

Table 1. IWV energy efficiency methods comparison

	Modified EEDI	DST EEDI
Attained EEDI	$EEDI^* = \frac{P_{Bref} \cdot SCF \cdot CF}{m_{DWT} \cdot V}$	Deep water $P_D = \alpha_1 \cdot m_{DWT}$ P_D measure V_s calculate $EEDI_{IWV}$ $EEDI_{IWV} = CF \cdot SCF \cdot \frac{P_D}{V_S \cdot m_{DWT}}$ Shallow water $P_D = \left(\alpha_2 + \beta_1 \cdot \exp(-\gamma_1 B) - \delta_1 \cdot \exp\left(\frac{h}{-\delta_1}\right)\right) \cdot m_{DWT}$ P_D measure V_s calculate $EEDI_{IWV}$ $EEDI_{IWV} = CF \cdot SCF \cdot \frac{P_D}{V_s \cdot m_{DWT}}$
Required EEDI	$EEDI^*_{Req} = a \cdot m^c_{DWT}$ Coeffitients for deep and shallow water conditions given in [1].	Deepwater $EEDI_{Req} = \alpha_4 + \beta_2 \cdot \exp\left(\frac{m_{DWT}}{-\gamma_2}\right) + \vartheta_1 \cdot \exp\left(\frac{m_{DWT}}{-\delta_1}\right)$ Shallowwater $EEDI_{Req} = \left(\alpha_5 + \beta_3 \cdot V_C + \gamma_3 \cdot V_C^2\right) + \left(\delta_1 + \varepsilon_2 \cdot V_C - \varsigma_1 \cdot V_C^2 + \eta_1 \cdot V_C^3\right) \cdot \exp\left(\frac{m_{DWT}}{-\theta_1}\right)$ Coeffitients for deep and shallow water conditions given in [3].
Applicability	10 km/h ≤ V ≤ 22 km/h 0.4 ≤ Fnh ≤ 0.65 100 t ≤ m_{DWT} ≤ 3000 t	Deepwater $T = 1.5D$ $T = 2 - 3.2$m Shallow water $T = 1.5D$ $h = 3.5$-7.5 m $T = 2$-2.8 m $L = 40$-135 m $B = 5$-17 m $m_{DWT} = 250$-6000 t $Vc = 2$-8 km/h $\min(h/T) = 1.4$
Explanations	$EEDI^*$ - Modified energy efficiency design index, in gCO_2/t km; P_{Bref} - Reference engine power for achieving V, in kW; SFC - Specific fuel consumption, assumed 200, in g/kWh; CF - Carbon emission factor, 3.206, in gCO_2/g fuel (for diesel); m_{DWT} - mass of deadweight, in t; V - actual vessel speed throught water, in km/h.	$EEDI_{IWV}$ - attained (estimated) energy efficiency design index, in gCO2/t km; $EEDI_{Req}$ - required energy efficiency design index, in gCO2/t km; D - propeller diameter, in m; B - vessel breadth, in m; h - river depth, in m; SCF - specific fule consuption, assumed to be 220, in g/kWh; CF - carbon emission factor, 3.206, in gCO2/g fuel; P_D - delivered power, in kW.
Review/Notes	- V is not governed on 75% of MCR like in IMO's *EEDI*, but pose an actual speed with the reference to the water; - P_{Bref} is not based on MCR like in IMO's *EEDI*; - $EEDI^*$ is to be assessed for all vessels in same speed and same river constaints (for instance: shallow and deep water) to allow comparison. - Required EEDI is based on more than 10 years old vessels, but is proposed that data should be collected from vessels built in the past 10 years; - a , c are funcions of vessel type and V or Froude number Fnh in case of shallow water - h = 5 m; - The formula is proposed to be strengthened over the years for 10%, 20% and 30% like in case of IMO's EEDI.	- For dry bulk and container vessels; - For deep water (h > 7.5 m) and shallow water (zone 3) navigation; - The method is proposed to be strengthened over the years for 15% and 25%.

3. CONCLUSION

There are no mandatory nor provisional regulations for the energy efficiency of IWV. This work is trying to review methods that are just proposed so far. It is obvious that these proposals need to be harmonized. DST method has rigid applicability limit regarding the draught and is almost unable to get compared to the modified EEDI or other EEDI-like IMO's procedures. Moreover, its shallow and deep-water diversification are not relating to the efficiency happening in practice. Therefore, IWV sector needs more straightforward and unified procedure to address energy efficiency.

Acknowledgment: This work was partially supported by Ministry of Education, Science and Technological Development (Project no. TR 35009) of Serbia.

References:

[1] Simić, A., Energy Efficiency of Inland Self-Propelled Cargo Vessels, Doctoral dissertation, University of Belgrade, Faculty of Mechanical Engineering, Belgrade, 2012.

[2] Radojčić D., Simić A., Momčilović N., Motok M., Friedhoff B., Design of Contemporary Inland Waterway Vessels – The Case of the Danube River. Publisher: Springer. ISBN: 978-3-030-77324-3, DOI: 10.1007/978-3-030-77325-0, 2021.

[3] DST, Evaluating the Energy Requirement of Inland Vessels using Energy Efficiency Indices, R&D project (DST, German Federal Ministry of Transport, CESNI), 2020

Enhancement of National Regulations for Preventing Marine Pollution in the Adriatic Ionian Region

Marija Koričan *[1], Nikola Vladimir [1], Dario Omanović [2], Loukia Prentza [3], Eirini-Asimina Stamatopoulou [3], Nikolaos P. Ventikos [3]

[1] University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, CROATIA. (E-mail: marija.korican@fsb.hr)

[2] Ruđer Bošković Institute, CROATIA

[3] National Technical University of Athens, School of Naval Arch. & Marine Eng., GREECE.

Keywords: *Adriatic Ionian Region; early warning systems; marine pollution; regulation.*

Abstract: The Adriatic Ionian region is a well-populated and functional area whose progress is closely linked to the Adriatic and Ionian basins. In recent years, the emphasis is mainly on the development of tourism, but there is also great potential for investment in fisheries and aquaculture, marine transportation and green technologies. However, this progress is followed by social, economic and ecological issues. Intensive fishing, aquaculture and coastal development represent threats to the natural habitat, while maritime transport, insufficient wastewater treatment and excessive use of nitrates in agriculture have a great effect on marine environmental safety. The paper presents an early warning system that will ensure real-time evaluation of water quality deviations. The early warning system is based on a network of multiparameter probes installed across the Adriatic Ionian Sea. Based on the obtained data, it is possible to raise awareness about the marine environment in the Adriatic-Ionian area. By engaging general public and widening the sources of information through a mobile application, a database will be created that will serve to create guidelines for improving current regulations for the protection of the marine environment and ensuring the quality of seawater. The ultimate goal is to urge local and regional authorities to raise awareness of marine pollution issues and to encourage proactivity in the pollution prevention.

1. INTRODUCTION

Marine pollution is a continuous concern, widespread across the world and triggered by variety of sources [1]. Possible oil spills, sewage waste, harmful emissions are just several forms of marine pollution threatening the marine waters. Overcrowding, a great number of ships, aquaculture, development of nautical tourism, pose a threat to the Mediterranean Sea and affect the living conditions of the local residents [2]. Without proper policies for sustainable development, environmental degradation will steadily increase. The legislative framework is being developed to approach the environmental issues, reduce their impact and/or remove them completely.

2. METHODOLOGY

To deal with the environmental problems in the marine area, the European Union has undertaken projects that investigate the impact of climate change on the marine system and develop solutions for its mitigation. One of them is the Interreg ADRION Project

SEAVIEWS, aimed to tackle environmental vulnerability and preserve the ecosystem in the Adriatic – Ionian area [3]. In the project, a network of multiparameter sensors was established and real-time data is being collected on the SEAVIEWS platform developed on the project. Parameters, e.g. pH, temperature, salinity, dissolved oxygen etc., determine the water quality which is an important factor in tourism (bathing areas) and industry (aquaculture) [4]. The database will be expanded with data from the general public, which will be entered via the SEAVIEWER mobile application also developed during the project.

3. RESULTS AND DISCUSSION

First measurements in Croatia have been performed in August 2021 and are still in progress. The large database made it possible to observe disturbances in an aquaculture farm, where the sensors are installed. The results showed parameter differences during summer and winter periods and, with the help of research related to the impact of environmental change on marine organisms [5], the sensitivity to changes in water quality can be determined. A crucial part of the project is the promotion of the results obtained in order to raise awareness and enhance marine environmental protection.

4. CONCLUSION

The project is focused on monitoring, collecting data about the current state of the marine environment and preparing improvement actions which will be issued at the end of the project. This approach creates a wide database that will help Croatia in implementing measures but also ensures good international cooperation through data sharing. By revising the environmental strategies and proposing measures for individual sectors, a faster implementation of measures is possible and a better environmental state of the marine environment in the Republic of Croatia will be achieved.

Acknowledgment: This research was co-funded by a European transnational programme INTERREG V-B Adriatic-Ionian ADRION Programme 2014-2020, under the project SEAVIEWS (Project No. ADRION-951).

References:

[1] European Environmental Agency. https://www.eea.europa.eu/ (accessed 05 June 2022).

[2] Ferrarin C., Penna P., Penna A., Spada V., Ricci F., Bilić J., Krzelj M., Ordulj M., Šikoronja M., Đuračić I., Iagnemma L., Bućan M., Baldrighi E., Grilli F., Moro F., Casabianca S., Bolognini L., Marini M., Modelling the Quality of Bathing Waters in the Adriatic Sea, Water, 13(11):1525, 2021. https://doi.org/10.3390/w13111525.

[3] ADRION Programme, https://www.adrioninterreg.eu/ (accessed 05 June 2022).

[4] Food and Agriculture Organization, 1993. Water quality and fish health, http://www.fao.org/3/t1623e/t1623e.pdf (accessed 05 June 2022).

[5] Carić H., Cukrov N., Omanović D., Nautical Tourism in Marine Protected Areas (MPAs): Evaluating an Impact of Copper Emission from Antifouling Coating. Sustainability 2021, 13, 11897. https://doi.org/10.3390/ su132111897.

Utjecaj starosti ribarskih brodova na značajke energetske učinkovitosti

Ivica Ančić *[1], Lidija Runko Luttenberger [2]

[1, 2] Sveučilište u Rijeci, Studij politehnike, HRVATSKA.
(E-mail: ivica.ancic@uniri.hr, lidija.luttenberger@uniri.hr)

Ključne riječi: *Ribarski brodovi, starost flote, porivni sustav, energetska učinkovitost*

Sažetak: Pogon ribarskih brodova ima značajnu ulogu u pogledu očuvanja, odnosno degradacije morskog okoliša. To se prvenstveno odnosi na njegove energetske i ekološke značajke, tj. snagu, vrstu korištenog goriva i specifičnu potrošnju goriva. Ovaj rad je analizirao utjecaj starosti ribarskih brodova na njihov utjecaj na okoliš uspoređujući instalirane snage glavnih motora u ovisnosti o starosti broda. Analiza je pokazala da noviji brodovi imaju u prosjeku jače motori, međutim također i da su u prosjeku veći, a zbog veće korisnosti novijih motora, ukupna razlika u potrošnji goriva nije značajna.

1. UVOD

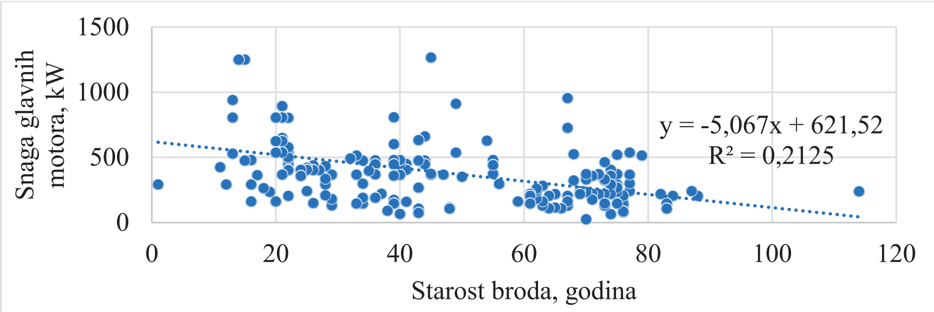
Ribarski brodovi i njihova oprema predstavljaju ključni alat u gospodarskoj grani ribarstva, te su kao takvi predmetom politike na razini Europske Unije. Obzirom da se u javnosti redovito spominje starost hrvatske ribarske flote, s time da je nakon 2000. godine ona ponešto i obnovljena uz povećanje kapaciteta, napravljena je analiza nacionalne ribarske flote utemeljena na podacima iz službenog registra brodova. Iako je tijekom obrade podataka utvrđena određena neusklađenost spomenutih podataka u odnosu na stvarno stanje, to su jedini podaci kojima se raspolaže za provedbu početne analize koja je ovdje i izrađena, a koja pruža ne samo uvid u značajke ribarske flote, već predstavlja i podlogu za moguće ažuriranje podataka u registru.

2. METODOLOGIJA

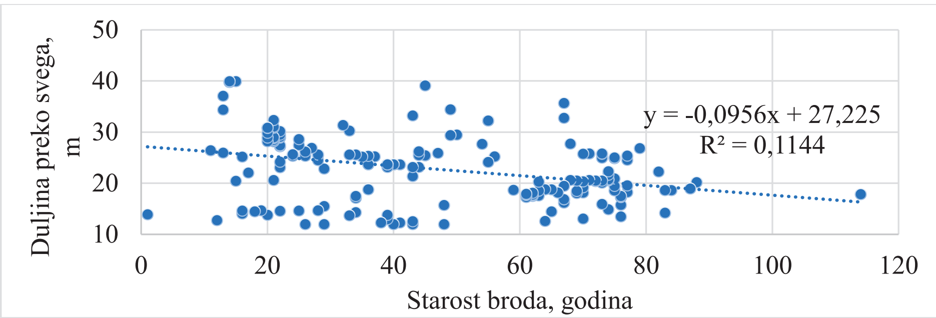
Kao izvor podataka korišteni su javno dostupni podaci, a koji su objedinjeni u Registru ribarske flote Republike Hrvatske [1]. Budući da ti podaci nisu prikladni za statističku obradu, korišteni su podaci o ribarskim flotama koje objedinjuje Europska komisija [2]. Na temelju dostupnih podataka uz korištenje ugrađenih funkcija prikaza i analize grafova unutar Microsoft Excel-a, regresijskom analizom i metodom najmanjih kvadrata određena je ovisnost snage motora i starosti ribarskih brodova.

3. REZULTATI I RASPRAVA

Slika 1 prikazuje utjecaj starosti brodova na snagu glavnih motora, dok Slika 2 prikazuje utjecaj starosti brodova na duljinu preko svega. Iz obje slike je jasno da je flota ribarskih brodova u Republici Hrvatskoj zastarjela. Ako se promatra snaga glavnih motora u ovisnosti o starosti broda, vidljivo je da se ta dva parametra ne mogu izraziti jasnom matematičkom ovisnošću, zbog premale vrijednosti koeficijenta determinacije. Međutim, trend je ipak jasan: stariji brodovi imaju u prosjeku manju snagu glavnih motora. Iz toga bi se moglo zaključiti da noviji brodovi imaju nepotrebno snažne motore te su stoga manje energetski učinkoviti od starijih. Međutim, taj bi zaključak bio pogrešan jer Slika 2 ukazuje da su stariji brodovi također u prosjeku i nešto kraći.



Slika 1. Utjecaj starosti broda na snagu glavnih motora



Slika 2. Ovisnost duljine preko svega o starosti broda

4. ZAKLJUČAK

Iako se starost flote ribarskih brodova isticala kao dominantan uzrok negativnog utjecaja na okoliš, rezultati ove analize to ne potvrđuju. Naime, noviji brodovi u prosjeku imaju jače motore, međutim u prosjeku su i dulji. Kako noviji motori imaju u pravilu manju specifičnu potrošnju goriva, razlike u potrošnji goriva nisu značajne.

Zahvala: Ova analiza je provedena u okviru projekta „Mreža organizacija ribara i znanstvenika – MORZ" koji je sufinanciran sredstvima Europske unije iz Europskog fonda za pomorstvo i ribarstvo.

Reference:

[1] https://podaci.ribarstvo.hr/

[2] https://webgate.ec.europa.eu/fleet-europa/search_en

University of Rijeka
FACULTY OF ENGINEERING

FLOW
SHIP DESIGN

ALLSTARS
ENGINEERING GROUP

TSi
Technical Services

Lng
HRVATSKA

CRS
CROATIAN REGISTER OF SHIPPING

MACGREGOR

BETINA
brodogradilište i marina

MARINA PUNAT
ISLAND KRK, CROATIA
1ST NAUTICAL ADDRESS OF CROATIA
Your 2nd Home

BUREAU VERITAS
1828

3. MAJ
Brodogradilište d.d.

Navis Consult
a KONGSBERG company

ATLANTSKA PLOVIDBA d.d.
DUBROVNIK

FESB

ITCR d.o.o.
Savska cesta 41, 10000 Zagreb

Royal IHC


LNG CROATIA
COOL EXPLORER
Lng
HRVATSKA

Creating the maritime future

About Royal IHC

Anchored in a rich Dutch maritime history, Royal IHC is a leading supplier of maritime technology and expert craftsmanship.

With the right people and skills on board, and driven by innovation, we provide a competitive edge to our worldwide customers in the dredging, offshore, mining and defence industries. However, Royal IHC is much more than vessels, equipment and services. We deliver reliable, integrated solutions that improve operational efficiency and allow for a more sustainable performance.

All over the world, our people are deeply committed to technological innovation, supported by our long-standing experience in our core markets. Our experts work in close collaboration with multiple stakeholders to meet the specific needs of each customer.

As we navigate new waters in an ever-changing world, our aim remains unchanged: to discover the smartest and safest way forward for both our customers and our people. Together, we create the maritime future.

IHC Engineering Croatia d.o.o.

As subsidiary of Royal IHC, IHC Engineering Croatia d.o.o. (IEC) became a knowledge centre in detailed engineering due to continuous collaboration with Royal IHC's yards. With locations in Rijeka and Pula and a comprehensive capacity of 90 engineers, IEC is an esteemed supplier of engineering services. Alongside detailed engineering, IEC is increasingly providing basic engineering services to diversify its expertise.

In addition to collaborating with Royal IHC, IEC actively works for external customers and other partners to continually develop its expertise in the cruise ship, mega yacht, and special equipment engineering sectors.

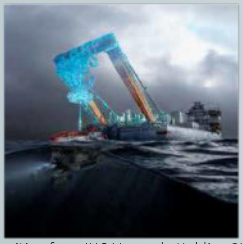
Considering that Croatia has a longstanding tradition in the shipbuilding sector, IEC is perfectly positioned to develop local engineering skills. These are vital to continually deliver exceptional professional standards in the global maritime industry.

IHC Dredging

IHC Offshore Energy

IHC Mining

IHC Defence



Scope of work

- Basic engineering
  - stability calculations
  - statutory drawings
  - hull strength calculations and production plans
  - schematics
  - Piping and Instrumentation Diagrams (P&IDs).

- Detail engineering
  - hull design
  - pipe routing
  - outfitting

- HVAC

- Production documentation

- Conversions

Contact

Royal IHC
Wim van de Voorde
Director Engineering
T +31 88 015 37 88
M +31 6 20 81 66 38
E wj.vandevoorde@royalihc.com

Smitweg 6
2961 AW Kinderdijk
The Netherlands

IHC Engineering Croatia d.o.o.
Marijeta Miklić
Technical Manager
T +385 51 37 23 88
M +385 99 24 41 195
E m.miklic@royalihc.com

Milutina Barača 7
51000 Rijeka
Croatia

Types of vessels

We deliver engineering packages for the following types of vessels.

- Dredgers
  - hopper
  - trailing suction
  - backhoe
  - cutter suction

- Offshore vessels
  - pipelay
  - cablelay
  - heavy lift
  - drilling

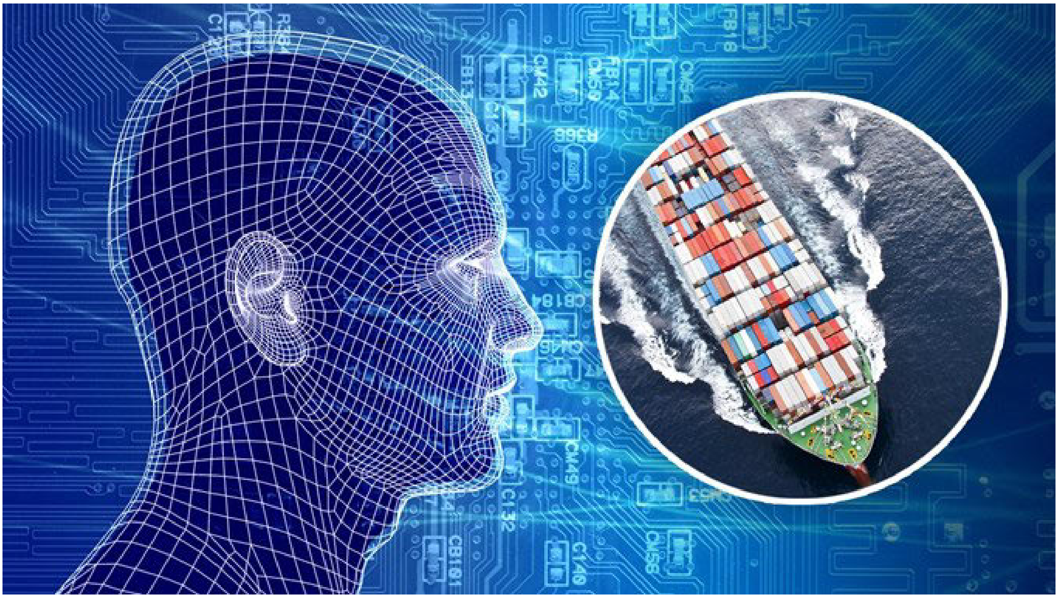
- Other
  - cruise ships
  - megayachts
  - ferries
  - patrol boats

Royal IHC

Creating the maritime future

royalihc.com/croatia

MacGregor – the leader in intelligent maritime cargo and load handling



MacGregor is a world-leading provider of cargo and load handling equipment, services and solutions delivered through a strong portfolio of established brands.

We understand the maritime industry and our customers' business needs, with a proven track record in the delivery of innovative, value-adding solutions. Our expertise is also often sought by industry bodies when developing new standards and regulations.

Shipbuilders, owners and operators are able to optimise the profitability, safety, reliability and environmental sustainability of their operations by working in close cooperation with MacGregor.

Our vision, together with our commitment to excellence and bold spirit, drives us forward.

FLOW
SHIP DESIGN

COMPANY

An independent ship design and consultancy company.
Established, owned, managed and fostered by a team of 4 naval architects with the aim to deliver innovative design and engineering solutions.
Close cooperation with customer, in forefront of new technologies implementation, research, development and experience are key factors to successful designs and satisfied customers.

TEAM

Team of 18 engineers - Naval architects, marine engineers, electrical engineers with comprehensive knowledge and experience from designed, built and delivered vessels.
All employees with average more than 15 years working in ship design, production and commisioning departments in various field in shipyards, class society and as ship owners' representatives.

PROFICIENCY

Flow ship design delivers innovative designs with customer specific requirements.
The close cooperation with the customer is a key factor in the design process.
The company specialization covers various types of vessels, including all the phases of the ship design process.

FLOW
SHIP DESIGN

- Concept
- Hull & Structural
- Outfitting
- Electrical & Automation
- R&D
- Conversion & Retrofit
- Consultancy
- E&A Turn Key Projects

info@flowship.eu
+385 98 980 3283
+385 52 354 692
Anticova 9,
52100 Pula, Croatia

www.flowship.eu

ALLSTARS
ENGINEERING GROUP

ALLSTARS GROUP FINLAND

In 30 years our company has advanced from a shipyard engineering office into a project management corporation of marine, process, and machine technology industries. We are specialized in executing demanding design projects for e.g. shipyards and paper mills. We also provide state-of-the art turnkey deliveries of glass product solutions for ships as well as private and public buildings.

ALLSTARS ENGINEERING CROATIA

Allstars Engineering Croatia is part of Allstars Group Finland, with offices in Finland, Bulgaria, Poland and Croatia. Since incorporation of the Croatian company 9 years ago, we have successfully completed projects for a number of renowned clients, including:

- Meyer Turku, Europlan, Rauma Marine Constructions, MacGregor (Finland)
- Chantiers de l'Atlantique (France)
- FKAB Marine Design (Sweden)
- MacGregor Croatia, Navis Consult (Kongsberg), Brodosplit, Brodotrogir, DIV MES, Nuclear powerplant Krsko, KLIMAOPREMA, PROKLIMA (member of WOLF Group) (Croatia)
- Electroteknik (Turkey)
- Shapeair (Australia)
- Exmar Offshore (USA)

WE ARE EXPERIENCED AND FAMILIAR WITH

AUTOCAD, Ansys, AVEVA MARINE, CADMATIC, CATIA, NAVISWORKS, SOLIDWORKS, AUTODESK INVENTOR, E3D, NAPA

OUR CAPABILITIES IN THE SHIP-OFFSHORE DESIGN/ POWER PLANTS/ HVAC

Comprehensive project management

- Project planning
- Implementation and reporting
- Document management
- Quality control
- Risk management

Calculation, basic and detail design, product development

- FEM services
- Hull classification and workshop design
- Machinery and system design
- Deck outfitting and equipment design
- HVAC and piping design
- Interior and electrical design
- Mechanical engineering

Specialist service

- Project managers and assistants
- Design engineers
- Foremen and supervisors

Current employee structure

- Hull - 14 employees
- Machinery/HVAC - 15 employees
- Outfitting - 5 employees
- Interior - 5 employees
- Electro - 1 employee

Technical Services

www.tsi.hr

TSI Company Profile

TSI d.o.o. is ship design and engineering company present on shipbuilding market as a part of MEYER Group.

TSI team consists of 166 employees, mainly naval acrhitects, electrical and mechanical engineers.

TSI main focus is to **meet high expectations of the shipyards and the shipowners** through outcome that meets all client's quality standards and delivery on schedule.

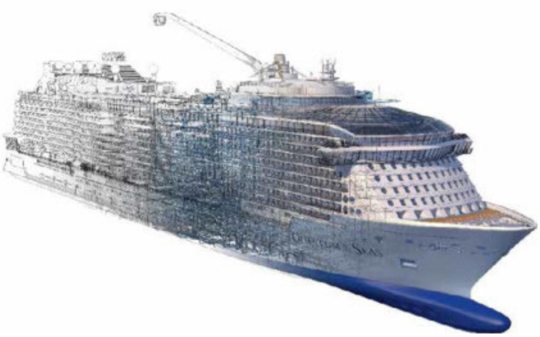
MEYER Group is an international consortium with three shipyards in Papenburg, Rostock and the Finnish city of Turku, as well as other subsidiaries and companies of MEYER Group. Around 7,000 people work directly for us. We work with our highly qualified network to build cruise ships, river cruise ships and ferries for customers around the world. Our vessels are tailored exactly to each market and target group.

The MEYER Group generates a total of 40,000 jobs in the shipbuilding and supply industry, as well as in various trades involved in shipyard operations in Germany, Finland and other European countries.

NEPTUN WERFT
ROSTOCK 1850

MEYER WERFT
PAPENBURG 1795

MEYER TURKU
SHIPYARD 1737



TSI Company Activities

- **Design and engineering in ship building** from initial design and feasibility studies to production support
- **Close cooperation** with our clients, mainly shipyards and shipowners
- Permanent development of **working procedures and quality**
- Internal education meeting project requirements
- HVAC Marine Engineering

TSI Company Products and Services

- Feasibility studies
- Concept design
- Detail engineering
- Production support
- Equipment engineering
- New building and conversion supervision

TSI d.o.o., Slavka Tomašića 5, 51000 Rijeka, Croatia
Tel. +385 51 734 225 | Fax. +385 51 563 946

sorta.fsb.hr

9 789537 738860