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IAMU 2024 Research Project
(No. YAS202406)

ROV education and training for seafarers

By

University of Rijeka, Faculty of Maritime Studies

August 2025

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This report is published as part of the 2024 Research Project in the 2024 Capacity Building Project of International Association of Maritime Universities, which is fully supported by The Nippon Foundation.

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Published by the International Association of Maritime Universities (IAMU) Secretariat
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ISBN : 978-4-907408-63-3

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Executive summary

The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW Convention) establishes minimum required standards for education and training of seafarers worldwide. At present, there are no standardized or widely adopted training programs for the operation of inspection-class Remotely Operated Vehicles (ROVs) within maritime education. As these tools become more common on commercial vessels, the absence of formal training contributes to inefficient usage, inspection errors, and increased operational risks.

To bridge this gap, the development of a dedicated training program for seafarers was identified as a critical need, supplementing existing maritime education. This was also recognized by International Association of Maritime Universities (IAMU) when the Research Project proposal for Young Academic Staff in FY2024, entitled "ROV Education and Training for Seafarers" was accepted. Given the 13-month timeframe of the project, a structured approach was essential, with each phase carefully planned and executed within the allocated time.

The project began with a comprehensive review of existing literature on ship hull inspections, with the focus on those using ROVs. This was followed by a series of interviews involving ROV manufacturers, shipping companies, and seafarers. The goal was to identify core competencies and practical challenges associated with using ROVs for hull inspections, especially in the very first stage of using the equipment. To ensure relevant and experience-based input, the interviews were conducted exclusively with individuals who had firsthand experience operating ROVs for this specific purpose.

Research indicates that ROVs are mainly used on ships to minimize the need for divers and verify their work, inspect hulls for fouling to determine when hull cleaning is necessary, assess damage after seabed contact, and identify entanglements such as ropes around propellers and rudders. ROV piloting skills are typically acquired informally and than shared among crew members (officers) and across ships within a fleet. The most common operational concern is cable entanglement, especially near propellers and rudders.

Senior officers often encourage junior officers to develop additional competencies beyond standard training, as such skills enhance performance evaluations and future job opportunities. All interviewed seafarers support the idea of integrating basic ROV training into maritime education to better prepare future seafarers for the onboard responsibilities. Some users remain hesitant to engage with new technology, such as ROVs, primarily due to fear of potential equipment damage as the result of unfamiliarity.

According to ROV manufacturers, sales of inspection-class ROVs to the shipping industry are on the rise. While most manufacturers provide online training materials, they agree that this method cannot replace the value of hands-on experience. Their training sessions typically focuses on operating the ROV itself, with no emphasis on inspection techniques. As a result, inclusion of inspection-related training into standard maritime education would be beneficial for future ROV operators.

The representative of the shipping company which is also involved in the recruitment process points out that even basic ROV operation skills are considered an advantage during recruitment, which emphasizes the growing relevance of this technology.

In addition to the interviews with key stakeholders, pilot hull inspections were conducted by the authors on several vessels in different environments. These practical trials served to validate findings from the

interviews and uncover further training needs that may not have been captured through the previous stage.

Based on the collected insights and relevant literature, an extended training syllabus for inspection-class ROV operation, specifically for hull inspection purposes, has been developed. The proposed syllabus integrates both theoretical foundations and hands-on skills essential for safe and effective underwater inspections.

It is recommended that the developed syllabus be shared with maritime universities and training institutions worldwide. Providing future seafarers, particularly deck officers, with these specialized competencies will not only improve the safety and efficiency of vessel maintenance but also broaden their career prospects within the expanding blue economy, where ROV technology is increasingly in demand.

Acknowledgement

We would like to express our honest gratitude to the International Association of Maritime Universities (IAMU) for their support and collaboration throughout this research. We are also deeply thankful to all individuals who kindly participated in our interviews. Their insights and readiness to share valuable experiences significantly contributed to the findings of this research project.

Final Report for the IAMU

Capacity building Project "ROV education and training for seafarers"

Theme: Maritime Education and Training in the era of global change

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Abstract – The maritime industry is rapidly evolving due to technological innovation, stricter safety regulations and growing environmental demands. Although the STCW Convention establishes baseline competency standards for seafarers, these often fall behind modern developments, highlighting the need for enhanced and specialized training. One critical area requiring attention is the underwater inspection of a ship's hull, an essential procedure for ensuring vessel integrity, operational efficiency, environmental compliance and security. Traditionally performed by divers, these inspections involve considerable safety risks, high costs and logistical challenges.

The emergence of Remotely Operated Vehicles (ROVs), particularly inspection-class models, offers a safer and more efficient alternative for underwater hull inspections. As these technologies become increasingly accessible to the commercial shipping sector, a growing number of shipping companies are beginning to implement them on their vessels. However, this shift highlights the need for qualified personnel capable of operating the equipment effectively and safely.

This paper suggests the integration of ROV operation into maritime education, especially for future deck and technical officers. Interviews were conducted with ROV manufacturers,

shipping companies and seafarers currently involved in ROV hull inspections. Additionally, pilot in-water hull inspections were carried out to validate and supplement the collected insights. The objective was to identify practical challenges associated with implementing this technology and to incorporate these findings into a comprehensive training framework. The final training syllabus combines theoretical knowledge with practical (hands-on) skills, aligning maritime education and training with industry needs. Such competencies will not only improve onboard maintenance and safety procedures but also expand career prospects for seafarers within the wider blue economy.

Keywords: *Maritime Education and Training (MET), Remotely Operated Vehicle (ROV), ship's hull inspection*

1. Introduction

1.1 Background

The maritime industry is undergoing a significant transformation, driven by technological advancement, evolving safety standards and environmental imperatives. While the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW Convention) provides a framework for the minimum required competencies of seafarers, these requirements often lag behind the continuous developments in maritime technology and operations. As a result, seafarers are increasingly encouraged to expand their professional competencies and go beyond regulatory minimums to remain competitive in the industry. This especially applies to those at the beginning of their careers.

Safety, security, and environmental protection remain central concerns in maritime operations. However, these must be balanced with efficiency and economic performance, which are critical for commercial sustainability. The education and training of seafarers must follow evolving technologies in the shipping industry, particularly in specialized areas such as underwater hull inspection.

The purpose of regular underwater inspections is to assess a vessel's condition, detect structural damage, and evaluate the level of corrosion and biofouling. These inspections are crucial not only for safety and operational efficiency but also for environmental compliance and security purposes, such as the detection of smuggled goods attached to the hull. Traditionally, these inspections have relied on professional divers, who conduct visual assessments and prepare reports supported by photographic or video evidence. However, this method has limitations, including safety risks to divers, high operational costs, logistical challenges, and procedural complexity.

An increasingly feasible alternative is the deployment of remotely operated vehicles (ROVs), particularly the compact inspection-class models. Once limited to military and offshore industries due to their cost and complexity, modern ROVs are now becoming more affordable and accessible to the commercial shipping sector. These devices eliminate human risk, offer extended operational time, and can be equipped with advanced tools such as ultrasonic thickness gauges, laser measurement systems, and manipulators. As such, ROVs present an opportunity to enhance underwater inspection practices onboard vessels.

The growing interest in the use of ROVs by shipowners highlights the potential for cost-effective, timely inspections without relying on external diving services. However, this transition drags along a targeted training for the personnel involved in this task. Currently, ROV operations are often assigned to existing crew members without adequate preparation or the development of specific competencies. This leads to suboptimal results, including poor inspection quality, equipment misuse, following by damage to the equipment and extra costs.

It is, therefore, imperative to integrate ROV operational training into maritime education, particularly for future deck and technical officers. Developing specific training programs that encompass both theoretical knowledge and practical skills will not only improve the efficiency and safety of underwater inspections but also align maritime education with the industry's evolving technology.

1.2 Objectives and aims of the research project

The research objectives of this project are:
- To analyse the primary purpose, scope and approach to the use of inspection-class ROVs by seafarers aboard vessels;
- To analyse the type of familiarization, instruction, or training seafarers receive before using an ROV, and
- To assess the essential theoretical knowledge and practical skills a seafarer must acquire and develop to safely and effectively operate an ROV for ship hull inspections.

Based on these objectives, the main aim of the project is to develop a breakdown of the training program for lectures and exercises that align with industry needs. Incorporating ROV training into the standard maritime education program would enhance seafarers' proficiency in smart technology, underwater robotics and digital solutions. By integrating relevant competencies, future maritime professionals will be better prepared to adapt to technological advancements and industry demands in that respect.

The knowledge and skills gained during both the theoretical and practical parts of the proposed education/training for operating an ROV for ship inspections can be easily applied to various water-related industries that utilize ROV operations. This facilitates future seafarers an easier transition into other sectors of the blue economy.

1.3 Research deliverables and self-assessment of the project

As per Consignment Contract between IAMU and University of Rijeka, Faculty of Maritime studies (Contractor), all required deliverables were completed:
- Interim report presentation, presented in AGA2024, organized by Massachusetts Maritime Academy, from 9-12 October 2024,
- Progress report submitted to the Secretariat, by the end of March, and
- Final research report (this report) – submitted no later than 31 May 2025.

In addition, the abstract for the IAMU Conference 2025 was submitted and accepted for presentation at AMET University in Chennai, India, scheduled from 17-18 October 2025. Therefore, the full paper, containing key findings of the research, was submitted for publication in the Proceedings of the International Association of Maritime Universities Conference (IAMUC) 2025.

The project has generally adhered to the time schedule in the application form, with some tasks extended and some added due to the extensive nature of the research. The literature review commenced on time, but continued beyond the anticipated end date, as the broad scope of the topic required a more detailed analysis than initially anticipated. Interviews with two inspection-class ROV manufacturers were completed as scheduled, while a third was postponed due to scheduling conflicts, requiring additional coordination.

The survey and interviews with seafarers were initiated as planned but extended beyond the intended timeframe. Each respondent provided valuable feedback, leading to refinement in the questionnaire to better support the development of the training course. All contributions, both within and beyond the scheduled period, were included in the creation of the syllabus and training materials, thereby enhancing their quality. This extension is therefore considered justified.

An interview with a shipping company representative was conducted as scheduled. Initially, the plan was to include multiple companies in the research. However, it became apparent that this would be quite a challenging task as few companies currently use this type of equipment on their ships and arranging the interview with the management personnel of the companies proved difficult.

The interviews with classification society representatives didn't take place due to similar reasons. However, this part is not considered essential for the course development. Instead, its main value lies in offering a broader perspective on the research.

The training syllabus framework was completed and presented at AGA 2024 in Massachusetts, USA. Construction of the underwater training polygon experienced a slight delay due to necessary adjustments after its deployment at the Torpedo port area. Ultimately, the polygon turned out to be very beneficial for developing various training scenarios in a controlled environment.

Pilot in-water hull inspections were conducted in addition to the original plan, as it was realized during the interviews that verification of the collected findings was necessary. Furthermore, these inspections also provided a valuable first-hand understanding of the operational challenges, which were used for the final syllabus development.

The development of the training program description began as scheduled and was completed as planned. The program comprises a comprehensive and well-structured syllabus divided into sections, ensuring that practical training is covered with a thorough understanding of its theory. Emphasis is placed on developing hands-on skills, enabling participants to effectively apply learned skills in real-world scenarios.

While minor delays occurred in certain areas, additional elements were incorporated that were considered essential for improving the overall outcome. The extended research period (particularly the interviews with seafarers) and the continued refinement of training materials have significantly contributed to a higher-quality result. As such, the project remains aligned with its objectives and is considered successful within the overall timeframe.

2. Literature review

Structural failure is one of the major contributors to serious maritime accidents [1], and can be caused by a range of factors, including structural overloading, flaws in ship design, material imperfections, poor welding, coating breakdown, corrosion, etc. [2]. To mitigate these risks, ships are constructed by

following strict safety standards and are subject to thorough inspections both during construction and throughout their service life [3].

Additionally, grounding or collision incidents can have serious effects on the structural integrity of the ship's hull. "Touch and go" incidents, where a vessel briefly contacts the seabed and continues moving, should also be taken seriously, as they can result in localized denting of bottom plating, early coating wear and damage to the propeller or rudder. If not addressed, these issues can lead to long-term corrosion. Inspections following such incidents are essential for identifying defects early, enabling timely repairs and maintenance that help preserve the condition of the ship's hull and reduce the risk of structural failure.

Regular hull inspections are also essential for identifying and controlling biofouling, i.e., the accumulation of aquatic organisms on the hull surface [4]. If not properly managed, even a minor microfouling can reduce a vessel's efficiency by 10-16% [5]. In parallel with that, the fuel consumption is increasing, as well as the risk of spreading invasive species across ecosystems. Timely hull inspections enable proactive maintenance, thereby improving the vessel's overall operational efficiency.

Hull inspection is essential part of class surveys carried out by classification societies, following strict rules and standards. Among other things, the objective of classification is to verify the structural strength and integrity of the ship's hull and its appendages. To remain in class, ships periodically need to undergo a specific type of inspection. These inspections are: class renewal (special survey), intermediate survey, annual survey and bottom/docking survey. Specific class requirements ensure that condition of the hull complies with the relevant classification society Rules.

A bottom/docking inspection involves surveying the ship's hull and related components. It may be carried out when the ship is in dry dock, known as dry-docking survey, or while afloat, referred to as an in-water survey (IWS). The acceptance of an IWS in lieu of a dry-docking inspection depends on several factors, such as the ship's type, age and inspection history.

The IWS must be performed in sheltered waters and ideally under low sea current conditions. If damage or deterioration is detected during an IWS, the Surveyor may require the ship to undergo dry-docking for a more detailed survey and necessary repairs [6]. These inspections are crucial for ensuring the structural condition of the hull [2].

The hull and its associated parts are typically inspected in conjunction with the special survey, which occurs every 5 years. However, regardless of the timing, the interval between two inspections should not exceed 36 months. One of these inspections must be conducted as part of the renewal/special survey [7].

As per International Association of Classification Societies (IACS) Requirement Z7, "close-up survey" differs from "Remote Inspection Technique" (RIT), where in the former case the details of structural components are normally within reach of hand of the surveyor, while the latter represents a means of survey that enables examination of any part of the structure without the need for direct physical access of the surveyor [8].

RIT techniques may include the use of: divers, unmanned robot arms, Remotely Operated Vehicles (ROV), climbers, drones, or other means acceptable to the Society. The presence of the Surveyor is required for this method of inspection. Use of this technique is limited where there is an indication of damage or deterioration, or if there are recommendations for repairs. This inspection needs to be completed by a qualified technician with adequate knowledge of the inspected items. To conduct a safe and efficient inspection, a meeting should be carried out prior to its commencement where all involved

parties will be present – the technician, the owner's representative and the attending Surveyor. It is required that underwater visibility is sufficient for a meaningful examination [9], where the exact level of visibility is not stated.

As RIT techniques could be used for remote inspection of internal and external areas, the Underwater Inspection in Lieu of Dry-Docking (UWILD) method is focused on external hull areas and their components. The goal remains the same – to inspect the submerged part of the ship during regular operations to avoid operational downtime, additional travel time to the location of the dock, and cost [10].

From a conservative point of view, underwater ship's inspection is carried out by properly trained and equipped divers (with a sufficient number of personnel) who, after completing the inspection, prepare a report with attached photographic/video material. When hull inspections are carried out for class verification or insurance purposes by using diving services, they are usually performed in accordance with requirements and guidelines from classification societies. Such requirements for in-water surveys include diver qualifications, visibility conditions, and acceptable inspection procedures.

Along with the inspection itself, various tasks could be performed using this method, such as: hull cleaning, propeller polishing, anode replacement, repair or replacement of the thruster, etc. These operations, although very effective in collecting detailed visual assessments, proved to be very hazardous. Numerous studies have documented the considerable risks associated with diving operations, with a number of deaths and serious injuries of divers during ship inspection and other related tasks. This has been related to factors such as poor supervision, poor planning and safety management, equipment failure and dangerous environments [11].

As per Hermans' research of fatal accidents in the commercial diving sector, there have been recorded 577 fatalities in a 40-year period, where 15% of the accidents fall in the shipping sector [12]. Most of the fatal accidents in all sectors (22%) were caused by a pressure differential, while in shipping sector the main cause (27%) was drowning (flooding of the helmet or the band mask), followed by accidents in connection with the unexpected start of the propeller (18%). Scuba diving method caused 77% of the fatalities, while the rest (23%) falls on diving from the surface with an umbilical (SSD method).

The annual repartition of the fatalities in the Shipping sector is presented in Figure 1, while causes (%) of the diving fatalities is shown on Figure 2. Also, working hours in this sector often exceed the working time found in other observed sectors. All of the above indicates that a safer alternative is needed, at least for the portion of the tasks that can be done by the other method.

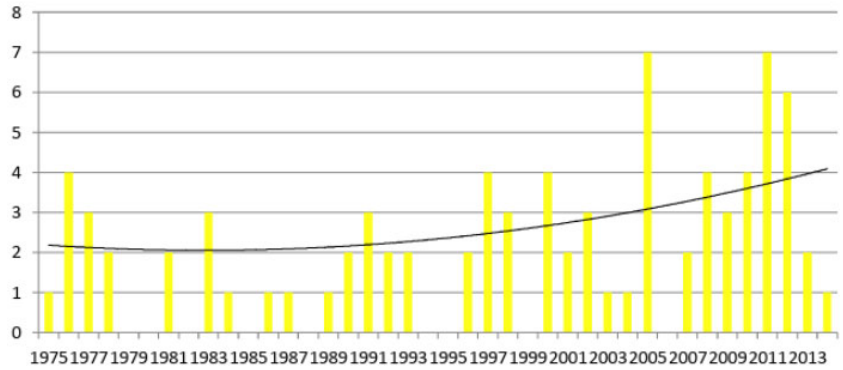


Fig. 1. Annual distribution of the fatalities in the shipping industry [12]

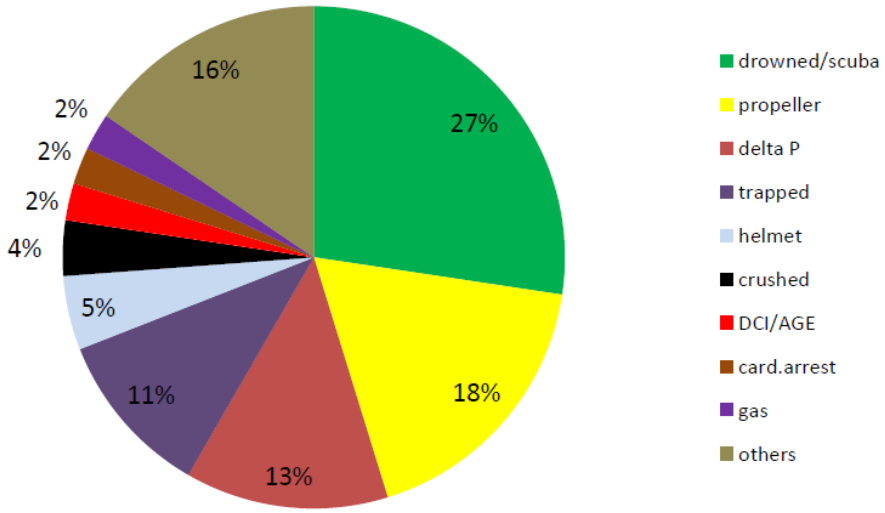


Fig. 2. Causes of the diving fatalities (%) in the shipping industry [12]

In addition to safety concerns, diving operations present significant logistical and operational limitations. Difficulties arise in organizing these operations at a specific times and locations (convenient ports), preparing and maintaining specific documentation before, during and after inspections (including Risk Assessment, Dive Logs, Emergency Procedures, etc.), coordinating with relevant authorities, and adhering to Company ISM procedures (such as obtaining a Dive permit). The duration of the inspection itself further adds to the complexity. These requirements significantly increase the time and financial resources necessary to complete even routine underwater inspections.

Inspection itself may be carried out by approved companies, where specific procedures and requirements for approval and certification of these companies, known as service suppliers, are described in Procedural Requirements provided by the classification societies [13].

As per mentioned document, service suppliers carrying out an in-water survey on ships and mobile offshore units by diver or Remotely Operated Vehicle (ROV) are responsible for the training of their personnel, i.e. divers, ROV operators and supervisors, where specific knowledge is documented, including ship's underwater structure and appendages, propeller, rudder and its bearings, non-destructive testing, bearing clearance measurements on rudders and propeller shaft, under-water video monitoring, etc. In addition, there is stated minimum experience of the personnel involved in the operation, necessary equipment for the operation, as well as documented operational procedures and guidelines on how to conduct the survey and manage the equipment.

On the Certificate issued by specific Classification society needs to be clearly stated the type and scope of services and any limitations or restrictions. Thus, the results of the inspection are used by surveyors, affecting classification or statutory certifications [14].

As an example, the table below shows the number of service suppliers approved by the Det Norske Veritas (DNV) classification society over a four-year period [15]. The data includes number of

certificates issued annually from April 2021 to May 2025. Two categories are distinguished: “In-water survey by diver and ROV”, and “In-water survey by ROV”.

Table 1: Number of DNV approvals of service suppliers [15]

Approval of Service Suppliers (DNV)		
	In-water survey by diver and ROV	In-water survey by ROV
2021 (from April)	12	4
2022	31	7
2023	31	8
2024	33	6
2025 (until May)	6	8
Total	**113**	**33**

The data above indicates that classification societies are open to alternatives to diver-only services. This includes the adoption of new technologies, specifically the use of remotely operated vehicles (ROVs) for ship hull inspection. Furthermore, this area is increasingly becoming the subject of research, recognizing the benefits of using ROV technology during the hull survey, whether as a stand-alone method or in support of established diving services [16, 17].

ROVs are unmanned, tethered submersible units equipped with cameras, lights, manipulators and various sensors, enabling real-time, detailed inspection of submerged structures. The use of ROVs began in the 1950s for the recovery of torpedos and mines and later expanded to military and offshore industry applications. ROVs are categorised into several classes based on their weight [18]:

- Observation class ROVs (OCROV),
- Mid-sized ROVs (MSROV) and
- Work class ROVs (WRROV).

Observation (inspection) class ROVs range from the smallest micro-ROVs to larger units up to 100 kg and are further subdivided into:

- Micro (small) OCROVs (weight less than 4.5 kg),
- Mini (medium) OCROVs (weight between 4.5 and 32 kg) and
- Large OCROVs (weight above 32 kg).

This class of ROVs are generally limited to depths of approximately 300 meters and are commonly used either as a backup to divers or as a cost-effective substitute for shallow water inspection tasks. In most cases, these ROVs are hand-launched and are capable of operating reliably with minimal maintenance requirements [18].

Due to their portability, reliability, and cost-effectiveness, Mini OCROVs have become a desirable option in the maritime industry as an alternative or supplement to traditional diver-based hull inspection methods. These compact underwater vehicles are equipped with high-quality cameras, various sensors and tools to detect the condition of the submerged structure of the ship. The adoption of this technology has also increased inspection frequency, enabled rapid deployment and reduced the number of personnel required for the operation. In addition, they provide high-resolution video and photographic documentation that can be reviewed and analysed even after inspections, supporting more accurate,

consistent and traceable decision-making. Further in this paper, only this class of ROVs will be discussed in detail.

Jacob [10] carried out a case study where a ROV-based UWILD survey was implemented on a Ro-Ro cargo vessel. Mentioned inspection showed major damages and significant marine growth on part of the bilge keel and on intake greetings, as well as damages on the bow resulting from anchor chaffing. Additionally, the survey revealed irregularities in the paint condition of the stern and on the rudder itself. Further observations were a moderate loss of anode thickness and sufficient clearance for the rudder. The mentioned remarks are shown in Figure 3. This inspection was carried out in the presence of a class surveyor and shipping company representative, where an immediate action plan was drafted for the necessary repair of the bilge keel and cleaning of the intake gratings. As an additional benefit, it was concluded that the vessel could make these repairs without entering dry-dock, thus avoiding downtime and additional costs.

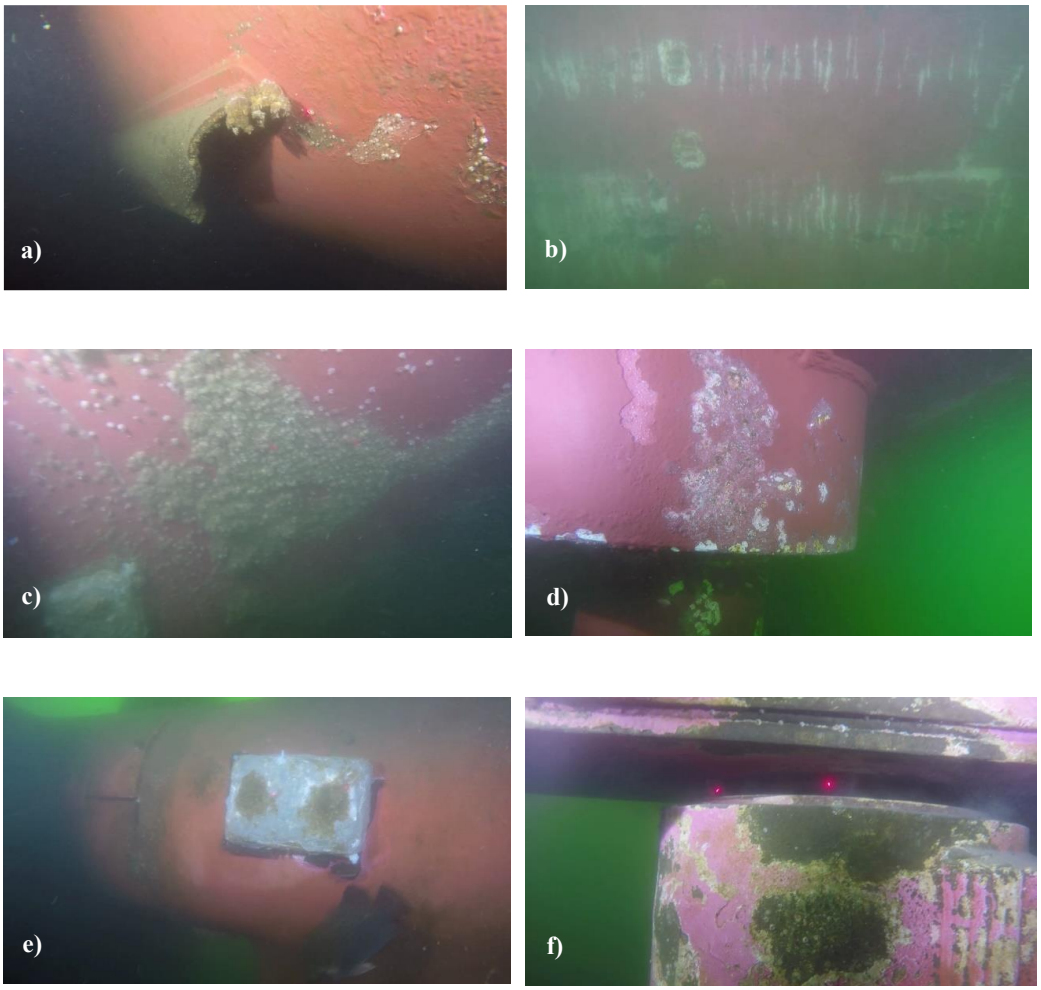


Fig. 3. Hull inspection using inspection class ROV a) damage on the bilge keel; b) scratch on the bow from the anchor chain; (c) biofouling on the stern; d) paint loss on the rudder; e) anode on the propeller and (f) rudder clearance from the support structure [10]

Although diver-based inspections continue to play a role in specific situations, particularly where human judgement and adaptability are crucial, ROV methods of inspection have proved to represent a transformative shift toward safer, faster, and cost-effective underwater ship inspection practices. Additionally, ROVs can perform inspections with greater endurance, as they are not subject to the physical limitations and fatigue factors that constrain divers.

As robotic inspection technologies continue to evolve and become more sophisticated, it is essential to highlight the parallel development of operator knowledge and skillsets. Both theoretical understanding and practical training are necessary to ensure that these technologies are used to their fullest potential. Without proper education and familiarity with the equipment, even the most advanced ROV systems may fail to deliver optimal results.

In the offshore sector, as working-class ROV technology became essential for various operations, the demand for qualified personnel (ROV Operators) grew rapidly. Although ROV Operator training has been carried out for approximately four decades, early programs were often inconsistent and varied in quality. The International Marine Contractors Association (IMCA), as a global association promoting safety, efficiency, and best practices within the offshore industry, recognized a need to ensure that newly employed ROV Operators must have minimum (base) standardized knowledge regarding ROV Operations and specific procedures. As a result, several publications were created (and regularly updated) emphasizing the need for structured education and training to increase safety and efficiency in their operations [19, 20]

A similar need is now emerging in the shipping industry, where inspection-class ROVs are increasingly being used on ships to support safe and cost-effective maintenance practices. In this context, a proactive approach should be adopted across maritime faculties at the international level to prepare future seafarers with the skills necessary for a smoother adaptation to onboard tasks.

This paper suggests upgrading of standard maritime education through the integration of ROV technology, with a particular focus on the ship hull inspection. The following sections outline the research methodology, present comprehensive interview results and pilot IWS conclusions and conclude with a detailed breakdown of the recommended training syllabus.

3. Methodology

To explore the use of ROVs for the ship's hull inspection, the study is divided into two parts: targeted interviews with key stakeholders and underwater inspections under real conditions. The main objective of the interviews was to gather first-hand insights from key stakeholders actively involved in ROV operations on ships and to incorporate their feedback into the design of the course framework. These stakeholders included ROV manufacturers, seafarers and shipping company representatives.

To ensure relevance and depth, a separate set of questions was compiled for each target group, reflecting their specific roles, responsibilities and expertise. Thus, there were 14, 11, and 8 main questions for seafarers, ROV manufacturers, and shipping companies, respectively. The interview was designed as unstructured, containing open-ended questions that allowed respondents more freedom and flexibility in their responses. Originally, the same number of questions were set for each participant in the same group. However, during the interview, new sub-questions were asked based on the direction and content of the previous answers.

Data collection was conducted through a combination of in-person and online interviews. However, two seafarers who were at sea at the time of the interview answered the questionnaire in writing, as this was

a more practical and convenient option under the circumstances. Interviews with ROV manufacturers also took place during the International interdisciplinary field workshop of maritime robotics and applications “Breaking the Surface 2024” held in Biograd na moru, Croatia, in September 2024. Each interview lasted between 20 and 30 minutes on average.

A total of 15 respondents took part in the interview and questionnaire phase of this research, with the most prominent group being seafarers (11 respondents). This group included 7 senior officers (Masters and Chief Officers) and 4 junior officers (2nd and 3rd Officers). These individuals were mainly employed on bulk carriers and passenger ships, offering valuable maritime experience.

In addition to the seafarers, three representatives from internationally recognized inspection class ROV manufacturers (Blueye, Deep Trekker and QYSEA) shared important information on technological advances, ROV design challenges and current market trends in the shipping industry. Their input was essential to understanding the broader context in which ROVs are being developed and deployed. Figure 4 presents a screenshot from the online interview with this group of respondents.



Fig. 4. Online interview with inspection-class ROV manufacturers

One respondent, a former Master who now holds a management position at a shipping company operating a fleet of bulk carriers, also contributed with valuable industry perspectives to enhance the research.

The participants’ feedback directly influenced the identification of key topics and skills that should be emphasized in the training syllabus for ROV-based inspections. Their experiences, especially valuable mistakes and adaptations, were seen as critical to designing realistic and effective educational content.

The research results were processed qualitatively, and the most important conclusions are presented in subsection 4.1.

To master piloting skills successfully and safely, it was clear from the very beginning that a training ground should be created. Thus, an underwater training polygon was constructed using water drainage pipes, creating loops, or „doors“ designed for ROV passage (Fig. 5-7). Each door measures approximately 100 x 100 cm, allowing inspection-class ROVs to pass through. The polygon consists of three independent loops, which can also be connected into a single part, two of which require horizontal movement of the ROV, while the third requires vertical movement (with an adjustable angle).



Fig. 5. Construction of training polygon - view 1



Fig. 6. Construction of training polygon - view 2



Fig. 7. Construction of training polygon – view 3

The loops can be arranged to create various training scenarios, changing courses and depths. Due to their lightweight design, the polygon was stabilized by weights on the lower part to maintain its position on the seabed. The structures can be deployed in various locations under varying environmental conditions, such as strong sea currents and low visibility, depending on the skill level of the participants.

In the figures below (Fig. 8-9) the training polygon is shown, deployed in the small bay in front of the Laboratory for Marine Technologies (LMT), located in a separate Faculty facility at the port of Torpedo.



Fig. 8. Training polygon positioned in the bay in front of LMT - view 1

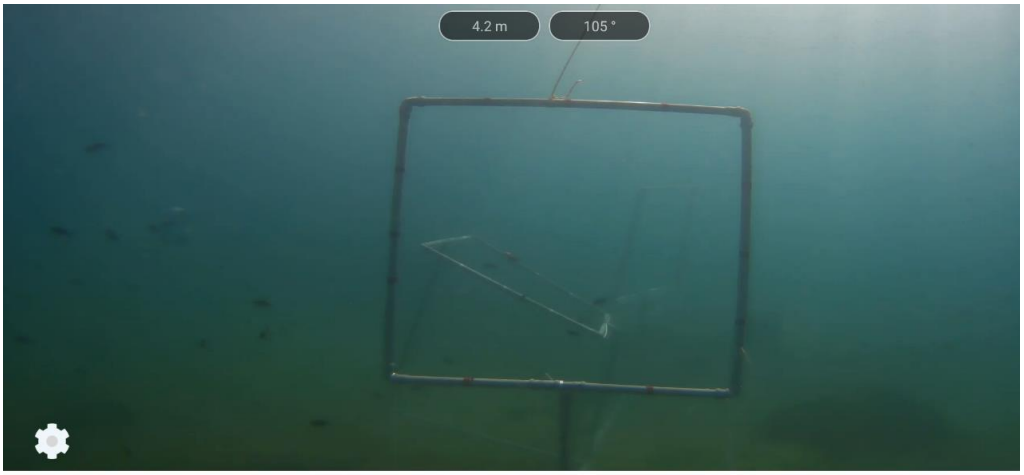


Fig. 9. Training polygon positioned in the bay in front of LMT - view 2

The purpose of building such a training ground is to offer a controlled environment where future seafarers, i.e. ROV operators, can safely develop their piloting skills (Fig. 10-12).



Fig. 10. Practical training with an ROV on the underwater polygon - view 1



Fig. 11: Practical training with an ROV on the underwater polygon - view 2

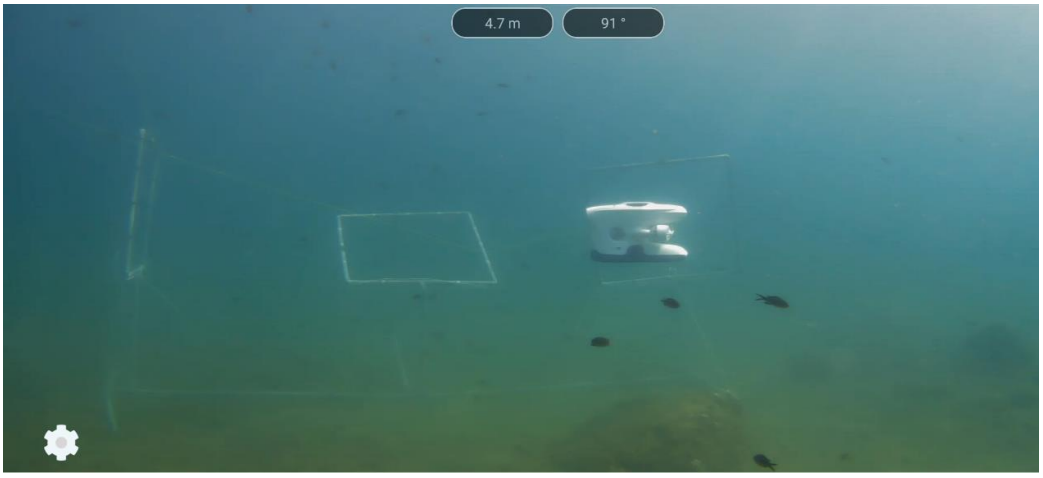


Fig. 12. Practical training with an ROV on the underwater polygon - view 3

Using an underwater polygon is enabling the participants to build confidence by passing through confined spaces with multiple obstacles. In addition, it allows for the practice of emergency procedures, such as cable entanglement (Fig. 13-14), which is a common challenge in real-world operations.



Fig. 13. Simulation of cable entanglement using underwater polygon - view 1



Fig. 14. Simulation of cable entanglement using underwater polygon - view 2

The primary objective of this research was to conduct in-depth interviews, which was only possible with seafarers actively using ROVs on board. Although the initial research plan was to include a larger number of respondents, the research revealed that most companies have not yet adopted hull inspections using ROVs, indicating that this concept is still relatively new and evolving. Therefore, the inclusion of respondents with no practical experience of ROV inspection was considered counterproductive to the aims of the study and would not have contributed to the quality of the results.

According to the original research timeline, all interviews were scheduled to be completed by September 2024. However, due to the valuable insights already obtained, a decision was made to adopt a more flexible approach by continuing with the interviews whenever an opportunity arises, i.e. when a suitable participant was found. This adjustment has allowed the research to remain dynamic and responsive to emerging insights in the industry.

Pilot in-water hull surveys were organized and conducted by the authors on several ships in the ports of Rijeka and Kraljevica. These ships were passenger ships and Ro-Ro passenger ships up to 100 meters in length. The inspections provided a broader perspective on the operational reality and the challenges seafarers face during underwater hull inspections. These surveys also served to validate the interview results and confirmed many of the insights gathered from various respondents. They also highlighted additional practical considerations that had not previously been emphasized and that will be important for the preparation of the course syllabus.

4. Results

4.1. Findings from the seafarers

In order to identify current practices, gaps, and opportunities for improving the use of ROVs in hull inspection, the following interview questions were developed. It consists of 14 main questions (with additional sub-questions) covering the implementation of this technology, crew training and competency as well as operational challenges and experiences. Unless otherwise stated, participants' responses were summed into shared conclusions/findings.

Interview questions for seafarers
Implementation of ROV Operations 1. When did your company start using ROVs for ship hull inspections, and what was the main reason for adopting this technology? 2. How frequently do you use ROVs for ship inspections? • Is this task included in the Planned Maintenance System (PMS)? 3. Do you use any additional equipment or probes with the ROV (e.g., robotic arm, thickness gauge, cathodic protection probes)? **Training & Competency** 4. Have you attended an ROV operator training course? If so: • Where was the course conducted? • Was it arranged/paid for by your company, or did you arrange it independently? • What was the duration and structure of the course (theory vs. practical training)? • How was the practical training conducted? 5. Who serves as the ROV operator on your ship? • Is this role officially assigned in task assignment? 6. Has the salary of the ROV Operator been increased due to this additional responsibility? **Operational Challenges & Experience** 7. What are the major challenges encountered during ROV operations?

- How difficult was it in the beginning?

8. Have you experienced any equipment damage during inspections?

    - If so, what caused the damage?

9. How long did it take for you to feel confident in conducting proper inspections (i.e., capturing high-quality photos/videos for reports)?

10. Can you compare the quality of the inspection data from when you first started using ROVs to your current level of expertise?

11. In your experience, what are the limiting external conditions (e.g., current, wave height, visibility) for effective ROV inspections?

    - How does experience influence these limitations?

12. Have you encountered any issues in obtaining permission from port authorities for ship hull inspections?

    - If so, what were the reasons?

13. Do you believe that basic ROV operating skills provide an advantage for candidates applying for onboard positions?

14. In your opinion, would it be beneficial to include basic ROV training in standard seafarer education? If so:

    - How many hours/days should the training last?
    - Should it focus on theory, practical training, or a combination of both (in what ratio)?

Finding No. 1. (Questions 1, 2 and 3): ROVs have been in use on the respondents vessels for a period ranging from 2 to 7 years. They are primarily used to minimize the need for divers, to verify divers' work, to inspect the hull for fouling after extended periods at anchor (thereby improving fuel efficiency), to assess potential damage after contact with the seabed and to identify entanglements such as ropes around propellers and rudder. The Planned Maintenance System (PMS) does not yet incorporate the ship's hull inspection using ROVs, and no additional sensors or probes were used during the inspection.

Finding No. 2. (Questions 4 and 6): None of the respondents attended a formal ROV operator course, but learned independently and shared knowledge within the fleet. Although the workload for the specific rank onboard increased due to additional task, there has been no change in salary.

Finding No. 3. (Question 5): Typically, Chief Officers are responsible for ROV operations. However, in many cases, junior officers often act as ROV operators under the supervision of the Chief Officer. These tasks are also valuable learning opportunities for cadets and junior officers in the area of ship maintenance, especially given the trend towards shorter contracts and less frequent dry docks.

Finding No. 4 (Questions 7 and 8): Technical and operational challenges of ROV operations include the limited tether (cable) length relative to ship size, which limits operational range, especially on larger ships. In addition, the low thruster power becomes particularly problematic in strong sea currents, which impairs the inspection quality. The risk of cable entanglement is also of great importance, especially around sensitive areas such as the stern, where propellers and rudders are located. To reduce these risks,

operators on some ships are taking additional safety measures, such as using heaving lines to "hold" the ROV during inspections, especially in strong currents when the vessel is at anchor. Although there were cable entanglements, no significant damage to the equipment was reported.

Finding No. 5 (Questions 9 and 10): All respondents agree that with each additional dive, it becomes easier. However, if there is a longer break between inspections, it takes a bit of time to "refresh" the skills. On average, after 3-4 inspections, the respondents feel confident for future inspections.

Finding No. 6 (Question 11): On average, seafarers consider the following external conditions as limiting for effective ship inspection: sea current speed above 0.5 knots, wave height above 0.5 meters for deploying the ROV and visibility below 1 meter.

Finding No. 7 (Question 12): In general, there were no issues obtaining permission from port authorities to conduct hull inspection using ROVs. However, respondents most often use ROVs while the ship is at anchor. Some also expressed the belief that, in cases where port authorities deny permission, it may be due to "competition" with local diving service providers.

Finding No. 8 (Question 13): Senior officers advise young officers to acquire skills beyond the STCW minimum requirements, where ROV operation becomes a valuable asset. Junior officers believe that previous experience in ROV handling would have a positive impact on their performance appraisal (evaluation of their work on board at the end of their contract) and improve their employability.

Finding No. 9 (Question 14): All interviewed seafarers agree that it would be beneficial to include basics of ROV operation into standard maritime education. An introductory training course of 3–5 days (or approx. 10 hours of practical piloting) would be sufficient to ensure safe and effective basic ROV operation for hull inspection purposes. In addition, basic knowledge of ship construction is necessary to better interpret the observed conditions and thus should be included in the course.

Additional findings:

- Although ROVs are increasingly accepted, there is still some reluctance and hesitation among some users. The concerns are often due to fear of responsibility, risk of equipment damage or a general feeling of uncertainty. Such reactions are common when new technologies are introduced, in particular when additional tasks are not accompanied by extra compensation.

- The majority of seafarers recognize the value and potential of ROVs. They expect ROV inspections to become standard practice in the future, especially as operational requirements increase and technological familiarity improves.

4.2. Findings from the inspection-class ROV manufacturers

This section presents a set of interview questions (11 questions) for inspection-class ROV manufacturers, covering topics such as general market trends, sales trends in the shipping industry and ROV operation and training. The responses are also summarized into shared conclusions/findings.

Interview questions for inspection-class ROV manufacturers
General market trends 1. Can you provide insights into the general sales trends of ROVs across all industries over the past several years?

2. Do you keep records of your customers, including reasons for purchasing an ROV?

ROV sales in the shipping industry

3. Can you share insights into the sales trends of ROVs specifically within the shipping industry over the past several years?

4. Do shipping companies typically purchase a single ROV for testing before making additional purchases, or do they acquire multiple units for their entire fleet from the start?

5. Which additional sensors or probes are most commonly requested by shipping companies?

ROV operation and training

6. Are you aware of which crew members onboard are designated to operate the ROV, or are shipping companies planning to hire specialized personnel for this role?

7. Have you received any feedback regarding equipment damage caused by unskilled handling?

8. Do customers request training when purchasing ROVs?

9. Do you provide any courses or training for your customers (shipping companies)?

    - If yes, how long does the course last (in hours)?
    - If no, do customers inquire about institutions that offer such training?

10. In your opinion, would it be beneficial to include basic ROV operation training as part of standard education for seafarers?

    - If yes, should it be theoretical, practical, or both?
    - How many hours or days would be necessary, and what should the ratio of theory to practical training be?

Additional comments

11. Are there any additional insights you would like to share regarding the ROV market, particularly within the shipping industry?

Finding No. 1 (Questions 1, 2 and 3): The sales trend of inspection-class ROVs, both in general and within the shipping industry, is increasing. All manufacturers interviewed keep records of their customers and, in most cases, are aware of the intended use of their products. One ROV manufacturer reports that from 2010 they have sold 5,000 - 6,000 units across all markets, with about 12% of sales going to shipping companies. Over the last 10 years, the capabilities of the inspection-class ROVs have significantly improved, approaching those of larger “professional” units. Another manufacturer has sold 1,300 ROVs in 70 countries since 2018 to all customers, while shipping companies account for about 20% of their sales. While the number of sold units has not dramatically increased over the years, the price per unit has gone up due to advanced sensors enhancing the capabilities of the robots. A third ROV manufacturer, which launched its first compact ROV model in 2016 for simple inspections, has seen steady growth, especially in North America, Europe and Japan, where shipping companies are key customers. Sales trends in the shipping industry shows a steady annual growth of approximately 5-10%.

Finding No. 2 (Questions No. 4 and 5): In most cases, shipping companies begin by purchasing a single ROV unit to test its quality and capability, eventually equipping each vessel with a dedicated ROV for basic inspections. There are cases where shipping companies buy one ROV for each vessel in their fleet to have something on board for simple (basic) inspections rather than arranging divers. Sensors and probes that are most wanted by the ship owners include thickness measurement gauges and cathodic protection probes. Laser scalers are often used for real-time measurements and various software solutions are being developed for post-processing. Also, new companies have emerged in the market, purchasing ROVs to offer ship hull inspection services to ship owners.

Finding No. 3 (Questions 6 and 7): ROV manufacturers do not have information about which rank on board will operate the ROV. But, as they are aware, no third-party companies will be employed for the inspection. None of the interviewed manufacturers have received feedback from shipping companies regarding any damage to the equipment.

Finding No. 4 (Questions 8 and 9): Manufacturers often provide online training materials (videos, presentations) which can be accessed through their websites or upon request. These resources include safety videos to minimize the risk of damage, learning from past mistakes. Video calls are often used to explain the use of specific ROV accessories (e.g. sonar). However, respondents of this group highlight that advanced skills in ROV operations cannot be adequately developed through virtual instructions alone and require hands-on experience. Sometimes manufacturers arrange on-site meetings for training, which have proved to be the most effective method. The duration of the training depends on the clients and their needs. During these sessions, the focus is on robot techniques, rather than inspection methodology.

Finding No. 5 (Question 10 and 11): As per ROV manufacturers, recommended training includes a 2–3 day program with 70% theory and 30% practical work, where the practical part should contain all the ROV features and functions, allowing time for additional questions and clarifications that arise during independent inspections. They share the opinion that a longer period of practical part is not necessary due to the equipment's user-friendliness. However, operators must also learn task planning, taking into account all external factors affecting the operation. In general, the most common operational issue remains the entangled tether, which often leads to costly equipment damage.

4.3. Findings from the shipping companies

The following section presents the interview questions (8 questions) designed for shipping companies, along with the brief summary of the responses. Since only one representative from a shipping company using this equipment on board was available, this data cannot fully reflect the diversity of ship types and company perspectives. However, onshore personnel are not a key factor in this research which primarily focuses on the needs of the seafarers and the challenges they face on board.

Interview questions for the shipping companies
Operational practices and challenges 1. Why and when did you/your company start using ROVs for ship hull inspection? • Are ROVs used across all ships in your fleet? • If not, what are the reasons and are there any plans to expand the use of ROVs within your fleet? 2. How would you compare inspections performed by divers with those conducted using ROVs?

- What are the main advantages and disadvantages of each method?
- In which situations do you still rely on divers?

3. How are the ROV operators selected on your vessels?

    - Is this role assigned to a crew member (specify rank) or a shore-based ROV operator?
    - If a shore-based operator - is he permanently employed or engaged when needed?

4. If a crew member serves as the ROV operator, is this role formally included in their task assignment?

    - Is there an adjustment in their salary to reflect the additional workload and responsibilities (as ROV operator)?

5. Have you received feedback from ROV operators regarding challenges faced during operations, particularly at the beginning?

    - What are the most commonly reported issues?
    - Does every ROV operation include inspection of the complete hull or only specific areas?
    - Has any equipment damage been reported?

6. Are you (or any shore-side position job) participating in „remote“ (online/shared) ROV inspections (inspection from the office)?

    - If not, are there plans to implement or expand the use of this feature?

ROV training

7. In your opinion, does prior basic experience as an ROV operator influence employment decisions for onboard positions?

8. Do you believe that including basic ROV operator training as part of standard seafarer education would be beneficial?

    - If yes, how many hours or days should it include?
    - Should the training be theoretical, practical, or a combination of both (in what ratio)?

Finding No. 1 (Question 1): Suisse Atlantique Group SA operates a diverse fleet of bulk carriers and began adopting ROV technology for hull inspections across its fleet in 2017. The primary reason for purchasing ROVs was the prolonged anchoring periods and the high cost of hiring divers for hull-fouling inspections. Additional motivations include damage assessment in case of grounding or “touch and go” incidents, as well as support for classification society inspections. This company has one ROV unit available on each ship of the fleet.

Finding No. 2 (Question 2): The Company still uses divers when hull cleaning is necessary. However, for determining the optimal time to perform the cleaning, using an ROV is the preferred choice. In general, divers are considered better for manual tasks, but their use comes with high costs, time consumption and safety risks.

Finding No. 3 (Questions 3 and 4): In general, chief officers are assigned the role of ROV operators and it is included in their task assignment. However, as younger crew members, such as junior officers and cadets, often adapt faster to the new technology, in most cases they take the role of ROV Operator, typically under the supervision of chief officers or Masters. Their salaries didn't change after the introduction of this additional task.

Finding No. 4 (Questions 5 and 6): Initial implementation of this new technology was challenging, especially without prior experience and training, where majority of the ROV Operators found using an ROV very difficult. Over time, experience accumulated across the fleet, with knowledge shared among officers. The most common fear when conducting the inspection is the possibility of cable entanglement around the propeller and consequently loosing the ROV. In situations where time is limited, inspections focus on the stern and propeller area. If fouling is detected there, it's typically assumed that the rest of the hull is in a similar condition. No significant damage of equipment was reported to the office. This Company did not yet introduce "remote" inspections (from the office), but this option is also something to consider in the future.

Finding No. 5 (Question 7): The representative of the company is also involved in the recruitment process and points that even basic ROV operation skills are considered an advantage during recruitment, which emphasizes the growing relevance of this technology.

Finding No. 6 (Question 8): Introducing basic ROV operator training into standard seafarer education is considered highly beneficial. This initiative would better prepare seafarers for the tasks they are likely to encounter on board. The training should cover both theoretical part and practical operation with an ROV, ensuring comprehensive understanding of the whole operation, from its planning stage to the generation of the inspection report.

4.4. Pilot IWS results

Pilot in-water hull surveys conducted as part of this research provided a broader perspective on the operational realities and challenges faced by seafarers during underwater hull inspections. These surveys also served as a validation of the results, confirming many of the insights gathered from various respondents. They also highlighted additional practical considerations that had not been previously emphasized and will be relevant for the course syllabus preparation.

The equipment which has been used for the pilot In-Water surveys included two inspection-class ROVs:
- Blueye Pioneer and
- Qysea Fifish Pro V6P.

The Blueye Pioneer ROV (Fig. 15) includes the ROV itself, its surface unit with a tether (150 m), a controller with a mobile device and movie mask. The ROV uses two rear thrusters, a sideway thruster and a vertical thruster, each of them with power of 350 W, giving the forward speed up to 1.5 m/s (3 knots) at normal use. The weight of the ROV is 8.6 kilograms, with IPX8 waterproof rating. The ROV is equipped with led lights of 3300 lumens, while its camera allows recording videos in full HD quality. The ROV is equipped with a gyrocompass, accelerometer, depth sensor, thermometer and barometer. This ROV is very stable due to the low center of gravity and high center of buoyancy, thus preventing the ROV from turning around its transverse and longitudinal axis. Auto-depth and auto-heading functions improve maneuverability and video capture quality. Two batteries were available during the inspections, each battery lasting for 2 hours.



Fig. 15. Blueye Pioneer

The Qysea Fifish Pro V6P (Fig. 16) is equipped with a wide-angle lens, offering a 166° field of view, a 4K UHD camera with 12-megapixel resolution, and 6.000-lumen LED lights. The ROV features a distance and altitude sonar lock system that maintains the required distance from the hull during the inspection. The ROV has six degrees of freedom, capable of maintaining or adjusting its orientation in any desired direction. Also, the ROV has the option to use two laser beams making a reference for the measurements required during inspection.



Fig. 16. Qysea Fifish Pro V6P

One of the most significant findings from these pilot inspections was the importance of comprehensive pre-inspection planning. It became evident that thorough preparation is a fundamental prerequisite for a successful and efficient hull survey, particularly when using ROVs in changing maritime environments. The complexity of underwater inspections demands a structured approach.

Figure 17 shows the proper approach on the planning the inspection by determining the areas of focus (based on the type of inspection), such as the bow, stern, propeller, rudder, sea chests and any region prone to corrosion, fouling, coating degradation, etc. In this phase, the order of the inspection (dive path) will be agreed between the personnel included in the inspection (ROV team).

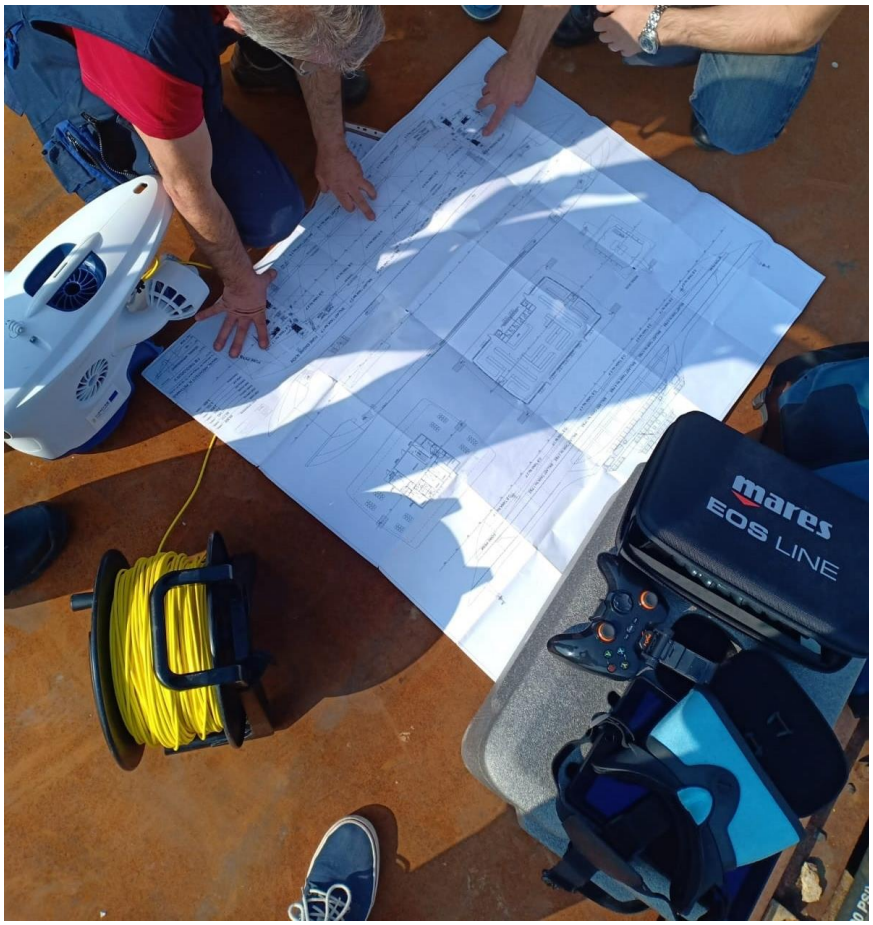


Fig. 17. Planning the inspection using ship's plan (Pilot IWS)

Key preparatory actions identified through the pilot inspections include:

- Gathering of all available technical and environmental data related to both the vessel and the inspection location, such as underwater hull plans/sketches and precise under-keel clearance (UKC) measurements.
- Obtaining formal permission for ROV deployment from the relevant authorities (e.g. port authority, harbor master’s office) as well as obtaining consent from the ship’s Master,

- Reviewing meteorological and oceanographic data, emphasizing on both forecasted and real-time conditions at the site. This will anticipate potential disruptions and reduce the risk of hazardous inspection periods.
- Ensuring operational readiness of all devices necessary for the inspection, including the full charging of the ROV set and associated mobile phone or tablet,
- Consulting a checklist of required equipment before leaving the “base” in order to avoid omissions and streamline the operational workflow,
- Coordinating with the vessel to announce the commencement of the inspection, ensuring that the ship’s crew is aware of the underwater operations.

Once all preparatory work is complete and ROV is deployed, the focus should shift to the inspection itself while ensuring equipment safety, particularly avoiding tether entanglement, which represents a frequent operational risk in confined underwater areas. All personnel involved in the operation (ROV Operator, ROV Supervisor and Cable manager) must be familiar with a clearly defined inspection plan, including contingency procedures i.e. potential deviations (plan B) in case of unexpected developments in the situation. Continuous and clear communication among the ROV team proved to be an essential success factor during the ROV operations.

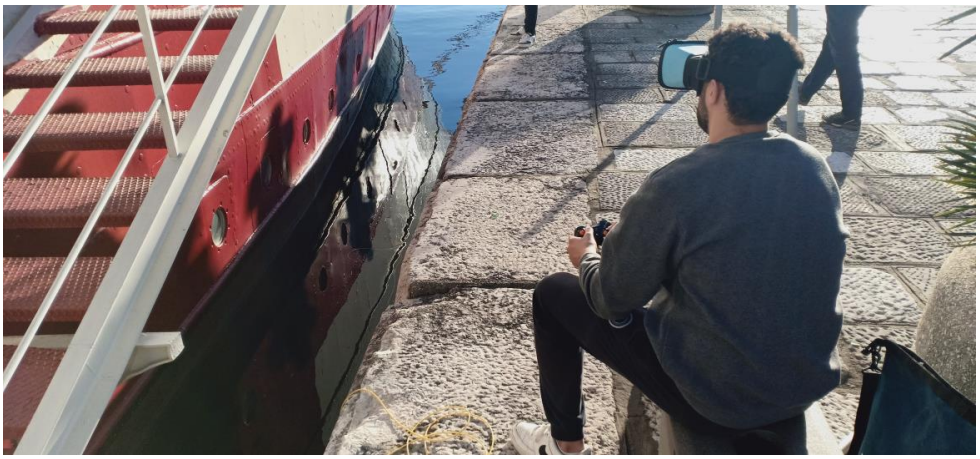


Fig. 18. ROV operator during Pilot IWS

Environmental variables such as sea current strength and underwater visibility are the most critical external factors influencing the inspection quality. These factors are found to be highly dynamic, requiring continuous monitoring during the inspection. Any changes in current strength and/or direction, or sudden drop in visibility should be promptly addressed within the ROV team resulting in adjustments “on the go” or temporary pauses. The efficiency and safety of the inspection are directly influenced by the ability to rapidly assess and react to such changes in the external factors.



Fig. 19. Inspection of the ship's propeller during Pilot IWS



Fig. 20. Inspection of the suction intake during Pilot IWS

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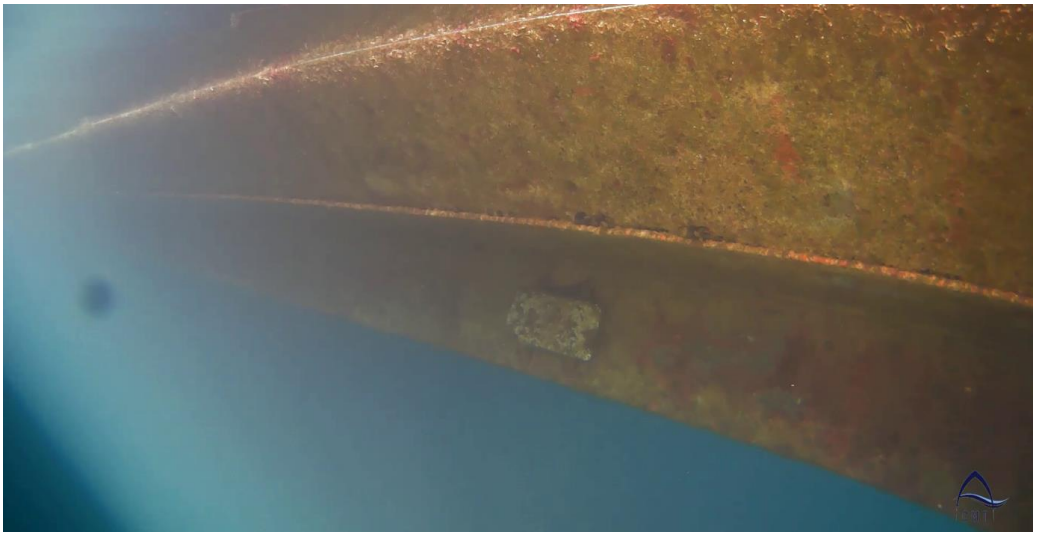


Fig. 21. Inspection of bilge keel and corrosion protection during Pilot IWS

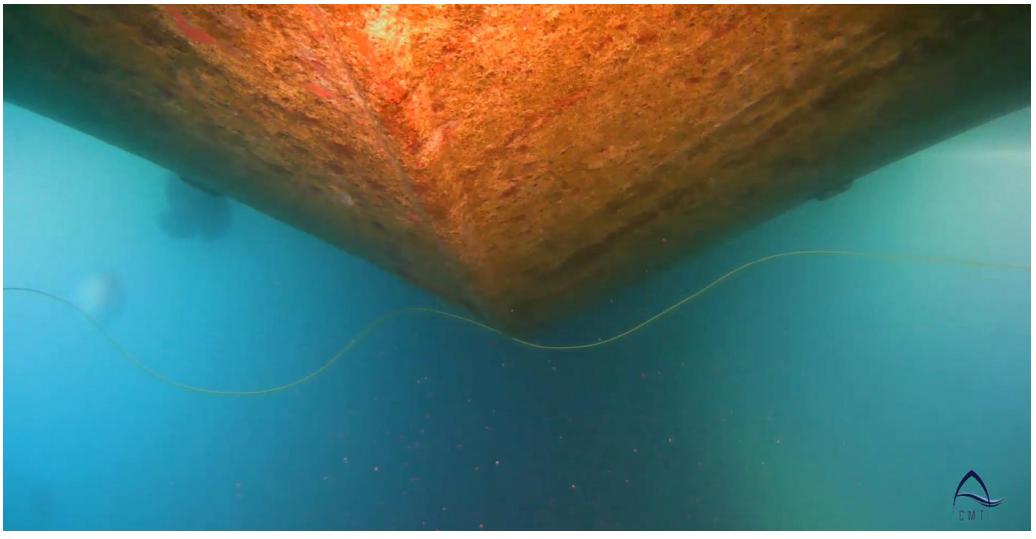


Fig. 22. Inspection of the keel during Pilot IWS

5. Course syllabus development and structure

After thorough research of the literature, completed targeted interviews and pilot IWS on real ships under different environments, it is concluded that the proposed training syllabus needs to cover the topics given in Table 2:

Table 2. Theoretical lectures and practical exercises for the proposed ROV training

THEORETICAL LECTURES	PRACTICAL EXERCISES
1. Structure of the ship's underwater hull (including ship plans) 2. Underwater ship inspection – Purpose and methods 3. Inspection-class ROVs – parts and functions 4. Understanding external conditions on ROV operation (focus on sea current and visibility) 5. Safe practices and basic procedures (launch and recovery, cable management) 6. Basic underwater orientation and navigation (including ROV navigation features) 7. The importance of a thorough plan of the inspection (using the ship's plan) 8. Additional features/probes for specific inspection 9. Maintenance/troubleshooting of the ROV 10. Use of inspection materials (photos, videos) – transfer of data and issuing a report	1. ROV components of a specific ROV model (familiarization). Launching and recovery in calm water conditions 2. Surface maneuvering and cable handling 3. Inspection of a simple underwater structure (e.g. the pier) using auto-features (auto-heading, auto-depth) 4. Piloting through underwater polygon – untangling 5. Using search patterns for finding hidden objects – use of the compass and the speed of the ROV 6. Operation in challenging conditions (vc>1kt, Hs>0.5 m, vis.<1 m) 7. Small boat hull inspection (with plan/drawing and proper planning of the operation) - taking photos and video materials 8. Ship's hull inspection (using the ship's plan) – data collection and reporting (making an adequate form)

As per the author's opinion, theoretical lecturers and instructors should possess a relevant educational background in the maritime field, have a thorough understanding of the course structure and learning objectives, and have a minimum of one year of practical experience in inspection-class ROV operations, covering a variety of inspection tasks under different environmental conditions.

The class size for theoretical lectures does not require any special conditions. However, it is necessary to provide at least two additional desks dedicated to equipment dismantling and the practice of relevant maintenance procedures.

Ideally, the ROVs used in training should be of different designs and from different manufacturers, allowing participants to experience and understand the advantages and limitations of various equipment types, depending on the purpose of the inspection. It is recommended to have a minimum of two units available.

For successful and effective practical exercises, a sea basin (or suitably sized pool, preferably with the option to simulate current) should be available, providing sufficient space to operate at least two ROVs simultaneously under the supervision of two instructors. In such a setting, the optimal recommended group size is up to six participants. If additional space and instructors are available, the number of

participants may be proportionally increased. In addition, it is necessary to organize, in a timely manner, a vessel that can be used for inspection during the course.

Below, the training syllabus is explained in more detail:

THEORETICAL LECTURES

1. Structure of the ship's underwater hull (including ship plans)
Duration: Approx. 1,5 hours

The first theoretical lecture is designed to familiarize participants with the condition of the hull and its components (such as propellers, rudders, sea chests, cathodic protection plates anodes, etc.) in order to effectively detect any damage, corrosion and degree of biofouling. Therefore, the lectures will cover:

a) All components of the hull, supported by pictures and/or videos illustrating their acceptable condition and common defects.
   - This should be done for different types of vessels, as some of the underwater equipment and components may differ from vessel to vessel,
   - Knowing the correct terminology will help to accurately document the findings of the survey,
   - Certain components should be associated with potential hazards (e.g. moving parts or sharp edges), whether for the ongoing ROV inspection or in case of diver arrangement.

b) Use of the ship's plan throughout the process
   - It is important to verify the actual position of the ROV and relate it to the components expected to be encountered,
   - Help to avoid disorientation underwater,
   - Participants should be shown several shipbuilding plans (drawings) on which the mentioned components can be identified.

2. Underwater ship inspection – Purpose and methods
Duration: Approx. 1,5 hours

This section will provide participants with a broader understanding of ship hull inspections by covering the following topics:

a) The factors contributing to structural failures, which are often the root cause of serious maritime accidents (corrosion, poor welding, material imperfections and other defects),

b) Potential hazards (incidents) that can lead to corrosion, deformation and coating degradation of the ship's hull, such as grounding, touch and go incidents and collisions,

c) Classification societies' regulations regarding underwater ship inspections, providing a deeper understanding of industry standards,

d) The importance of early problem detection in ship maintenance, emphasizing both safety and economic benefits,

e) An overview of available methods for underwater ship hull inspection, with a focus on:
   - Remote Inspection Techniques (RIT), including diver inspection and ROV inspection,
   - The benefits and limitations of each method, and the potential for combining both methods for a more comprehensive inspection.

3. Inspection-class ROVs – parts and functions
Duration: Approx. 1,0 hour

In this section, technological advancements in ROV-based inspections will be explained through the following topics:

a) A brief history of ROV development,
b) Classification of ROVs, based on their size, capabilities and applications (including images of different types of ROVs).
    - The primary focus will be on Inspection-class ROVs, highlighting their scope of work beyond hull inspections, such as ammunition searches, marine biology studies, marine archeology exploration and support for mariculture operations.
c) The key components and functions of the ROV, including frame, buoyancy system, thrusters, battery, camera and basic sensors (e.g. compass, echosounder), tether (umbilical/cable), lighting system, control mechanism (work station).
d) An explanation of the concept of Degrees of Freedom (DOF), detailing the various movements an ROV can achieve based on its thruster configuration.

4. Understanding external conditions on ROV operation (focus on sea current and visibility) Duration: Approx. 2,0 hours

This section emphasizes the importance of environmental factors in ensuring the safety of the ROV operations and the overall effectiveness of ship hull inspections. The following topics will be covered:

a) Explanation of key factors: wind, sea state (waves), sea current and visibility,
    - Understanding that safe ROV deployment and recovery depend primarily on the sea state (surface waves), making accurate assessment of these conditions crucial.
    - Overview of wind-wave generation (fetch, wind duration, swell formation),
    - It is important to highlight that the most significant impact of sea state on the ROV is typically experienced within 1 m of depth (this can increase in cases of prolonged strong wind)
b) Factors affecting the safety of a moored or anchored ship
    - Consideration of horizontal movement along the berth, anchor dragging and under-keel clearance (UKC) and their influence on ROV operations,
    - Special attention should be given when the ROV is deployed from another ship/boat, considering that not all ship sizes react to the same sea state and wind speed (wind gusts) in the same manner.
c) Understanding how to prevent contact between the ROV and other structures or the vessel during deployment and recovery, especially under challenging wave conditions.
    - Emphasis on reaching safe operating depth (below the wave impact zone) as quickly as possible. If sea conditions do not allow cable tracking, ROV operations to be suspended until conditions improve.
d) Influence of the wind on the vessel and on the ROV
e) Sea currents
    - Focus on surface currents and tidal streams, including expected times and locations of maximum speeds,
    - Consideration of additional influences such as river mouths and underwater springs,
    - Typical areas of increased current speeds: narrow channels and passages, isolated ridges, vertical walls and regions affected by prolonged winds,
    - Specific spots of significant sea current strengths in the local area,
    - The effect of sea currents on inspection-class ROVs
        - Operational limitations depending on the ROV characteristics and capabilities (ROV shape, thruster power, maximum speed),
        - Importance of planning the inspection, particularly in determining the ROV direction of travel - either straight or sideways relative to the inspected area (the operating speeds of the ROVs used in practical exercises should be clearly mentioned and specific guidance provided to ensure safe and efficient operations)
f) Visibility and its impact on the inspection performance and image quality)

- Key factors to consider during planning
    - Turbidity and pollution, plankton blooms (sea bloom) and freshwater effect from rivers or underwater springs,
    - Impact of the ROV's own thrusters, stirring up the sediment/mud, significantly reducing visibility. This can be mitigated by careful planning, including proper selection of approach angles and operating distances,
    - Optimal lighting setup – lights should be positioned as far as possible from the camera to reduce backscatter.
- Minimum recommended visibility - at least 2 meters for standard inspection tasks, with 1 meter as the absolute minimum for achieving acceptable survey results.

g) Importance of checking the latest weather forecast and meteorological warnings in force using reliable sources, such as Windy, PredictWind, PassageWeather, Buoyweather, etc.

h) Evaluation of the exposure of the operation site
- Leeward conditions, shore height, fetch, sea currents, and seabed configuration

5. Safe practices and basic procedures (launch and recovery, cable management)
Duration: Approx. 2,0 hours

In this section, focus is on personal safety and safe operating procedures for using the ROV. Before each dive, a comprehensive plan must be prepared, covering the entire operation, from launching the ROV to its recovery.

a) Safe operating procedures
- Avoiding contact with rotating propellers,
- Understanding the impact of using LED lights outside of water,
- Being aware of the maximum allowed (limited) weather conditions (equipment specific),
- Maintaining a safe distance between the ROV (with the cable) and other objects,
- Monitoring marine traffic and other people in the water (swimmers, divers),
- Identifying potential electromagnetic interferences (steel structure, other WiFi signals) and
- Recognizing the dangers of operating during thunderstorms.

b) Operational procedures
- Downloading required applications on the mobile phone,
- Connecting the ROV unit to the controlling device,
- Compass calibration,
- Short testing of the thrusters and main functions.
- Explanation of the proper methods of deploying the ROV, whether from the shore or a boat/ship, along with the additional equipment that can simplify lowering or retrieving it from the water.
- In case of deployment from a boat, explanation of the methods when the boat is alongside, at anchor or drifting. All possible dangers during each of these situations should be thoroughly explained, giving solutions on how to deal with various risks.

c) Cable management
- Effective cable management is crucial to the training and should not be overlooked. It includes:
    - ensuring the cable is properly reeled and
    - monitoring the length of the deployed cable (effect on resistance and speed of the ROV).

6. Basic underwater orientation and navigation (including ROV navigation features)
Duration: Approx. 2,0 hours

This section covers various methods and tools used for underwater navigation, emphasizing their importance for safe and efficient ROV operation. Many of these techniques are already implemented in SCUBA diving.

a) Basic concepts of underwater navigation (in general)
- understanding underwater topography
- use of natural navigation techniques, such as recognizing seabed features, using sunlight and observing sea current direction.

b) Compass navigation
- Highlighting the advantages (and limitations) of using a compass for underwater navigation
  - ROV operations in low visibility conditions
  - Effect of the ship's steel structure on the compass accuracy
- Explaining the use of nautical and bathymetric charts for underwater navigation and how to use them in combination with the compass for accurate navigation.
- The following topics are briefly included in this section:
  - Magneto-inductive technology,
  - Understanding the difference between true (geographical) north and magnetic north,
  - Understanding the difference between "heading" and "course",
  - Common navigation patterns applicable in underwater navigation (from search and rescue operations in surface navigation),
  - Factors affecting navigation accuracy (internal, external).

c) Underwater navigation sensors
- Primary navigation sensors – camera, Inertial Measurement Unit (IMU) and depth sensor
- Advanced navigation sensors – Multibeam Imaging Sonar, Ultra Short Baseline (USBL), Doppler Velocity Log (DVL)
- Understanding „sensor fusion" – increased navigation accuracy.

d) Remote control and teleoperation
- Explanation of remote control and teleoperation, with practical examples of when to use each

e) Automatic ROV control functions for underwater navigation
- Overview of automatic functions that assist in navigation
  - "auto heading",
  - "auto-depth",
  - "auto-altitude" and
  - "auto stand-off".
- Calculating distance traveled in a specific direction
  - using the formula: Distance = Speed of the ROV x Time

f) Factors affecting the maneuverability, stability and speed of the ROV
- Classification of factors as internal or external
  - Internal factors - ROV shape, buoyancy material placement, number of thrusters, thruster power and their position,
  - External factors - covered in Section 4.
- Understanding how to use the mentioned factors for effective navigation and inspection while being aware of the equipment limitations.

g) Familiarisation with the controller device

- Forward/backwards movement
- Turning
- Up/down movement
- Sideways
- Additional degrees of freedom (depending on ROV)
- Camera and light
- Automatic functions (auto-heading, auto-depth as minimum)

7. The importance of a thorough plan of the inspection (using the ship's plan)
Duration: Approx. 2,0 hours

Before each dive, a diving plan must be prepared. Depending on the task complexity, the plan will be orally and/or in writing. For thorough hull inspection, it is recommended to use the ship's plan with detailed underwater elements (propellers, thrusters, sea chests, cathode protection plates, etc.).
This section will include:

a) Explanation on how to conduct a proper risk assessment
   - Identification of possible hazards and consequences for a hull inspection
   - Identification of protective measures

b) Using different ship plans for exercises
   - Finding underwater hull components on the plan
   - Determination of movement plan (scenarios) for ship hull inspections (possible effect of sea currents – various directions and speed)

c) Determination of necessary equipment (checklist) for the inspection

d) Number and role of persons involved in the operation

e) Object of inspection and location
   - Define elements that should be collected about the ship and location (ship plans, images, charts, etc.)
   - Define permissions that should be collected (port authority, harbor master, ship's Master)

f) Application of Section 4
   - Understanding the weather forecast for the specific location (prior dive)
   - Monitoring the actual weather situation (during the dive)
   - Defining limiting conditions (Max Hs, Max Vc, Min Vis, precipitations)

g) Final plan and "plan B" in case of a change in weather conditions
   - Exercise with different scenarios

8. Additional features/probes for specific inspection
Duration: Approx. 1,0 hour

This section introduces additional components (features, probes, sensors) that are typically integrated to increase inspection quality and efficiency. The choice of a specific component depends on the type of inspection. Brief explanation of the following:

a) Compensation of additional weight to the ROV – additional buoyancy modules (integrated or newly created)

b) Installation and use of additional cameras

c) Installation and use of additional lighting systems

d) Sonar systems
   - Working principle
   - Types of sonar used in ROV operations
   - Images/videos from sonar systems

e) Cathodic protection probes

- Objective of the inspection and working principle
- Installation and operation

f) Thickness measurement tools
- Working principle
- Additional components for thickness measurements
- Installation and operation

g) Positioning and navigation systems
- Acoustic and inertial systems for localization
  - Doppler Velocity Log (DVL)
  - Ultra Short Baseline (USBL)
  - System integration

h) Other sensors and add-ons
- Laser scaler
- Environmental sensors (temperature, salinity, turbidity)
- Manipulator arms
- Cleaning tools

9. Maintenance/troubleshooting of the ROV
Duration: Approx. 2,0 hours

Although inspection-class ROVs do not require demanding maintenance, it is important to follow basic procedures before and after each dive, or at specific intervals to ensure reliable operation and keep the equipment in good condition. It should be noted that each ROV model may have specific procedures depending on the manufacturer, so the operating/maintenance manual should always be consulted. However, the general (basic) procedures that apply to most systems should be explained to the attendees (recommended hands-on training in the classroom):

a) Visual inspection for visible wear and damage (frame, connectors, cable)

b) Visual inspection of locations around seals
- Check for grease
- Replacement of main seals

c) Replacement of the battery (if applicable)

d) Inspection of thrusters
- Cleaning the area of grass, plastic bags, etc.
- Replacement of the thruster

e) Cable (tether) replacement

f) Replacement of other spare parts

g) Vacuum test (on specific models)

h) Freshwater rinse – after each dive (end of the operation)

a) Most common issues (troubleshooting) during ROV operations will be explained in this section:

i) A loss of control - various causes: empty batteries, errors in application, mobile phone issues, etc.

j) Entanglement
- Around the ship's propeller, thruster tunnel, rudder, bilge keel, hull protrusions (anodes, sea chests, intake grills), anchor chain (if at anchor)
- With other ROVs (in case of inspection with multiple ROVs)
- External (pier) structures, seabed, etc.

k) Breaking of the cable (tether),

10. Use of inspection materials (photos, videos) – transfer of data and issuing a report
Duration: Approx. 1,5 hours

The last theoretical lecture covers the transfer of materials collected through the inspection process. Here, the operational manual will be consulted for a specific model that will be used in the practical part of the training. After that, the following procedure should be explained:

a) Data analysis and sorting
   - Creation of folders/renaming images/videos - Location on the hull, date/time

b) Video/image editing – collecting the best images (view angle, clarity, distance from the ship)

c) Making a report – example in the attachment
   - Recommendations for maintenance/repair - optional

PRACTICAL EXERCISES

1. ROV components of a specific ROV model (familiarization). Launching and recovery in calm water conditions
Duration: 1,0 hr

In the first practical session, all main parts of the ROV are explained and demonstrated to the attendees, along with safe practices for its launching (a brief review of Sections 3 and 5 from the theoretical part). Once all equipment is switched on and properly connected, the following steps are carried out:

a) Launching the ROV from the pier (at the water level)
   - Cable manager is releasing the ROV in the water (reel to be kept away from the pier edge)
   - ROV operator stands by with controller, ready to take the ROV into a safe area
   - Cable manager adjusting the cable as per the Operator's request

b) Basic manoeuvres on the sea surface – familiarization with the controller
   - Forward/backwards movement
   - Turning
   - Up/down movement
   - Sideways
   - Additional degrees of freedom (depending on ROV)

c) Safe approach to the pier and recovery
   - Cable manager to pick up the ROV from the water level

2. Surface maneuvering and cable handling
Duration: Approx. 1,0 hour

This exercise can be conducted as a continuation of Exercise 1 or as a standalone exercise, particularly in situations where a larger number of attendees are rotating in piloting ROV:

a) Understanding the behavior of the ROV on different orders in surface navigation
b) Testing "auto functions" (auto depth, auto heading) below the water surface
   - Monitoring depth gauge and compass
c) Testing of various thruster power (if applicable)
d) Cable handling and communication between the ROV Operator and the Cable manager
e) This exercise is to be carried out in good visibility, clear of obstructions

3. Inspection of a simple underwater structure (e.g. the pier) using auto-features (auto-heading, auto-depth)
Duration: Approx. 1,0 hour

The purpose of this exercise is to understand and test various possibilities for the inspection of underwater structures (e.g. quay side inspection):

a) Understanding the benefits/limitations of different movement patterns
b) Inspection with and without auto-features
c) Inspection in calm waters and good visibility
d) Inspection under different environmental conditions
   - Handling sea currents
   - Handling low visibility and night navigation/inspection
   - Use of light (adjusting light)
e) Use of FPV goggles

4. Piloting through an underwater polygon – untangling
Duration: Approx. 2,0 hours

This exercise requires a previously arranged underwater polygon (training ground) with carefully prepared obstacles (without sharp objects, not allowing damage to the ROV and its cable), as shown in Section 3:

a) Presentation of the polygon with the intended route - images of the polygon "on dry"
b) Practicing precise navigation and advanced manoeuvres
c) Understanding orientation (use of a compass)
d) Estimating distance from objects/seabed (using distance meter, if available)
e) Communication with the Cable manager throughout the whole exercise
f) Introduction of "third person" in a team (ROV Supervisor or assistant)
   - Use of Spectators/Observer view
g) Practicing untangling manoeuvres
   - Use of another ROV for an additional view

5. Using search patterns for finding hidden objects – use of the compass and the speed of the ROV
Duration: Approx. 1,0 hour

In this exercise, various search patterns will be used to find the object hidden at the seabed. The purpose of this exercise is to practice compass navigation and using the speed of the ROV for position estimation:

a) Expanding square search
b) Parallel search
c) Sector search

6. Operation in challenging conditions (vc>1kt, Hs>0.5 m, vis.<1 m)
Duration: Approx. 1,0 hours

This exercise is designed to experience ROV operations under challenging environmental conditions to "feel" limiting conditions and how to properly plan the dive by using these external forces to their advantage:

a) Sea current speed over 1 knot
b) Significant wave height over 0.5 m
c) Visibility less than 1 m

At first, attendees should practice this exercise in a controlled environment, excluding the possibility of equipment damage.

7. **Small boat hull inspection (with plan/drawing and proper planning of the operation) - taking photos and video materials**
   Duration: Approx. 2,0 hours

After gaining sufficient piloting experience from the previous exercises, attendees will be prepared for their first inspection of the hull. It is advisable to inspect a small boat in calm waters first, after which the size of the boat or ship can be increased, along with the environmental conditions.

a) Planning the inspection as per Section 7 of the theoretical part (brief recap)
b) Choose an adequate movement pattern to inspect the desired area (focus on the sea current)
c) Paying special attention to possible entanglement around the propeller, mooring lines, anchor chain, etc.
d) Use of laser scaler (if available) for accurate measurements of underwater objects
e) Image/video materials to be collected during this exercise
    - Upon completion of the inspection, collected data to be checked
    - Spotting "mistakes" of the materials – distance from the boat, angle of shooting, inadequate lighting, too fast movement etc.

8. **Ship's hull inspection (using the ship's plan) – data collection and reporting (making an adequate form)**
   Duration: Approx. 3,0 hours

    - Attendees are to act independently
    - Integration of all the knowledge acquired
    - Generation of a comprehensive report that includes all findings from the ship's hull inspection (as per the Inspection report in the attachment)
    - Assessment of the inspection
    - Overall conclusions

6. Conclusion

This paper highlights the growing importance of the use of inspection class ROVs for underwater hull inspections in the maritime industry. Although ROVs have only been used by some shipping companies for a relatively short time, they are already showing significant operational, economic and safety benefits compared to traditional diver-based methods.

This project began with a thorough review of existing literature on ship hull inspections using ROVs. A series of interviews involving seafarers, ROV manufacturers and shipping companies was carried out with the goal to identify core competencies and practical challenges when using ROVs for hull inspections. To ensure relevant and experience-based input, the interviews were conducted exclusively with individuals who had firsthand experience operating ROVs for this specific purpose.

Key findings reveal that seafarers have a strong interest in acquiring ROV operational skills, not only to improve vessel maintenance and inspection outcomes, but also to increase job opportunities in an increasingly competitive labour market. Research indicates that ROVs are mainly used on ships to minimize the need for divers and verify their work, inspect hulls for fouling to determine when hull cleaning is necessary, assess damage after seabed contact, and identify entanglements such as ropes around propellers and rudders.

ROV piloting skills are typically acquired informally and shared among crew members (officers) and across ships within a fleet. The most common operational concern is cable entanglement, especially near propulsion and rudders. All interviewed seafarers support the idea of integrating basic ROV training into maritime education to better prepare future seafarers for the onboard responsibilities.

The representative of the shipping company which is also involved in the recruitment process points out that even basic ROV operation skills are considered an advantage during recruitment, which emphasizes the growing relevance of this technology.

In addition to the interviews with key stakeholders, pilot hull inspections were conducted by the authors on several vessels in different environments. These practical trials served to validate findings from the interviews and uncover further training needs that may not have been captured through the previous stage.

The research shows a clear gap in the structured training and practical preparedness among current seafarers. The lack of formal education and training in the use of ROV often leads to suboptimal inspection quality and increased risk of equipment damage. In response, a targeted training syllabus has been proposed, developed through a combination of theoretical lectures and practical exercises. The recommended curriculum addresses critical aspects such as environmental awareness, inspection planning, equipment handling and reporting.

By equipping future seafarers (officers) with the skills required for the safe and effective operation of ROVs, the proposed training advances maritime education in line with modern technological trends. It also supports wider goals within the blue economy by promoting sustainable practices, reducing inspection costs and increasing overall safety. The integration of ROV training into standard maritime education will help to establish best practices for underwater inspection of the ship's hull.

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Attachement

IN-WATER SHIP SURVEY REPORT

M/V “KORNATI”



Survey type: Partial in-water survey of: FWD port thruster, port sea chest grating and bilge keel

Location Port of Valbiska, Croatia

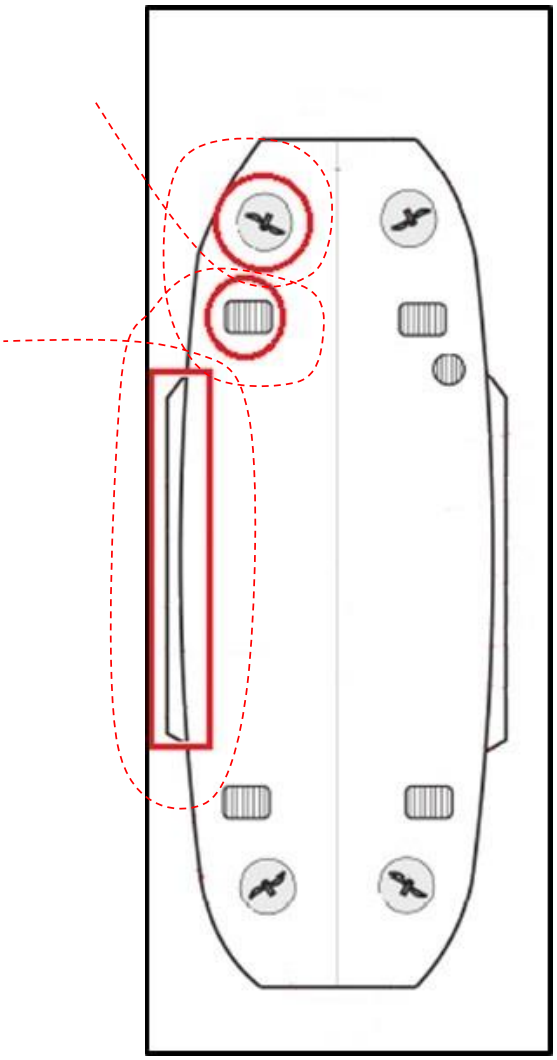
Date and time: 10 March 2025, 10:00-12:00

Equipment: Inspection class ROV - Blueye Pioneer

Ship’s information			
Class/Class No.	CRS / 16233	**Ship owner**	Jadrolinija Rijeka
Year Built	2014	**Type**	Ro-Ro Passenger Ship
IMO No.	9703708	**Flag**	Croatia
Gross Tonnage	3827	**DWT**	950 t
Length / Beam	99,8 m / 17,5 m	**Draft (Aft / Mid / Fwd)**	2,3

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ROV DIVE PATH



PROPELLER – FWD PORT					
Type	AZIMUTH THRUSTER		**No. of blades**	4	
Damages	NONE				
Fouling (1-5)	YES - HOUSING 3 / BLADES 2				
Cap	OK				
Rope Guard	NONE				
Condition of blades	**Blade No.**	**Bended**	**Cracks**	**Blade edge**	**Cavity**
	1	NO	NO	OK	NO
	2	NO	NO	OK	NO
	3	NO	NO	OK	NO
	4	NO	NO	OK	NO
	5	/	/	/	/
Comments	FOULING PRESENT ON THE THRUSTER HOUSING AND BLADES APPROX. 60% OF SURFACES				

BOTTOM SHELL PLATING		
	PORT SIDE	**STB SIDE**
Damages	NONE	/
Corrosion protection	GOOD	/
Fouling (1-5)	YES (3)	/
Comments	FOULING PRESENT ON APPROX. 60% OF SURFACE	

SIDE SHELL PLATING		
	PORT SIDE	**STB SIDE**
Damages	NONE	/
Corrosion protection		/
Fouling (1-5)	YES (3)	/
Comments	FOULING PRESENT ON APPROX. 60% OF SURFACE	

BILGE KEELS		
	PORT SIDE	**STB SIDE**
Damages	NONE	/
Ends / Edges	OK	/
Welds	OK	/
Corrosion protection	OK	
Comments	/	

SUCTION GRATINGS		
	PORT SIDE	**STB SIDE**
Damages	NONE	/
Fouling (1-5)	YES (3)	/
Bolts	OK	/
Grating	OK	/
Comments	APPROX. 30% OF GRATING BLOCKED WITH FOULING	

PHOTOS



Fig. 23. FWD port thruster 1

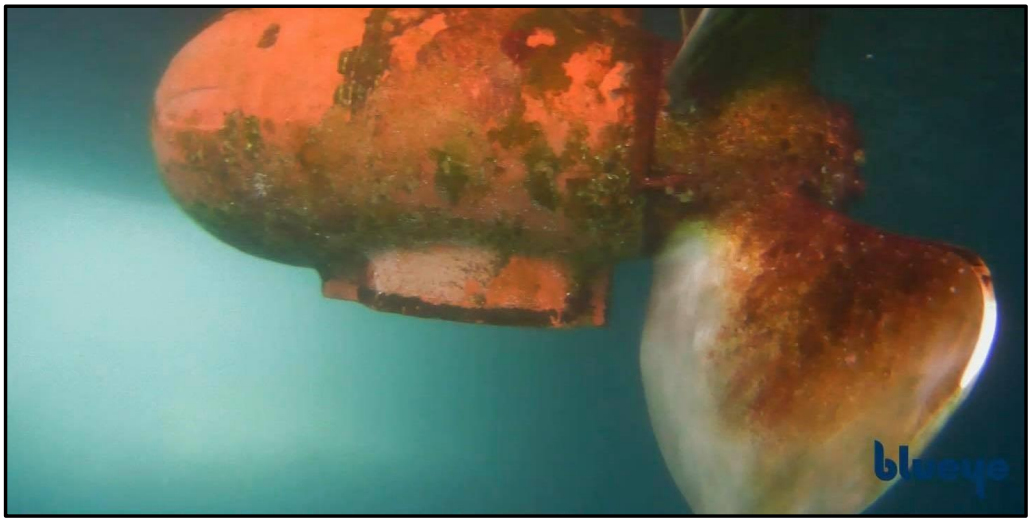


Fig. 24. FWD port thruster 2

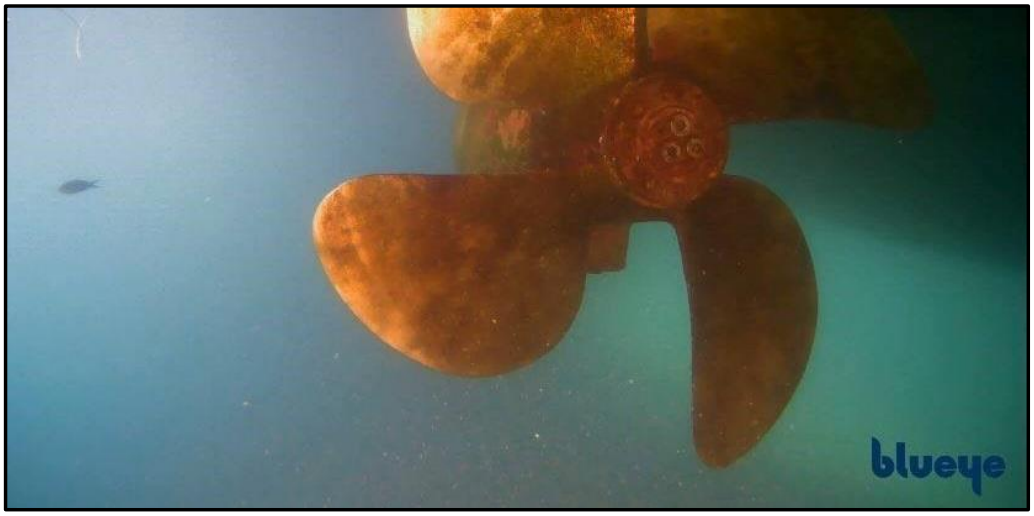


Fig. 25. FWD port thruster 3



Fig. 26. FWD port thruster 4



Fig. 27. FWD port thruster 5

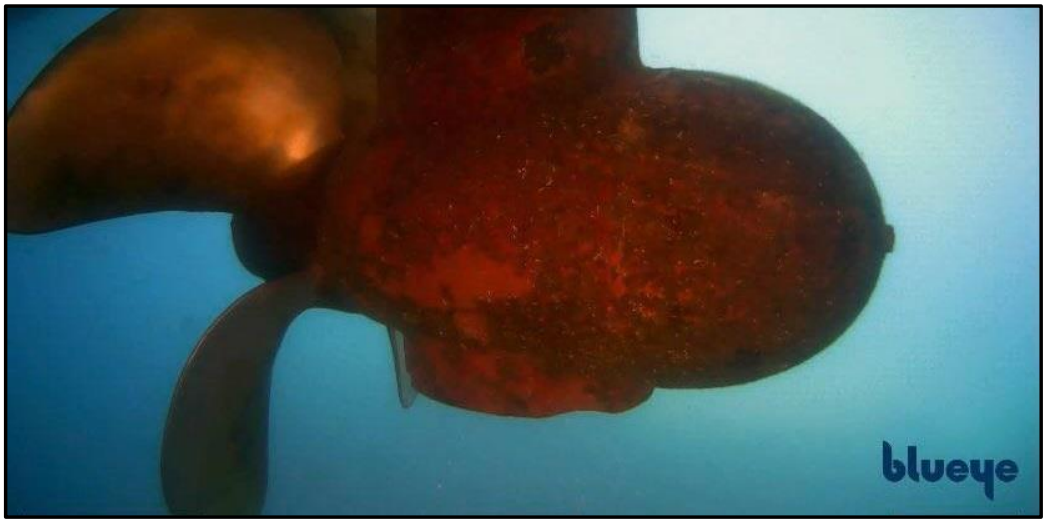


Fig. 28. FWD port thruster 6



Fig. 29. FWD port suction intake 1

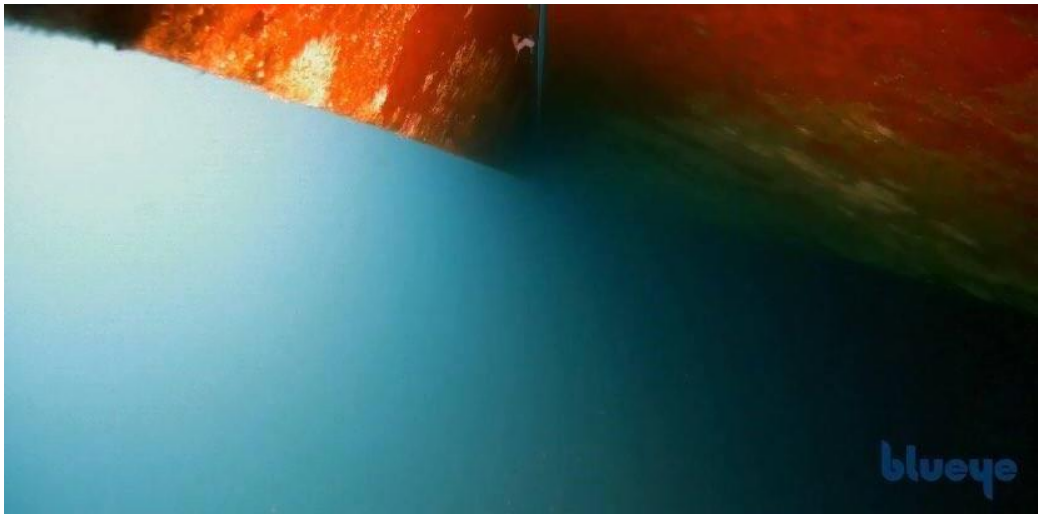


Fig. 30. Port bilge keel inner side



Fig. 31. Port bilge keel aft



Fig. 32. Port bilge keel corrosion protection

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ISBN : 978-4-907408-63-3