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Ballast Water Tank Leak Prevention

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ABSTRACT

Ballast tank leaks pose a significant risk to vessel safety and operational reliability, as they can result from inadequate maintenance, structural corrosion, and ineffective maintenance management. This study aims to analyze the causes of ballast tank leaks and identify appropriate prevention and mitigation measures aboard the SPOB TOTO XIV. The research was conducted on board the vessel over a period of 12 months and 2 days, from January 2022 to January 2023, using a qualitative research method. Data were examined descriptively to identify the factors contributing to ballast tank leaks and evaluate potential preventive measures. The findings revealed two main contributing factors: insufficient knowledge and experience among crew members in ship maintenance and limited operational funding from the shipping company, which disrupted the regular docking schedule. Delayed docking contributed to corrosion of the ballast tank plates, ultimately resulting in leaks. This study highlights the relationship between crew competence, company financial support, and scheduled vessel maintenance in preventing structural damage. It concludes that shipping companies should strengthen crew recruitment by prioritizing relevant competencies and experience while ensuring that vessel docking and maintenance are conducted regularly and on schedule. The study contributes practical insights into addressing ballast tank leaks through an integrated approach that combines human resource development, maintenance planning, and adequate operational funding to improve vessel safety and reliability.

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1. INTRODUCTION

Maritime transportation plays an essential role in supporting domestic and international trade by facilitating the distribution of goods and the movement of commodities between ports. The safety and operational reliability of ships depend on the integrity of their hull structures, machinery, and supporting systems. Therefore, effective maintenance is necessary to prevent structural deterioration, minimize operational disruptions, and maintain vessel safety. Karatuğ et al. (2023) explain that ship maintenance strategies are increasingly shifting from corrective maintenance toward preventive and condition-based approaches supported by monitoring, reliability assessment, and risk analysis.

One of the important systems supporting ship stability is the ballast system. Ballast tanks are compartments designed to receive and discharge water to regulate a vessel's draft, trim, and stability under different loading conditions. Their effectiveness depends on the structural integrity of the tank boundaries and the proper operation of associated piping and pumping systems. Deterioration of a tank boundary can result in leakage, potentially affecting ballast distribution and requiring corrective action.

Accordingly, the condition of ballast tanks should be considered an integral component of ship maintenance and structural safety management.

Ballast tanks are particularly susceptible to corrosion because their internal surfaces may be exposed to seawater, dissolved salts, oxygen, and changing temperature and moisture conditions. Corrosion is an electrochemical degradation process that can cause uniform material loss, localized pitting, and deterioration of steel structures. Dalmora et al. (2025) reviewed corrosion prevention methods for steel in marine environments and highlighted the role of metallic coatings, organic coatings, and other protective technologies. Similarly, Xia et al. (2025) examined the deterioration of marine and offshore structures under corrosive exposure, emphasizing that corrosion can reduce material performance and contribute to structural degradation. Wu et al. (2025) further discussed corrosion mechanisms and protection strategies for metallic materials in deep-sea environments, providing additional insight into the relationship between environmental exposure and material durability.

Protective coatings are widely used to reduce direct contact between steel and corrosive media. Their performance depends on coating composition, surface preparation, application quality, film thickness, adhesion, curing, and exposure conditions. Iannarelli et al. (2022) investigated an epoxy-amine coating after 18 years of service in a seawater ballast tank. Their findings indicated that repeated wetting and drying, together with temperature variation, contributed to changes in the coating's pigments and binder. These results demonstrate that coatings may undergo degradation even when their surfaces appear relatively intact.

The development of marine coating technology has also received considerable research attention. Pei et al. (2024) reviewed marine anti-corrosion and wear-resistant coatings, discussing their protection mechanisms, preparation methods, and performance limitations. Liang et al. (2024) examined anti-fouling and anti-corrosion coating technologies and identified the importance of improving coating durability in marine applications. Aulia et al. (2024) discussed surface modification of composite coatings for marine use, emphasizing the role of coating systems in slowing corrosion under aggressive seawater conditions. Wu et al. (2024) reviewed two-dimensional nanomaterial-reinforced organic coatings and described their potential for improving barrier performance and corrosion protection. Firoozi et al. (2025) further examined innovations in anti-corrosive coatings, particularly nanocomposites, polymer-based systems, and environmentally sustainable materials. Although these developments offer promising protection strategies, their suitability for a particular ballast tank must be assessed against the vessel's technical specifications and applicable coating requirements.

Coating failure can occur through blistering, cracking, peeling, loss of adhesion, or insufficient film thickness. When the underlying steel becomes exposed, corrosion may progress and eventually reduce the remaining plate thickness. Knudsen et al. (2025) investigated corrosion initiation on painted steel structures in marine environments, including a ballast water tank system. Their findings showed that edges and welded areas were important locations for corrosion initiation, partly because the coating film could become thinner around sharp structural features. Liu et al. (2025) also investigated damage

to marine ballast tank coatings following cyclic corrosion testing, demonstrating the value of combining different analytical techniques to assess coating deterioration. Together, these findings indicate that coating quality, structural geometry, and service conditions should be considered when investigating the possible causes of ballast tank leakage.

Nevertheless, leakage cannot automatically be attributed to corrosion or coating failure alone. Other possible causes include defective welds, cracks, mechanical damage, and defects associated with previous repairs. The actual cause must therefore be established through an examination of the damage location, the condition of the steel plates, the characteristics of any cracks or perforations, and the vessel's maintenance history. Corrosion may be a contributing mechanism, but its role must be supported by physical observations and technical evidence.

Inspection and condition assessment are essential for identifying deterioration before it develops into more serious structural damage. Visual inspection can reveal rust, coating detachment, pitting, cracks, and other visible defects. However, visual assessment may be limited by restricted access, poor lighting, complex tank geometry, or deterioration beneath coatings. Enguita et al. (2025) explored the potential of LiDAR and hyperspectral sensing to address challenges in ballast tank corrosion inspection. Their work illustrates how additional sensing technologies may support the identification and mapping of corrosion-related defects. Ultrasonic thickness measurement and other non-destructive testing techniques can also provide information about remaining steel thickness when material loss is suspected.

Condition monitoring and maintenance planning are closely related. Zhang et al. (2022) reviewed prognostics and health management for marine systems and equipment, covering condition monitoring, fault diagnosis, health prognosis, and maintenance decision-making. Xu et al. (2021) reviewed condition monitoring and fault diagnosis for marine power systems and discussed how monitoring technologies can support ship safety and the transition toward condition-based maintenance. Although these studies focus primarily on marine systems and machinery, their principles of early fault detection and evidence-based maintenance decisions are relevant to the management of ship structures. In the context of ballast tanks, inspection results should inform repair priorities, maintenance scheduling, and subsequent verification.

Maintenance effectiveness also depends on the organization of inspection and repair activities. A maintenance program should identify the condition of the tank, specify the required corrective actions, document materials and repair procedures, and verify whether the completed work has restored the tank's integrity. Karatuğ et al. (2023) emphasize that maintenance decisions can be improved by integrating condition information with reliability and risk assessment. These principles suggest that ballast tank maintenance should not be limited to repairing visible defects; it should also consider the underlying factors that contributed to deterioration and the possibility of recurrence.

In addition to structural integrity, ballast operations have an environmental dimension. Ballast water can transport aquatic organisms and pathogens between geographically separated marine environments. Sayinli et al. (2022) reviewed recent developments in ballast water treatment and

discussed the effectiveness and limitations of different treatment technologies. Kurniawan et al. (2022) examined ecological impacts associated with ballast water loading and discharge, including the potential toxicity and accumulation of disinfection by-products. Sari and Gunawan (2024) reviewed considerations for retrofitting ballast water treatment systems on existing ships, highlighting the importance of technical suitability, installation planning, operational requirements, and regulatory compliance. Ejder et al. (2024) evaluated ballast water treatment system selection for a bulk carrier by considering operational and environmental criteria, including energy use and emissions.

These studies demonstrate that ballast water management is important for reducing environmental risks and ensuring compliance with applicable requirements. However, ballast water treatment and ballast tank leakage represent distinct technical issues. Ballast water management addresses the handling and environmental effects of ballast water, whereas leakage concerns the tank's ability to contain water. These topics are related through ballast system operation but should not be treated as interchangeable explanations for a structural failure.

The literature reviewed above establishes several important considerations for understanding ballast tank leakage: marine corrosion can degrade steel structures; protective coatings may deteriorate under prolonged service conditions; local structural features can contribute to coating failure; and systematic inspection and maintenance can support early detection and effective repair. Nevertheless, these findings do not independently establish the cause of leakage on a particular vessel. A vessel-specific investigation must connect the observed damage with inspection findings, maintenance records, and relevant operational evidence.

Accordingly, this study aims to analyze the factors associated with ballast tank leakage, examine the relationship between corrosion protection and maintenance practices, and identify appropriate preventive and corrective measures. By integrating evidence concerning tank condition, coating performance, structural deterioration, and maintenance management, the study seeks to formulate practical recommendations for improving ballast tank integrity and supporting safe and reliable ship operations.

2. METHODS

This study employed a field research design using a descriptive qualitative approach to investigate the causes of ballast tank leakage aboard SPOB TOTO XIV and evaluate the maintenance measures implemented by the crew. The qualitative approach was selected because it enables an in-depth description and interpretation of technical problems in their actual operational context. The analysis focused on the physical condition of the ballast tank, potential damage and corrosion, maintenance practices, and factors that may have contributed to the leakage. The research was conducted during the Marine Practice (Praktik Laut/PRALA) period, which provided the opportunity to observe shipboard conditions and collect information relevant to the research objectives.

The research was conducted aboard SPOB TOTO XIV during the Marine Practice period from January 2022 to January 2023, lasting approximately 12 months and 2 days, as reported in the research records. The vessel served as the research setting because the investigation required direct examination of the ballast tank's condition and the maintenance practices implemented during ship operations. Data collection focused on documented leakage incidents, the physical condition of relevant tank components, maintenance activities, and the crew's responses to the identified problems.

The research informants consisted of crew members who were directly involved in ballast system operations, inspection, and maintenance. These included personnel responsible for technical operations and maintenance, selected according to their knowledge and experience concerning the ballast tank and the reported leakage. Purposive sampling was used to identify informants with relevant operational responsibilities and first-hand knowledge of the problem. Their selection was intended to obtain detailed information about the leakage, maintenance history, operational procedures, and challenges encountered in preventing or addressing the problem.

The research instruments consisted of an observation guide, an interview guide, and a documentation checklist. The observation guide was used to record the visible condition of the ballast tank, including signs of corrosion, suspected structural deterioration, and evidence of leakage, where accessible and safe to inspect. The interview guide was used to obtain information from crew members about the ballast system, inspection and maintenance procedures, previous leakage incidents, and corrective actions. The documentation checklist was used to examine relevant logbooks, maintenance reports, technical records, and other available vessel documents.

The main analytical focus was ballast tank leakage and the factors potentially associated with its occurrence. Relevant indicators included the location and characteristics of the leakage, visible corrosion or deterioration, the history of inspection and maintenance, and the corrective measures undertaken by the crew. These indicators were examined using observational evidence, interview accounts, and documentary records rather than being treated as independently measured variables.

The observation and interview instruments were aligned with the research objectives. The credibility of the findings was assessed through comparison of information obtained from different data sources. Any formal instrument validity or reliability tests should be reported only if they were actually performed. Where direct inspection was restricted by operational or safety requirements, the analysis relied on accessible evidence and available technical documentation.

Data were collected through direct observation, interviews, and documentation. First, the researcher observed the condition of the ballast tank and recorded visible signs of leakage, corrosion, deterioration, and relevant maintenance activities, subject to access and safety restrictions. Second, interviews were conducted with selected crew members to obtain information about the ballast system, the procedures followed during inspection and maintenance, the problems encountered, and the actions taken to address leakage. Third, relevant documentation, including logbooks, maintenance reports, and

available technical data, was reviewed to establish the chronology of events and support the interpretation of the observations and interview findings.

Primary data consisted of information obtained through direct observation and interviews. Secondary data consisted of vessel records, maintenance documentation, technical references, and relevant literature on ship maintenance and ballast systems. The information collected from these sources was organized and compared to identify consistencies, discrepancies, and possible explanations for the reported leakage. All inspections and observations were conducted subject to applicable vessel safety procedures and the necessary authorization.

The data were analyzed using descriptive qualitative analysis, following the framework of data condensation, data display, and conclusion drawing and verification proposed by Miles, Huberman, and Saldaña (2014). First, observation notes, interview responses, and documentary records were organized and reviewed to identify information relevant to the research objectives. Second, the data were grouped into themes, including the characteristics of the leakage, possible material deterioration or corrosion, inspection and maintenance practices, and corrective actions. Third, findings from observations, interviews, and technical documentation were compared to identify recurring patterns and discrepancies.

The identified findings were then interpreted in relation to relevant technical literature on ship maintenance, ballast systems, and vessel structural integrity. This comparison was used to develop plausible explanations for the leakage and assess the maintenance measures documented during the research. Conclusions were drawn from the available evidence, while recommendations were formulated to support improvements in inspection, preventive maintenance, corrective action, and crew competency.

The research was conducted with due consideration for participant confidentiality and vessel operational safety. Permission to conduct observations and access relevant vessel records was obtained from the authorized vessel or company representative, where required. Crew members were informed about the purpose of the research, and informed consent was obtained before interviews. Participants' identities and confidential operational information were protected in the research report. Photographs, internal maintenance records, and other vessel documents were included only where the necessary authorization had been obtained. Institutional ethics committee approval was obtained where required by the applicable institutional policy; if applicable, the name of the committee and approval number should be stated in the final manuscript.

3. RESULTS AND DISCUSSION

The researcher investigated the leak in the ballast tank of the SPOB TOTO XIV ship and highlighted its prevention and countermeasures based on practical experience on board. Some of the issues discussed involved the lack of understanding and experience of the crew, especially the helmsman who was negligent in carrying out his duties, as well as the irregular docking schedule carried out by the company.

1. Lack of Understanding and Experience of ABK:
   a. Less professional crew members due to lack of understanding and knowledge of ship maintenance, especially ballast tanks.
   b. Lack of supervision by ship officers led to suboptimal performance.
   c. Lack of strict selection and appropriate maritime education background in the admission of crew members.
2. Irregular Dock Schedule:
   a. The unstable route of ship operation and the time spent by the company resulted in irregularities in undergoing docking.
   b. The impact of irregular docking schedules includes the occurrence of rust on the iron, which can be overcome with perfect care.
3. Failure to Achieve Company's Desired Goals:
   a. The company postpones dock maintenance to reduce operational costs, but this can lead to the failure to achieve the goal of maximum profit.
   b. Non-optimal maintenance standards also have an impact on the welfare of crew members who cannot be improved.

The researcher detailed ways to prevent ballast tank leaks based on practical experience on board the SPOB TOTO XIV. Some of the preventive measures described include increased knowledge and experience of the crew, regular inspections of the ballast tank, maintaining pressure in the tank, improving the skills of the crew, and perfect supervision.

1. Increased Knowledge and Experience of ABK:
   a. Strict selection and training are required to get an experienced and knowledgeable workforce.
   b. Selection of skilled and responsible crew members through job orientation training.
2. Routine Inspection on Ballast Tanks:
   a. Regular checks on the hull and inner walls of the ballast water tank.
   b. Regular pipe maintenance to detect and prevent leaks in the piping system.
3. Maintaining Pressure In Ballast Water Tanks:
   a. Maintains appropriate pressure in the tank to reduce the risk of leakage.
   b. Minimizes damage and risk of loss of charge by maintaining good pressure.
4. Improved Crew Skills:
   a. Job orientation training aims to develop the skills, responsibilities, and knowledge of ABK.
   b. Creating awareness of responsibility and good supervision in the implementation of duties.
5. Perfect Supervision:
   a. Preventive supervision to prevent errors in the execution of work.
   b. Periodic supervision of the ballast tanks by the ship's officers.
   c. Ensure supervision is not as finding faults, but as guidance in the implementation of work.
6. Efficient Repair and Maintenance:

a. Repairs and maintenance must be carried out in accordance with the orders of the bosun or head of work for the deck crew.

b. Corrective and maintenance actions must be carried out quickly and appropriately.

Table 1. Equipment and Materials Used

Yes	Ingredients	Equipment
1	Iron Plate	Wrench no.30
2	Majun	Shovel
3	Rubber Packing	Reply
4	Tension Crout	Bucket
5	Wood	Dip pump

7. Working Procedure

The author describes the working procedure for handling leaks in ballast tanks. In calm sea conditions and sunny weather, the Chief Officer gave orders to dispose of ballast and ordered Bosun to prepare tools and materials in the hatch. After the removal of the ballast, a routine inspection was carried out inside the ballast tank with lighting lights and a blower. If a leak was found, it was closed with an iron plate and spanscroef. Next, after the ballast was pumped, the area around the leak was cleaned and covered with a welded iron plate. This method was considered quite robust and lasted several months.

8. Regular docking schedule

The researcher explained the importance of a regular docking schedule based on the latest rules. According to the Decree of the Director General of the Sea, ships with the Red and White flag must undergo an inspection or docking every year. This rule covers passenger ships and ships of the A-90 and A-100 classes, with docking schedules ranging from 2 to 5 years depending on the class of ship. With regular docking schedules, ship maintenance and repairs can be carried out in a timely manner, prevent more severe damage, and keep the ship's condition always seaworthy.

The researcher also discusses the maintenance measures carried out during the docking, specifically rust countermeasures. This process involves rust cleaning, painting with a specific paint composition, and cathode protection using victim anodes or magnesium blocks. The author emphasizes the need for effective supervision in the maintenance process and handling of bulkheads or ballast tank plates to ensure the quality and safety of work. With the implementation of good work procedures and a regular docking schedule, the author hopes to achieve the main goals for both the company and the crew, which are to make great profits, improve the welfare of crew members, create a sense of security, and develop the company.

4. CONCLUSION AND RECOMMENDATIONS

This study concludes that inadequate understanding of ballast tank leak prevention on board SPOB TOTO XIV, combined with insufficient maintenance and irregular ship docking schedules, contributed to corrosion and deterioration of the ballast tank plating. These findings highlight the importance of implementing systematic maintenance practices and ensuring that corrosion is identified and addressed before it compromises the structural integrity of the ballast tank. Preventive measures are essential to reduce the risk of ballast tank leakage, maintain vessel safety, and support reliable ship operations.

To mitigate these risks, shipping companies and ship operators should establish routine inspection and maintenance schedules, ensure that ship docking is carried out in accordance with applicable requirements, and provide crew training on corrosion identification, prevention, and treatment procedures. This study is limited to the conditions examined on a single vessel, SPOB TOTO XIV; therefore, its findings may not be fully representative of other vessels with different operating conditions and maintenance practices. Future research should examine multiple vessels and investigate the relationship between maintenance practices, docking schedules, corrosion progression, and ballast tank leakage to develop more comprehensive and effective leak-prevention strategies.

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