Visual Corrosion Inspection, Evaluation, and Repair Procedure for Ship Tanks Navigating the Mediterranean Sea

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Abstract

This study addresses the formidable issue of corrosion faced by shipping companies, particularly in the Mediterranean Sea. Following the Spanish Legislation Royal Decree 1837/2000, a thorough visual inspection of various ship tanks was conducted, employing an inspection code for surface condition and repair prioritization. The predicament confronting shipping companies revolves around the detrimental impact of corrosion on vessels, leading to economic costs and safety concerns. Tanks such as the fore-peak, sanitary tank, center tank (1A), and double bottom tanks were scrutinized. The fore-peak exhibited significant corrosion (30%), necessitating an urgent epoxy coating. The sanitary tank, initially estimated at 6-25% corrosion, was revised to approximately 10%, requiring a high-pressure wash and epoxy coating. The center tank (1A) displayed localized corrosion (15%), emphasizing the need for prioritized repair with epoxy coating. Double bottom tanks 1 PT and 1 SD manifested corrosion (5%) and blisters (35%), necessitating repairs involving high-pressure washing and epoxy coating. Other tanks, such as freshwater tanks, demonstrated varying degrees of corrosion and required extensive repairs. The findings underscore the importance of customized maintenance strategies based on environmental factors. This study provides valuable insights for shipping companies navigating corrosive marine environments, underscoring the significance of timely detection and targeted repairs.

Key words

marine corrosion, visual inspection, ship tanks, preventive maintenance, marine environment.

1. Introduction

Corrosion is a highly expensive problem; it is estimated that corrosion losses in the United States amount to approximately $275.7 billion per year, accounting for 90% of failures [1]. Corrosion in ships leads to disruptions in cargo transportation, potential accidents, and repair costs. Statistical data indicates that corrosion is responsible for 90% of the costs associated with structural failures [2]. It should also be noted that numerical simulations are extremely useful for studying the complex phenomenon of corrosion, as it is very difficult to conduct experimental studies while the ship is in full operation [3]. Recently, artificial intelligence methods have been applied for the detection of marine corrosion [4]. One of those strategies is to use pyridinines and quinolines compounds as inhibitors on the surface of ships using machine learning [5]. Momber mentions various protective measures for ships, including the application of protective coatings, corrosion allowance, cathodic corrosion protection, low-corrosion design, climatization of internal sections, and monitoring and inspection [6].

As it is well known, corrosion degrades materials into their oxides and sulphides [7]. Ballast tanks are particularly vulnerable to corrosion as they come into contact with seawater when filled, yet they remain in a chloride-rich state when emptied. Moreover, certain areas within the ship pose challenges for effective maintenance due to limited lighting and difficult access [8]. The impact of microorganisms on the corrosive process should not be overlooked [9]. Approximately 65% of ships carry microorganisms in their ballast tanks [10] [11]. The high surface-to-volume ratio of certain bacteria facilitates rapid chemical reactions [12] and their metabolic activity can induce changes in their environment that promote corrosion in the material [13]. In addition to the corrosive effects, the transport of microorganisms has detrimental consequences for the environment, prompting the investigation of inert gas treatments for their removal [14].

In the realm of corrosion prevention for maritime structures, a multitude of coating technologies presents a promising panorama. Diverse options, such as polymeric coatings, nanocrystal electrodeposition, and self-assembled nanocoatings, are showcased in the literature, offering a nuanced approach to safeguarding both ships and machinery from corrosive elements [15]. Notably, innovative additives, as demonstrated in research involving carbon nanotubes and a hyperdispersant (polymethyl naphthol sulfonate), bring forth encouraging results, indicating a potential leap in corrosion resistance capabilities [16]. Recent studies by Upiah underscore the paramount importance of both painting and coatings for repairing or inhibiting corrosion in both ships and ship unloaders [17] [18]. Furthermore, the comprehensive strategy proposed by Bai et al., involving a stable multifunctional linkage anticorrosion composite coating with Zn^{2+} on serecite surfaces, adds a layer of complexity to corrosion protection approaches [19]. In a quest for enhanced stability, Shamsaee et al. meticulously developed Ni-PTFE composite layers through electrodeposition, with an optimal PTFE concentration, standing out as a significant advancement in corrosion resistance and long-term stability, attributed to the inherent hydrophobic nature of PTFE [20].

However, amidst these promising avenues, certain challenges persist. The presence of mill scale, if inadequately addressed during ship construction, emerges as a potential catalyst for accelerated corrosion. The cyclic nature of tank ballasting and deballasting operations introduces a vulnerability, subjecting surfaces to repeated wetting and drying and thereby expediting corrosion. The reliance on anti-corrosion coatings in tanks underscores their critical role, emphasizing the need for vigilant maintenance. Structural bending within a framework of a ship introduces the specter of stress corrosion, characterized by crack development perpendicular to applied stress at considerable speeds [21]. Additionally, the potential accumulation of gases in upper tank sections, contingent on the tank's filling level, poses a concern that warrants careful consideration in the pursuit of comprehensive corrosion mitigation strategies.

Research gaps in corrosion prevention for maritime structures encompass the need for long-term assessments of coating technologies, advanced detection methods for early identification, optimization of customized maintenance strategies, investigation into the environmental impact of anticorrosive treatments, and the effective integration of diverse technologies for holistic solutions. These areas present opportunities for enhanced understanding and improvement of practices in corrosion prevention within the maritime industry.

In the context of the maritime industry, corrosion emerges as a substantial challenge adversely affecting shipping companies, particularly during transit through the Mediterranean Sea. Widely recognized for its economic repercussions and potential hazards, this phenomenon manifests in the form of corrosive, mechanical damages, and other detrimental manifestations in the vessels' tanks. A detailed inspection will unveil the complexity of this issue across various tanks, each facing specific operational conditions and challenges. The dilemma lies in the urgent need to address these issues efficiently, prioritizing repairs based on the severity of the damages. In the insightful review conducted by Lin and Dong, the importance of regular hull inspections to ensure navigation safety is emphasized [22]. They propose employing computer algorithms and robots to enhance efficiency and reduce costs compared to traditional methods. However, it should be noted that a visual inspection utilizing appropriate technical means yields highly satisfactory results.

This study significantly contributes to the maritime industry's understanding and mitigation of corrosion challenges faced by shipping companies operating in the Mediterranean Sea. By meticulously inspecting and analyzing various tanks of a ship in accordance with Spanish Legislation Royal Decree 1837/2000 [23], the research provides valuable insights into the specific conditions of each tank, emphasizing the varying degrees of corrosion damage, mechanical issues, and other related concerns. The prioritization of repairs based on a detailed inspection code aids in addressing urgent issues promptly. Moreover, the study underscores the critical need for early detection and repair to prevent extensive damage, offering practical recommendations for surface cleaning, coating removal, and epoxy coating application. The findings serve as a comprehensive guide for maintenance and repair strategies tailored to ships navigating corrosive marine environments, thereby contributing to enhanced operational efficiency, safety, and cost-effectiveness within the shipping industry.

2. Materials and methods

The comprehensive inspection of the condition of the ship was meticulously conducted through a thorough visual examination, scrutinizing every aspect to ensure a comprehensive assessment. The vessel, with its main specifications meticulously documented, boasts a length of 93.53 meters, a beam width of 18.24 meters, and a draft reaching 4.61 meters. These vital statistics provide a detailed snapshot of the physical dimensions of the ship, emphasizing its substantial size and maritime capabilities.

In its maritime endeavors, this vessel predominantly plies the azure waters of the Mediterranean Sea, navigating through the diverse and dynamic maritime environment that characterizes this renowned body of water. The Mediterranean, with its historical significance and strategic importance, poses unique challenges and opportunities for seafaring vessels, and this ship, with its robust specifications, stands ready to navigate the intricate channels and open expanses of this captivating region.

The length of 93.53 meters signifies a vessel of considerable magnitude, allowing for the accommodation of various amenities and equipment essential for a successful voyage. Meanwhile, the beam width of 18.24 meters suggests a substantial breadth, contributing to the stability and seaworthiness of the ship, ensuring its resilience against the ebb and flow of the Mediterranean's often unpredictable currents.

Delving into the specifics, the draft of 4.61 meters highlights the depth of the vessel's immersion in the water. This measurement is crucial for assessing the ship's navigational capabilities, especially when navigating shallower or more challenging maritime terrains. It speaks to the vessel's adaptability, enabling it to traverse a range of depths and terrains within the Mediterranean, showcasing its versatility as it sails through varying conditions.

In essence, the specifications of the ship, coupled with its preferred maritime domain, underscore its role as a formidable seafaring entity, equipped to navigate the vast and diverse

Mediterranean Sea. The visual inspection, serving as a key component of the assessment process, ensures that the vessel meets the rigorous standards required for safe and efficient maritime operations, reinforcing its status as a reliable presence in the maritime landscape. Considering that each classification society has its own inspection regulations [24] [8], this inspection was performed in accordance with the Spanish Legislation Royal Decree 1837/2000 [23].

In order to streamline and enhance the efficiency of the inspection procedure, a systematic inspection code was established. This code is detailed in Table 1, where each element corresponds to a specific aspect of the ship's surface condition, along with a corresponding repair priority designation.

The inspection code in Table 1 outlines the criteria for evaluating the surface condition of the ship, with a focus on identifying and categorizing different types of damages. The categories range from a perfect surface condition ("-") to various degrees of superficial damage (1 to 5) based on the percentage of damage relative to the total area inspected. Additionally, categories "S" and "L" represent scattered and localized damage, respectively.

The repair priority is then assigned using letters: "U" signifies that urgent repairs are required, "M" indicates that the repair should be completed within 12 months, and "F" suggests that the repair can be carried out in more than 12 months. This prioritization helps in efficiently addressing and allocating resources to address the identified issues based on their severity and urgency.

In essence, this inspection code serves as a standardized and structured tool that provides clarity and consistency in communicating the findings of the inspection. It aids in the decision-making process by clearly defining the nature and extent of surface damage, as well as specifying the timeframe within which repairs need to be addressed. Overall, the establishment of this inspection code contributes to a more organized and effective approach to ship maintenance and repair planning.

The process followed in the inspection is outlined in the flowchart of Figure 1, providing a detailed visual representation of each sequential step and stage throughout the procedure.

3. Results and discussion

3.1 Fore-peak tank

The corrosion observed in the fore-peak tank accounts for approximately 30% of its total surface area. Minor mechanical damage is also present, with the majority concentrated in the reinforcements and peaks due to higher stress concentration levels in these areas. Additionally, corrosion damage was identified within the tank itself, attributed to the presence of salty water that remains inside after ballasting. Figures 2a and 2b illustrate that internal corrosion primarily occurs in vulnerable areas such as welds or openings in bulkheads. Figure 2b demonstrates the autocatalytic nature of the corrosive process, indicating a feedback loop and highlighting the importance of early detection to prevent extensive damage.

The repair process followed ISO 8501-1:2007 standards [25]. It establishes two cleaning degrees before painting: St2 and St3. St2 requires the surface to be free of visible oil, grease, and dirt, as well as mill scale, rust, paint coatings, and foreign matter showing poor adhesion. This is achieved by manual or machine steel brushing, leaving the surface with a soft metallic sheen. St3, a thorough manual and mechanical cleaning, requires the surface to have a clear metallic sheen. In this tank, the St3 cleaning degree was used to achieve maximum coating adhesion.

As the tank is used for ballast, the frequent presence of saltwater inside favors corrosion, particularly in the weakest parts, such as welding areas, bulkhead openings, or at the ends of the tank.

The fore-peak operates under two different working conditions: its surface is in contact with the marine atmosphere, and there is a splash zone. A summary of the tanker's condition is presented in Table 2.

As evident in Table 2, fore-peak repair is of utmost urgency. To address this, an epoxy coating was applied as follows:

- An initial layer of grey epoxy paint covered a total surface area of 1150 m^2. The paint had a 77% volume solid content. A primary coat was administered to the corroded surface, representing 30% of the overall surface area, with a designed thickness of 150 µm, expected to reduce by approximately 50% due to solvent evaporation during drying. This phase consumed 134 L of paint, resulting in an epoxy paint yield of 2.6 m^2L^{-1}.
- For the second layer, a red epoxy paint coating was applied to 40% of the total surface area, 10% more than the corroded surface, as a preventive measure. In this phase, 150 L of epoxy paint were used, equating to an epoxy paint yield of approximately 3.1 m^2L^{-1}.

This coating strategy not only addresses existing corrosion but also aims to prevent future damage. The careful application of protective layers with specific characteristics seeks to ensure effective and lasting protection.

3.2 Sanitary tank

The sanitary tank, crucial for the hygiene and proper functioning of the vessel, presents a significant challenge due to its location and purpose. Corrosion, assessed at 10% of the total surface during the inspection, may be influenced by the specific environmental conditions to which this tank is exposed. Given its position and purpose, humidity and temperature can play a significant role in the corrosive process.

With the aim of addressing these challenges, a high-pressure and high-temperature water washing strategy was implemented, ranging from 150 to 180 bars and between 70 and 90 °C, in accordance with ISO 8501-3: 2008 [26]. This approach not only removes grease, blisters, and inadequate repainting but also effectively prepares the tank's surface to receive the protective coating.

Table 3 provides a detailed summary of the corrosion status of the sanitary tank, highlighting the presence of corrosion (3S), mechanical damage (1L), blisters on 10% of the surface, and white repainting on 10%, which did not adhere correctly to the original layer, potentially causing additional damage. Furthermore, the table shows that 80% of the original coating remains in good condition, but repair is required on 20% of the total surface.

The application of an initial layer of gray coating with a thickness of 150 µm was strategically chosen to address specific damaged areas identified during the inspection. This layer not only provides a robust defense against corrosion but also establishes suitable conditions for the application of the final red coating layer.

The choice of the red coating is not solely for aesthetic purposes but is based on its preventive capabilities. By covering 40% of the total surface, 10% more than affected by corrosion, this layer aims to prevent future damage and contribute to the long-term integrity of the sanitary tank. This strategic approach not only addresses the damaged areas but also establishes a protective barrier to ensure optimal performance of the tank in the demanding maritime environment.

Figure 3 depicts the detachments and oxidations observed in the area of reinforcements.

3.3 Centre tank (1A)

This tank is situated at the bow of the ship, in the central section. It exhibits localized corrosion affecting approximately 15% of the surface, primarily concentrated in the reinforcement areas and their lower sections. The prolonged presence of liquids in these regions, coupled with the tendency for the accumulation of dirt, contributes to the onset of corrosion. Moreover, the reinforcement areas pose challenges for effective coating application, significantly increasing the likelihood of corrosion. Figure 4 visually illustrates the corrosion observed in the reinforcement area.

The corrosion damage in this tank is estimated to affect 20% of its surface, which includes 5% of white repainting with poor adherence. Considering the established codes, the condition of the central tank is summarized in Table 4.

The total area of this tank is 580 m^2. Initially, the surface damage, accounting for 20% of the tank's total surface, was treated with a 150 µm thick layer of grey epoxy coating. This stage required a total of 45 L of paint, resulting in a paint yield of 2.6 m^2L^{-1}. In the second layer, an additional 10% of the tank's surface was covered, which corresponds to 30% of the total surface, equivalent to 174 m^2. For this layer, red paint was used. The total volume of coating applied in this stage was 56 L, resulting in a yield of approximately 3 m^2L^{-1}.

3.4 Double bottom tank 1 PT

This tank is located at the bottom of the ship, specifically in the double bottom area on the port side. Corrosion is present on approximately 5% of the tank's surface, primarily affecting the lower sections of the bulkheads and the ceilings. Blisters are visible on approximately 35% of the tank surface, with an adjacent area exhibiting poor adhesion. In total, the damage amounts to approximately 40% of the tank's surface. Mechanical damage is minimal, accounting for less than 2% and confined to a localized area. Figure 5 illustrates the scattered blisters found throughout the tank.

Before coating, the surface was washed with pressurized water between 150 and 180 bars and a temperature between 70 and 90 °C. This procedure removes exfoliations, salts, grease, and repainted areas. The first layer of grey coating was applied over the damaged 540 m^2 of the tank, and the second layer, red, covered an additional 54 m^2. The thickness of each layer was 150 µm, and the total consumption of paint amounted to 172 L.

3.5 Double bottom tank 1 SD

The tank is located in the lower part of the ship, specifically in the double bottom area on the starboard side. Upon inspection, approximately 5% corrosion was detected, primarily attributed to mechanical damage. Scattered blisters were found on 15% of the tank surface. In the vicinity of the blisters, poor adhesion between the paint system and the steel was observed. Additionally, 20% of the tank surface was repainted white, but this paint exhibited limited adherence to the original coating. Considering all the damage, a total area of 40% of the tank required repair. Since this tank is identical to the previous one and exhibits nearly the same damages, the same procedure was applied: applying a first layer of grey coating followed by a second layer of red paint, with a total paint consumption of 172 L for both layers combined."

These changes mainly involve adjusting the sentence structure for smoother flow and specifying that the 40% repair area accounts for all types of damage mentioned

3.6 Central double bottom tank 1

This tank exhibited less damage compared to the previous ones. Corrosion was localized and affected 2% of the tank surface, specifically in the tank reinforcements. Additionally, a small portion of the surface showed peeling, and blisters were observed on 10% of the tank surface, scattered throughout. The presence of blisters caused a lack of adherence in the surrounding areas. Consequently, the area requiring repair accounted for 10% of the tank surface.

Similar to the previous cases, the damaged surface needed to be cleaned using high-pressure, high-temperature water to remove both the blisters and incompatible paint layers. Once the cleaning process was completed, two coats of coating, grey and red, were applied to the damaged surface, which in this case amounted to 71 m^2. The second layer covered an additional 10% of the surface.

Figure 6 illustrates the lack of adherence between the paint and the steel in the area near the blisters.

3.7 *Double bottom tank 2 PT*

The tank under examination is located at the bottom of the ship on the starboard side, specifically the second tank towards the stern. Corrosion in this tank is dispersed and accounts for approximately 2% of the tank's surface, primarily affecting the reinforcements, roofs, and lower sections. Mechanical damage is minimal, less than 2%, with localized areas showing cracking and peeling, amounting to 2% of the tank. Additionally, there is a lack of adhesion between the paint system and the steel. Overall, 5% of the tank requires repair due to damage occurring in the same areas.

Figure 7 illustrates the detachment and lack of adhesion between the paint and the steel. The faults are located in the three-lane roofs spanning the entire length of the tank.

The total area of this tank is 610 m^2. Following the same procedure as the previous tank, a total of 173 L of paint were used for the two layers.

3.8 Deep Tank 1 SD

Table 5 presents the inspection findings for starboard deep tank 1. The overall damage to this tank amounts to 10%. The corrosion is primarily attributed to mechanical damage. Blisters are observed in scattered locations, covering approximately 10% of the tank's surface. The presence of blisters results in a lack of adhesion in the surrounding areas.

Figure 8 shows the lack of adherence between the previous paint system and the steel in the area near the blisters.

Prior to the application of the anticorrosive coating, cleaning was performed using pressurized water at a high temperature ranging from 70 to 90 °C and at a pressure between 150 and 180 bar. The total surface area of this tank is 540 m^2, with approximately 54 m^2 requiring repair due to damage. Following the same procedure as in previous cases, a total of 60 L of epoxy coating was used for this tank.

3.9 Deep Tank 2 SD

This is the second-deep tank on the starboard side. Approximately 1% of the surface showed corrosion, which was attributed to mechanical damage. Blisters were observed on 2% of the total surface, causing a lack of adherence in the surrounding areas. The repair required addressing 3% of the tank's surface. Overall, the tank was in good condition. With a large area of 2,100 m^2, a total of 65 L of epoxy coating was consumed for the two layers. As in previous cases, the application of the epoxy coating was preceded by cleaning with high-pressure and high-temperature water.

3.10 Fresh water tank 13 PT

This tank is located on the port side of the ship. Corrosion was observed in a localized manner, representing 5% of the tank's surface, as indicated in the results shown in table 6. The corrosion can be attributed to mechanical damage and improper repainting, where the original paint scheme was not followed.

There were cracks present on 5% of the tank surface, along with peeling and blisters scattered across 30% of the surface. Taking into account the dispersed nature of the damage, a total of 70% of the surface requires repair. The repair process followed the cleanliness guidelines outlined in ISO 8501-3:2008 for achieving a St3 cleanliness degree.

To address the damage, a high-pressure and high-temperature wash with fresh water (between 150 and 180 bar and between 70 and 90°C) was conducted. This wash aimed to remove blisters, incompatible repainting, and grease from all possible areas. Furthermore, areas exhibiting exfoliation, oxidation, and detachment were meticulously treated by grinding and brushing. Additionally, a thorough abrasive blast cleaning was performed.

It is worth noting that the preparation process for this tank was more extensive compared to the previous ones. This is attributed to the fact that this tank is designated for storing clean water for the crew's consumption. Figure 9 provides a visual representation of the internal condition of the fresh water port tank 13.

3.11 Fresh water tank 13 SD

This tank is situated on the starboard side of the ship. The corrosion observed in the tank affected approximately 2% of its surface. The corrosion was primarily a result of mechanical damage and improper repainting that did not adhere to the original paint scheme.

Blisters were found on 50% of the tank's surface, leading to a lack of adherence between the paint system and the steel, as well as between the paint layers. Considering the widespread nature of the damage, a total area of 70% requires repair. Figure 10 provides a visual representation of the corrosion spread within the tank.

The repair of this tank was identical to the previous one, since both tanks have the same mission on the ship.

3.12 Deep Tank 2 PT

This tank is located on the port side. Corrosion was present in 5% of the tank surface and it was mainly due to mechanical damage. Scattered blisters were found in most of the tank, the percentage of the floor surface covered by them was 90%, which caused a lack of adhesion of the previous paint system on the tank floor. Total tank surface damage repaired was 25%. The above data is shown in a more schematic way in table 7

An SA $2^{1/2}$ cleanliness grade is also applied to this tank prior to coating. The blisters were scattered throughout the floor, covering approximately 90% of the surface. Figure 11.a shows the mechanical damage and oxidation on ceilings and bulkheads. The blisters were scattered throughout the floor, covering approximately 90% of the surface (11.b).

Upon completion of the inspection, it was found that the tanks with the greatest corrosion were those located from the central part to the bow (Fore-peak, Sanitary Tank, Central Tank 1 and Port Double Bottom Tank and Starboard Double Bottom Tank). This incidence was due to environmental effects (rain or wind) and temperature gradients, which are much more pronounced in this part of the ship.

The most damaged tanks on this ship and in need of major repairs were the 13 PT and SD freshwater tanks, which need 70% of their area repaired. Although it is true that the repair was mainly due to the presence of blisters and peeling and not so much to the state of corrosion of its plates.

The next tanks in repair order are double bottom tanks 1 Port and Starboard. Both tanks have 40% surface damage. Both tanks have similar damage to their protective shell. Although they are not the most corroded, but they have a lot of blisters on their surface. Double bottom tanks are considered to have a relative humidity of 90 to 100% [27].

Some authors such as Mendoza et al. established that the time of the wet state of the surface depends on climatic factors, including humidity, hours of sunlight, the temperature of both the air and the metal surface, the speed of wind and the duration and frequency of rain and fog [28]. Within a tank not all factors can coexist. However, the influence of the hours of sun is the most preponderant since it increases the temperature inside the enclosure.

On the other hand, Gardiner et al. [27] established that corrosion is a function of three parameters: time of wet state of the surface, salt deposits and temperature. Although in the present case tanks inside the ship were analyzed, and it could be thought that the influence of salt in the corrosion process is practically insignificant, however, in the ballasting and deballasting operations of tanks they are filled and empty with salt water, which is why the presence of salt inside the tanks cannot be neglected.

The tanks with the least damage are the Deep tank 2 SD and the Double Bottom tank 2 PT. These two tanks are located in the lower part of the ship and therefore have a more constant temperature, because they are always submerged and close to the water, controlling the internal temperature of the tank.

4. Conclusions

The comprehensive analysis of the integrity of the onboard tanks has revealed a detailed overview of the structural challenges facing the vessel. These results provide valuable insights to guide immediate actions and long-term strategies with the aim of strengthening structural resistance, extending the lifespan of tanks, and optimizing maintenance operations. The main conclusions are presented below, outlining directions for future work, merging the findings obtained with a forward-looking perspective.

By meticulously examining each tank, from the Fore-peak to the Deep Tank 2 PT, a prioritization for repairs has been established, highlighting those requiring urgent attention. Identifying specific damage patterns and evaluating successful repair methods have emerged as fundamental pillars for designing preventive and corrective strategies.

It is imperative to recognize the influence of environmental factors, such as exposure to wind and rain, and the correlation between temperature and humidity in the corrosive process. These aspects, supported by previous research, underscore the importance of addressing not only existing damages but also implementing preventive measures that preserve long-term structural integrity.

The most affected tanks, such as the 13 PT and SD freshwater tanks, have emerged as critical points requiring substantial interventions, mainly due to the presence of blisters and detachments. Although corrosion is a predominant concern, it is highlighted that the condition of the plates has also contributed to the need for repairs, revealing the complexity of the challenges faced.

Looking ahead, a deeper investigation into the specific effects of humidity and temperature inside the tanks is recommended, especially considering the presence of saltwater during ballasting operations. These studies could provide essential information to develop more effective and specific protection strategies for the vessel's conditions.

Through this work, not only does it fulfill the role of being a detailed report on the current state of the tanks, but it also serves as a platform for future research and corrective actions. In doing so, the aim is to ensure the continued safety and efficiency of the vessel, reaffirming a commitment to sustainable maritime practices and the long-term preservation of the flee

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Biographies

Juan José Galán holds a Ph.D. in Physics and is a professor in the area of materials science at the University of A Coruña. He has conducted research in the field of condensed matter, focusing on both metallic and polymeric materials, particularly those with various specific coatings. Currently, his research also encompasses topics related to sustainability and the recycling of materials within an industrial context.

Nuria Varela Fernández, who holds a Ph.D. from the University of A Coruña, stands out for her research focus on the corrosion of maritime materials. Her contributions to the field include the present work, which constitutes an integral part of her doctoral thesis. In addition to her academic achievements, Dr. Varela Fernández demonstrates a notable commitment to scientific pedagogy, enhancing not only the realm of research but also the dissemination and transmission of scientific knowledge.

Table 1 Inspection code

Surface condition:	Repair priority
-: Perfect	U The repair must be urgent
1. Surface damage less than 2% of the total area inspected	M The repair must be done within 12 months
2: Superficial damage between 2 and 5% of the total area inspected	F The repair can be done in more than 12 months
3: Superficial damage between 6 and 25% of the total inspected area	
4: Surface damage greater than 25% of the total area inspected	
5: 100% damaged surface	
S: Scattered damage	
L: Localized damage	

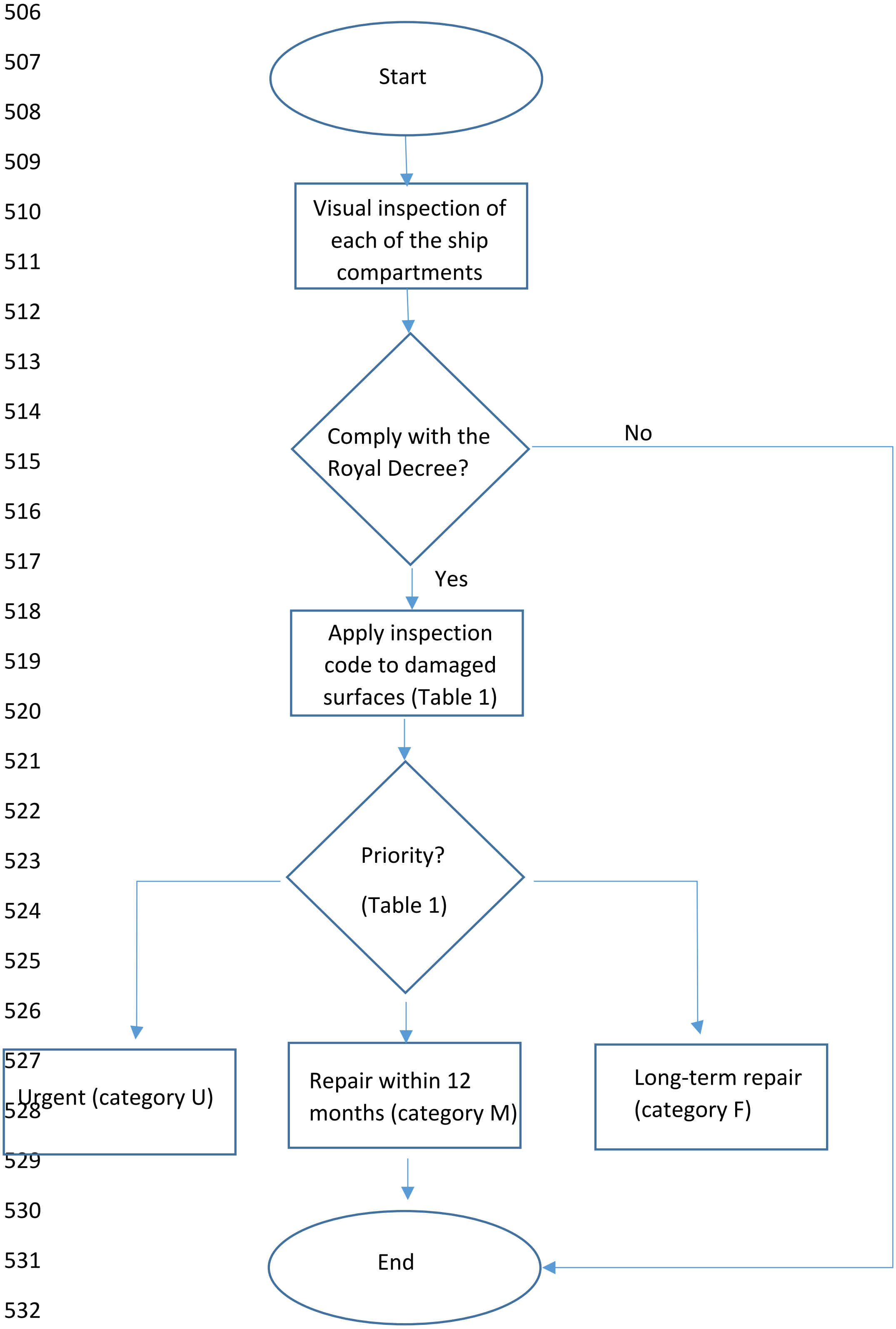


Figure 1. Flowchart of the inspection process for the compartments of a ship

(a) (b)

Figure 2a Corrosion damage inside the forepeak. Figure 2b autocatalytic process inside the forepeak

Table 2: Forepeak tank corrosion status summary

Forepeak	Corrosion	Mechanical damage	Rust cracking	Rust peeling	Blisters	Priority
Bulkheads, ceilings and floors	4L	1L	-	1L	-	U

Table 3: Sanitary tank corrosion status summary

Sanitary tank	Corrosion	Mechanical Damage	Rust cracking	Rust peeling	Blisters	Priority
Bulkheads, ceilings and floors	3S	1L	-	2L	3L	U

Figure 3 Detachments and oxidation in the area of reinforcement in the sanitary tank.

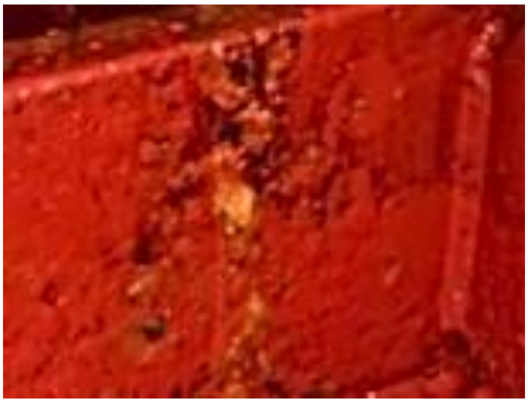


Figure 4 Corrosion in a reinforcement area of the central tank

Table 4: Centre tank corrosion status summary

Centre tank	Corrosion	Mechanical damage	Rust cracking	Rust peeling	Blisters	Priority
Bulkheads, ceilings and floors	3L	1L	-	2L		U

Figure 5 scattered blisters in double bottom tank 1 PT

Figure 6: Adhesion issue in double bottom central tank 1

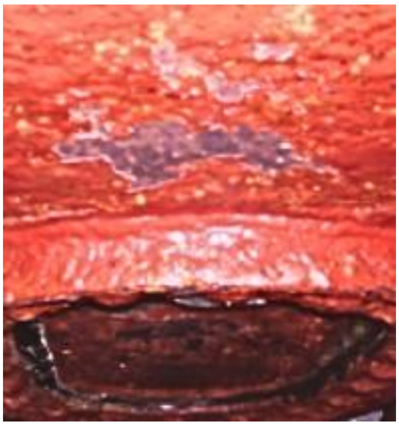


Figure 7: Image of the interior of double bottom tank 2 PT

Table 5: Summary of Corrosion Status in Deep Tank 1 SD

Deep Tank 1 SD	Corrosion	Mechanical damage	Rust cracking	Rust peeling	Blisters	Priority
Bulkheads, ceilings and floors	2L	2L		2L	3S	U

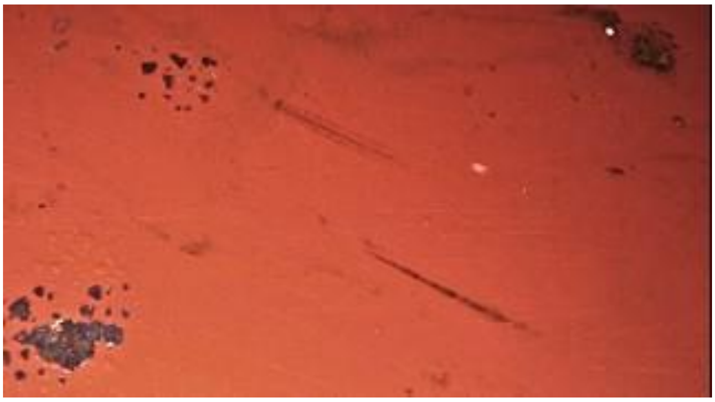


Figure 8: Interior Image of Deep Tank 1 SD

Table 6: Summary of Corrosion Status in Fresh Water Tank 13 PT

1Fresh water tank 13 PT	Corrosion	Mechanical damage	Rust cracking	Rust peeling	Blisters	Priority
Bulkheads, ceilings and floors	2L	2L	3S	4S	4S	

Figure 9. Inside part of the fresh water tank 13 PT

Deep Tank 2 PT	Corrosion	Mechanical damage	Rust cracking	Rust peeling	Blisters	Priority
Bulkheads, ceilings	2L	2L	1L	2S	2L	U
floors	2L	2L	2L	3S	5S	U

Table 7: Deep Tank 2 PT corrosion status summary

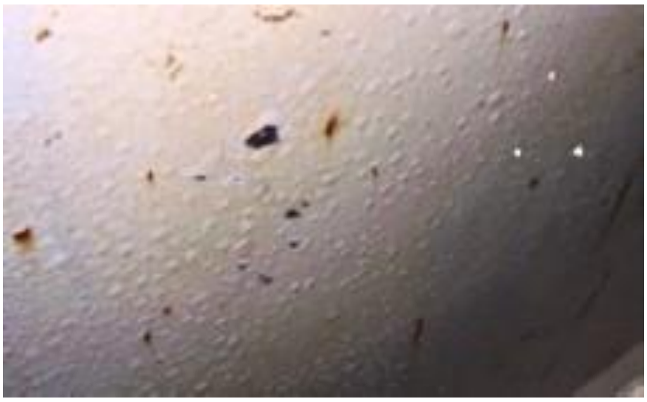
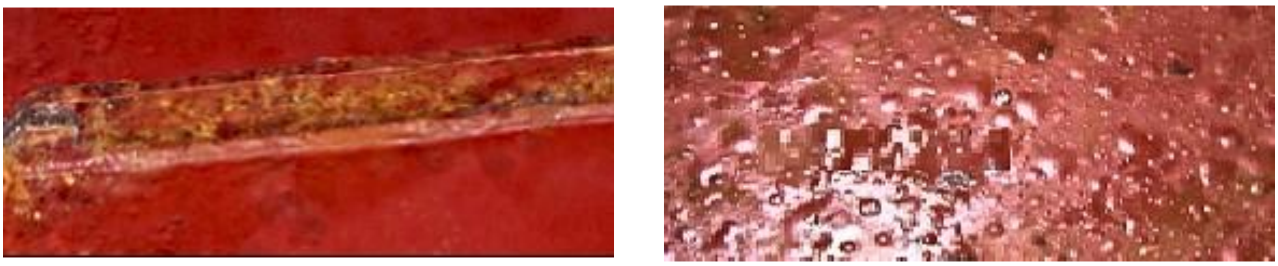


Figure 10. Inside part of the fresh water tank 13 SD



(a) (b)

Figure 11. Oxidation on bulkheads (a) Tank floor condition (b)