TRANSNAV
http://www.transnav.eu
the International Journal
on Marine Navigation
and Safety of Sea Transportation
Volume 19
Number 2
June 2025

DOI: 10.12716/1001.19.02.11

Simulation of the Unintentional Unberthing of Vessels (Ship Drift) in a Physical Hydraulic Model

R. Esferra, C.C. Fernandes de Jesus, R. de Oliveira Bezerra & J.C. de Melo Bernardino
University of Sao Paulo, Sao Paulo, Brazil

ABSTRACT: Ship drift refers to the unintentional movement of a vessel caused by external forces—such as wind, currents, and waves—acting on the hull without deliberate control by the crew. During navigation, drift may result from failures in the propulsion system or rudder, which impair or prevent maneuverability, leading to course deviations and increasing the risk of grounding or collisions. When the vessel is moored, drift may occur due to extreme environmental conditions or human error that result in the breaking of mooring lines. In such cases, the problem known as unintentional unberthing occurs, often representing an even more critical situation, as the vessel is located near fixed structures such as quays, piers, or other vessels, thereby increasing the probability of accidents and damage to the environment and port infrastructure. This paper presents a study of an estuarine port area, carried out in a Froude-number based reduced-scale physical modeling, to assess the risks associated with the unintentional unberthing of a VLOC-class vessel (400,000 DWT). The study involved the analysis of the drifting trajectory of the vessel under various environmental conditions, positioning of the vessel at the berths, and occupancy of adjacent berths. A digital camera tracking system was employed to monitor the vessel's position at each moment in time, allowing for the assessment of collision risks with port structures or other ships, as well as the potential for grounding in shallow areas. The results of the physical model simulations identified the scenarios with the highest potential for damage, underscoring the importance of strict maintenance of mooring systems and serving as a basis for the development of an emergency action plan to mitigate accident risks in the port area.

1 INTRODUCTION

Ship drift refers to the involuntary displacement of a vessel under the influence of currents, winds, or other natural forces, without active control by the crew. In other words, it is the passive movement of the ship caused by external forces rather than planned navigation or its own propulsion. When the vessel is in transit, drift may occur due to propulsion or rudder system failures or in areas with strong maritime currents, among other factors [3].

When the ship is docked, drifting can occur due to extreme environmental conditions or human errors that result in the rupture of mooring lines. In this case, what is known as unintentional unberthing occurs, which usually constitutes an even more critical situation, as the ship is near port structures such as quays, piers, or other vessels, increasing the likelihood of accidents and damage to the environment (leakage of hazardous substances) and port assets (collisions with other vessels or structures). Additionally, there are economic impacts, including delays in cargo delivery and costs associated with damage repairs. In such cases, a rapid response from the crew and port authorities is essential to prevent harm and ensure the safety of those involved [4] [6].

For these reasons, studying unintentional unberthing is crucial. Understanding drift patterns helps to prevent maritime accidents, optimize port and navigation operations, and support the development of effective maritime regulations and guidelines.

Froude-number-based reduced-scale model, also called physical hydraulic model (PHM), is an effective tool in this type of analysis. It allows a high-fidelity representation of hydraulic conditions affecting vessels, enabling direct assessment of the interaction between the flow and the port structures. Furthermore, this approach helps identify critical operational scenarios, validate damage mitigation strategies, and provide valuable insights for port operation planning and safety [5].

The application of PHM's is particularly advantageous compared to computer simulations, which often require greater simplifications of physical phenomena involved and face limitations in accurately representing complex flows around solid structures (such as vessels, berths, etc.). In contrast, when properly designed to avoid or mitigate major scale effects, PHM provides a realistic representation of the flow dynamics and their effect on vessels.

This paper presents a study of an estuarine port area carried out on a 1:170 scale PHM to assess the risks associated with the unintentional unberthing of a VLOC (Very Large Ore Carrier) class vessel (400,000 DWT). The study analyzed the vessel's drift trajectory under different scenarios of environmental conditions, VLOC positioning at berths, and presence of other vessels at adjacent berths.

A high-resolution digital camera-based tracking system was employed to accurately monitor the vessel's position. This tracking system also allows real-time calculation of the ship's drift velocity, in addition to a detailed analysis of potential collisions with port structures or other vessels and risks of grounding in shallow areas.

The main objective of this paper is to present the methodology for analyzing unintentional unberthing and vessel drift using physical hydraulic modeling, presenting the testing techniques and the results obtained in a case study.

2 MATERIAL AND METHODS

PHM's of estuarine and port regions allow the simulation of various environmental scenarios, including tides, currents, and waves, as well as different ship types, loading conditions, and mooring systems.

For this study, a non-distorted 1:170 geometric scale PHM was used, covering an area of 1,700 m² at the Laboratory of Hydraulics of the University of Sao Paulo (USP), Brazil. The model represents a port area located inside a bay, sheltered from wave action but subject to strong tidal currents (the current speed can reach up to 6 knots near the berths). Hydraulic similarity was ensured by maintaining equality of the dimensionless Froude number between the model and the prototype, guaranteeing the correct relationship between inertial and gravitational forces. Additionally, the model was designed to ensure that the studied flow conditions always remained in a rough turbulent regime, avoiding scale effects associated with viscosity.

Beyond topographic and bathymetric features, as well as the representation of port structures, the PHM includes scaled-down vessels (Figure 1) constructed based on real ship line plans and general arrangements, preserving geometric similarity. Vessel models calibration involved verifying the center of gravity and radius of gyration to ensure an accurate representation of the movements of the full-scale vessels.

Figure 1. View of the real 400,000 DWT VLOC (left) and its 1:170 scale model (right).

The calibration of currents in the PHM (Figure 2) was conducted using georeferenced measurements of velocity, direction, and water level, based on field surveys. Twenty-four (24) homologous points were established to assess tidal current velocity and direction, employing MicroADV sensors and limnimetric probes. The PHM was validated to accurately represent flood and ebb currents within the local tidal range. While the PHM calibration process is discussed in greater detail in [2], this paper focuses only on the aspects most relevant to the present study.

Figure 2. General view of the case study PHM (Geometric scale 1:170).

The position and elevation of the ship and berth's mooring elements (bollards, bitts, winches, chocks, fairleads) are strictly respected, ensuring that the angles formed by the mooring lines in relation to the vertical and horizontal planes are equal to the real values. The lines are positioned on the mooring elements (of both pier and ship) according to the predefined mooring arrangement.

Before the test begins, with the vessel fixed and centered in the berth (Figure 3), pretensions corresponding to 10% of the MBL (Minimum Breaking

Load) are applied to the lines. The MBL represents the minimum nominal breaking load of a line. This procedure follows the practice adopted in the mooring of real ships.

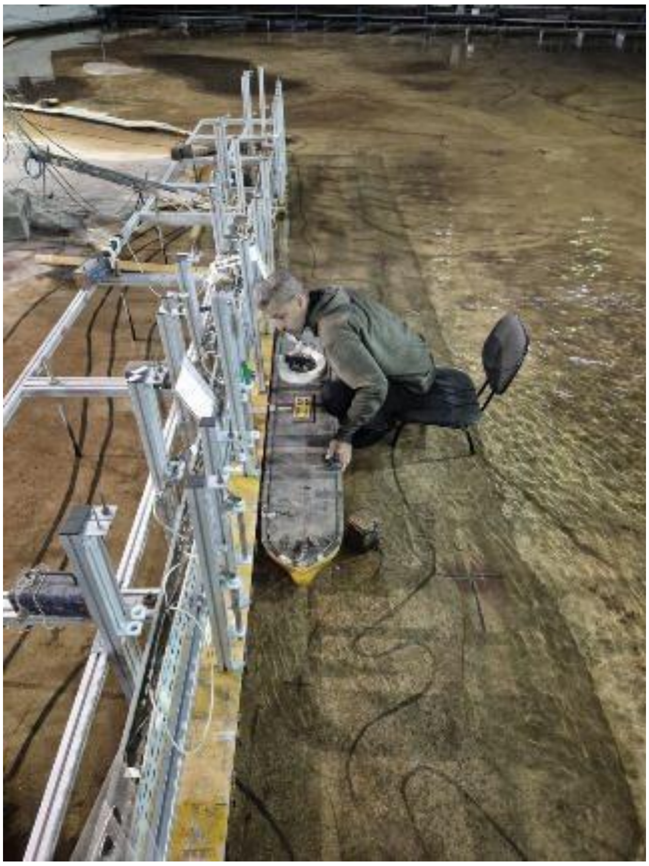

Figure 3. Ship positioning process at the center of the berth.

The simulation system for unintentional unberthing in the PHM consists of a set of mechanisms to which the mooring lines are attached and positioned on the ship's deck (Figure 4). These mechanisms allow each line to be individually released by means of a remotely sent signal. The release sequence of the mooring lines can be carried out in different ways, either based on hypothetical scenarios or real events observed in the field.

After the release of the mooring lines, with the ship drifting, a tracking system monitors the vessel's position, allowing analysis of its movement, including potential collisions with structures, displacement direction and speed, as well as grounding risk. The tracking system, known as ship tracking, operates using images captured by a set of digital cameras installed in a zenithal position and strategically distributed along the PHM, ensuring full coverage of the ship’s movement area during the tests (Figure 5). The images generated are processed by a software developed specifically for this purpose, which detects and continuously tracks the position of markers attached to the ship’s deck [1] (Figure 4).

Figure 4. Mechanisms (mooring elements in red) and markers (triangle and rectangle in white) installed on the ship's deck for unintentional unberthing simulation.

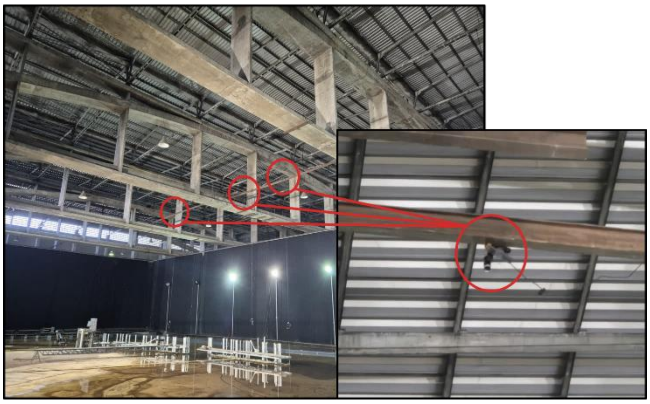

Figure 5. Digital camera system installed in a zenithal position.

In addition, the software correlates the captured images with a corresponding map of the study area, enabling the georeferencing of the tests. To achieve this, at least two reference points with known coordinates are used in the image from each camera. These points are marked on the floor of the PHM (Figure 6).

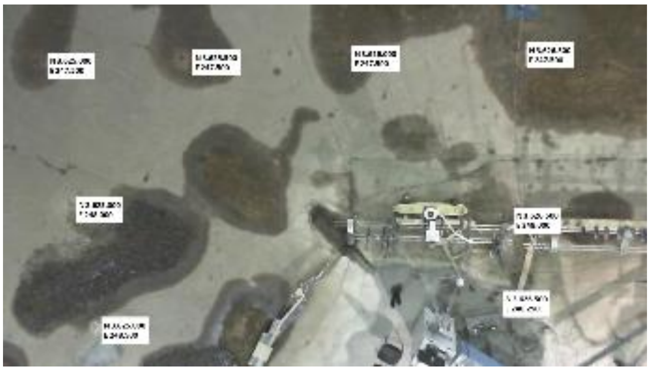

Figure 6. Image of the vessel's position monitoring system, highlighting reference points with known coordinates (in meters).

Thus, at each moment in time, the relative position between the deck markers and the reference points on the model floor is calculated, determining the ship’s location on the chart. Using this same system, it is also possible to calculate the drift speed of the ship model.

For the case study presented in this paper, the modeled port in the PHM has six berths (1 to 6), numbered from North to South (Figure 7).

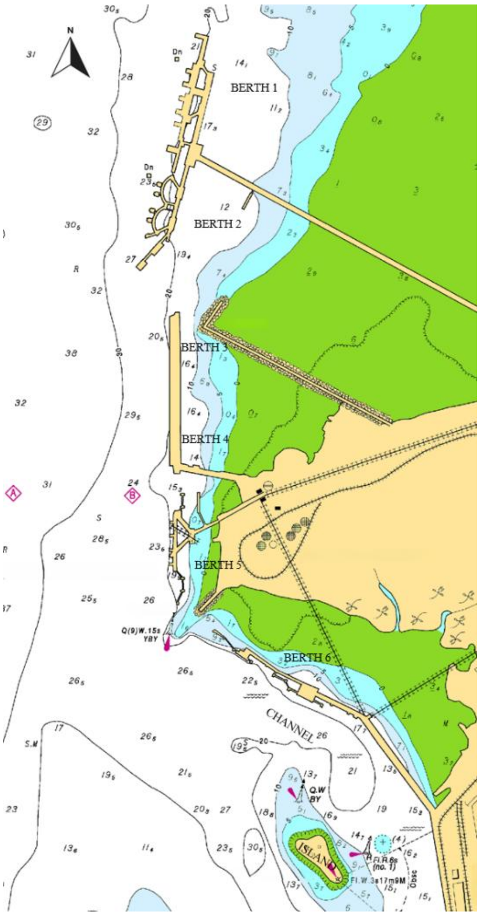

Figure 7. General layout of the case study port.

For the two simulation scenarios presented, one VLOC (400,000 DWT), with the unintentional unberthing system installed, was docked at berth 4, chosen because it is one of the berths used by large vessels and it is surrounded by adjacent berths, making it a critical point in cases of ship drift. For the first scenario, under flood tide conditions, another VLOC was docked at berth 5. For the second scenario, under ebb tide conditions, another VLOC was docked at the berth 2.

Through tests to measure forces on the mooring lines, previously carried out in the PHM, the most stressed lines of the simulated mooring arrangement were identified. The criterion adopted for the release sequence of the lines followed the order from the most stressed (highest measured forces) to the least stressed. The release was carried out at regular intervals of 5 seconds (in scale model), which corresponds to approximately 1 minute in full scale. To validate the results, the simulation of each scenario was repeated 12 times. The adopted mooring arrangement included a total of 20 HMPE (High Modulus PolyEthylene) lines with a minimum breaking load (MBL) of 100 tf, distributed as follows:

Table 1. Composition of the mooring arrangement.

Group	Abbreviation	Nº of ropes	Rope material (MBL)
After Breast 1	AB1	2	HMPE (100 tf)
After Breast 2	AB2	2	HMPE (100 tf)
After Breast 3	AB3	2	HMPE (100 tf)
After Spring 1	AS1	2	HMPE (100 tf)
After Spring 2	AS2	2	HMPE (100 tf)
Forward Spring 2	FS2	2	HMPE (100 tf)
Forward Spring 1	FS1	2	HMPE (100 tf)
Forward Breast 2	FB2	2	HMPE (100 tf)
Forward Breast 1	FB1	1	HMPE (100 tf)
Head 2	H2	1	HMPE (100 tf)
Head 1	H1	2	HMPE (100 tf)

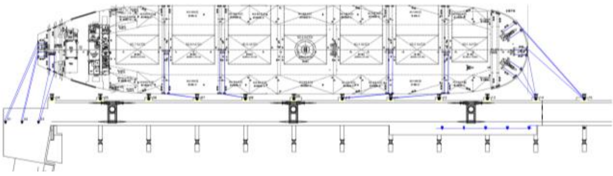

Figure 8. Mooring arrangement of the ship, moored to starboard.

The mooring lines release sequences for flood and ebb tide conditions were:

Table 2. Mooring line release sequence for the VLOC docked at the berth 4.

Vessel	Berth used in the simulation of ship drifting	Tide condition	Release sequence of mooring lines	Neighboring berth with a moored vessel
VLOC (400,000 DWT)	4	Flood	FB1-FB2-FS2-H1-AB3-AB2-AB1-H2-FS1-AS1-AS2	5
		Ebb	FB1-FS1-FS2-H1-FB2-H2-AB3-AB1-AB2-AS1-AS2	2

This method allows the assessment of damage risks associated with the ship drift. The objective is to provide technical support for defining risk mitigation strategies in situations involving mooring line failures.

3 RESULTS AND DISCUSSION

The results of the two drifting test scenarios are presented in Figures 9 and 10, which show the trajectory of the twelve repetitions of the tests carried out for each scenario: flood tide and ebb tide, respectively. The analysis of these tests was based on the following criteria:

- Allision: Checking for impacts of the unberthing vessel with the berth structure or adjacent berths.
- Collision: Evaluating collisions between the unberthing vessel and ships moored at neighboring berths.
- Yawing: Identifying uncontrolled yawing tendencies of the drifting vessel, which could pose risks to tugboat approaches.
- Speed: Analyzing drift speed, considering that speeds equal to or greater than 2 knots represent a risk for safe tugboat operations, as indicated by the port operation team and tugboat commanders.

In the flood tide scenario (Figure 9), the 400,000 DWT vessel was observed unberthing from the berth 4 and drifting. Allisions with the berth structure occurred, as well as a collision with the vessel moored at berth 5, and there was little tendency for yawing, resulting in a drift toward an island located further south, where the vessel grounded. The first line released was the forward breast line, considered the most stressful in the mooring arrangement. The maximum observed speed of the vessel was 2.7 knots (a value above the safety limit for tugboat approaches), and the average distance traveled by the vessel was 1.3 km. Considering the vessel's behavior during the drift, the scenario was classified as having a high potential for damage to the port due to the allisions with the berth structure, collision with the vessel at berth 5, and the grounding tendency on the island. It is emphasized that unintentional unberthing of ships at berth 4 could lead to the suspension of navigation in the access channel to berth 6.

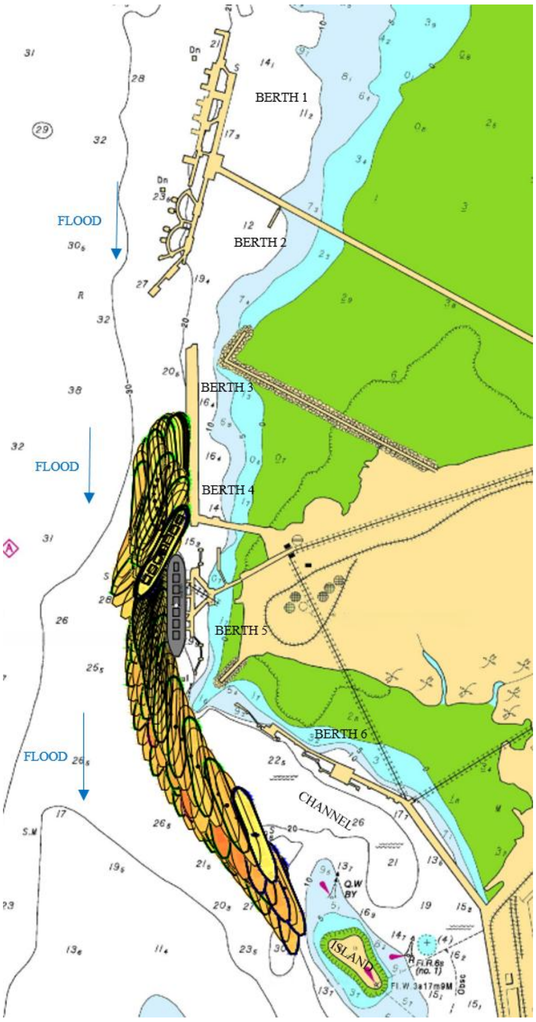

Figure 9. Vessel movement after unintentional unberthing during flood tide.

In the ebb tide scenario (Figure 10), the allision of the vessel with the structure of berth 4 was observed, along with a reduced yawing tendency and impact with the access bridge to berths 1 and 2, resulting in the vessel grounding at the back of berth 2, in a shallow area. It is highlighted that the allision with the access bridge to berths 1 and 2 could disrupt operations at those berths.

The first line released was also the forward breast line (highest observed forces). The maximum observed speed was 3.7 knots (a value above the safety limit for tugboat approaches), and the average distance traveled was 0.8 km. This scenario was classified as having a high potential for damage to the port, due to the multiple allisions, particularly with the access bridge to berths 1 and 2, and the high drift speed.

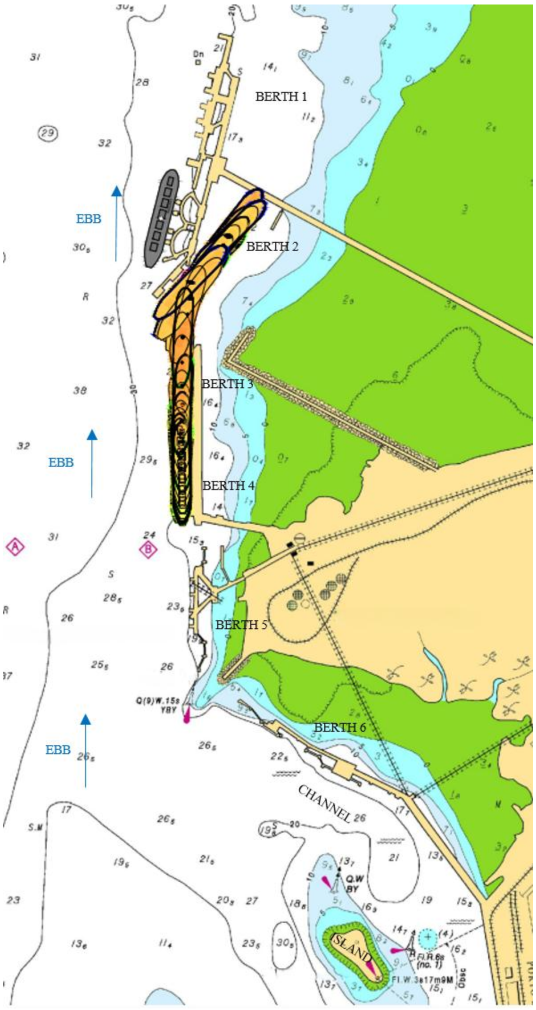

Figure 10. Vessel movement after unintentional unberthing during ebb tide.

Table 3 presents a summary of the results obtained in the tests, highlighting the main events observed: allision, collision, grounding, and yawing, as well as the maximum speed of the vessel. To facilitate data interpretation, the table uses a color-coded system indicating the probability of occurrence of each event:

- Red: High probability (event observed in more than 50% of the tests).
- Yellow: Moderate probability (event observed in less than 50% of the tests).
- White: Low probability (event not observed in any test).

In the case of maximum speed, the color scale reflects the magnitude:

- Red: High speeds (above 3 knots).
- Yellow: Moderate speeds (between 2 and 3 knots).
- White: Low speeds (below 2 knots).

Since there was little tendency to yaw in both scenarios, the "yawing" column of the table 3 was left blank.

The last column of the table presents a qualitative evaluation of the potential damage to the port, calculated by the sum of points assigned to each event:

- Red: 2 points.
- Yellow: 1 point.

– White: 0 points.

Scenarios with a total of 5 or more points are classified as high damage potential (red); between 1 and 4 points, as moderate damage potential (yellow); and with no points, as low damage potential (white).

Table 3. Summary of drift test results conducted at berth 4.

Ship (dwt)	Berth	Tide	Allision	Collision	Grounding	Yawning	Average speed (knots)	Potential for damage
400,000	4	Flood	🟥	🟥	🟥	⬜	🟨 2.7	🟥 7
		Ebb	🟥	⬜	🟥	⬜	🟥 3.7	🟥 6

The tests demonstrated that the involuntary unberthing of 400,000 DWT vessels at berth 4, followed by free drift, represents a high-risk scenario for the port, both under flood tide and ebb tide conditions. Allisions with fixed structures of the port, collisions with ships moored at adjacent berths, and groundings were frequent events. Additionally, it is important to highlight that drift speeds greater than 2 knots cause difficulties for the operations of tugboats, increasing the risk of accidents.

4 CONCLUSIONS

Physical hydraulic models are highly reliable tools for analyzing risks associated with accidents at ports. Mooring lines breakage can cause ship drifting. In this case, it is essential to understand the possible scenarios of the vessel's displacement in order to define emergency action plans to mitigate damage to the environment and port assets.

In the case study, for berth 4, both current conditions (flood tide and ebb tide) result in scenarios with high potential damage to the port. Allisions with the own berth, collisions with ships moored at berth 5 (flood tide), and groundings were observed, either on an island (flood tide) or on the back of berth 2 (ebb tide). The collision with the access bridge to berths 1 and 2, in particular, represents a serious consequence, potentially disrupting their operations.

This type of study highlights the importance of rigorously following inspection and maintenance procedures for mooring elements, ensuring that the operation teams can rely on the established load limits. Furthermore, when signs of breakage or overload of the mooring lines are detected, it is crucial to immediately call the tugboats, because most of the time only quick action can avoid accidents.

Since the study did not address the possibility of unberthing ships at adjacent berths due to collisions (the "domino effect"), further tests can be conducted to evaluate different scenarios of simultaneous occupancy of adjacent berths and multiple unberthings, which would provide a more comprehensive assessment of the potential damage to the port.

REFERENCES

[1] de Melo Bernardino, J.C. Abordagem experimental para avaliação de manobras de navios em modelos físicos de espaços náuticos. PhD thesis. 2015;

[2] Esferra, R., de Melo Bernardino, J.C., Alfredini, P. Physical modeling applied in evaluation of the safety and efficiency of vessel mooring plans. RBRH. 2018;

[3] Gao X, Makino H, Furusho M. Analysis of a ship drifting in a narrow channel using Automatic Identification System (AIS) data. WMU J Marit Affairs. 2016;

[4] Montewka J, Ehlers S, Goerlandt F, Kujala T. Risk assessment of ship grounding and its environmental consequences. Mar Pollut Bull. 2012;

[5] Uittenbogaard RE, Battjes JA, Stive MJF. Physical modeling of estuarine hydraulic phenomena using scale models. Coast Eng. 2005;

[6] Zhang S, Pedersen PT, Villavicencio R. Probability and mechanics of ship collision and grounding. 1ª ed. Oxford: Butterworth-Heinemann. 2019;