Berthing characteristics and the behaviour of the oil terminal of Leixões Harbour, Portugal

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Abstract

Larger depth requirements for large tankers together with security reasons necessitate the establishment of oil terminals located in areas more exposed to adverse sea state conditions, conditioning terminal operations' efficiency and putting severe demands on fender and mooring systems.

This paper describes the characteristics and behaviour of the berth "A" of Leixões Harbour oil terminal which is, from the three berths that compose the oil terminal, the one that has the most significant hydrodynamic and operational problems, due to its exposed location despite the adjacent breakwater.

The present conditions of berth "A" causes an obvious cost, as well as environmental and safety risks to the port authority, and for that reason this berth has been the subject of studies with the aim of improving its operational and security conditions. This paper will also present an overall overview of some conclusions of a recent study that has been carried out.
Keywords: operational conditions, oil terminal, breakwater overtopping, berth.

1 Introduction

Tranquillity conditions in the surrounding area of berths are essential to efficient and secure loading/unloading ship operations. In the external areas of harbours, these conditions are difficult to achieve and therefore terminals are more exposed to adverse sea state conditions.

Breakwaters play an important role in the reduction of wave conditions inside harbour basins although their action could be ineffective to long period waves. However, these structures are designed for an acceptable limit of wave conditions above which some overtopping can occur, worsening the wave conditions inside the harbour basin and affecting terminal operational conditions.

The operational conditions of berth "A" oil terminal are affected by the North breakwater overtopping due to its proximity, fig. 1. However the breakwater overtopping is not the only explanation to the operational problems of berth "A" that does not assure, in average, the necessary operational and security conditions during 23% of the days along the year.

Figure 1: Location of berths A, B and C of Port of Leixões oil terminal, APDL.

The operational and hydrodynamic problems can also be associated to other factors, such as: current transmission through the old breakwater core, proximity to the breakwater's head and possible resonance phenomena in that harbour area.

The characteristics of existing mooring and fendering systems could also contribute to the verified large motions of tankers moored on berth "A". These large motions originate, therefore, a reduction of the load/unload operations efficiency and, in exceptional adverse conditions, do not allow the vessel to be kept berthed and moored on the dolphin structure in security conditions.

2 Berth "A" characteristics

2.1 Location and wave climate

The Leixões Harbour is situated in the North of Portugal, in the Northwest of the Iberian Peninsula, about 2.5 miles to the North of the River Douro mouth, and its oil terminal is composed by three berths. Berth "A" is located in the harbour entrance, parallelly to the North breakwater, near the breakwater's head, whereas berths "B" and "C" are located in an inner harbour area, therefore in a more sheltered position, fig.1. Along side berth "A" oil terminal the water depth is about -16m CD.

Table 1: Offshore significant wave height (H_S) and maximum wave height ($H_{max.}$), near Leixões Harbour, [1].

Return Period (year)	H_S (m)	$H_{max.}^*$ (m)
10	12.7	20.3 - 22.9
50	13.3	21.3 - 24.0

* $H_{max} \approx 1.6$ to $1.8\ H_S$

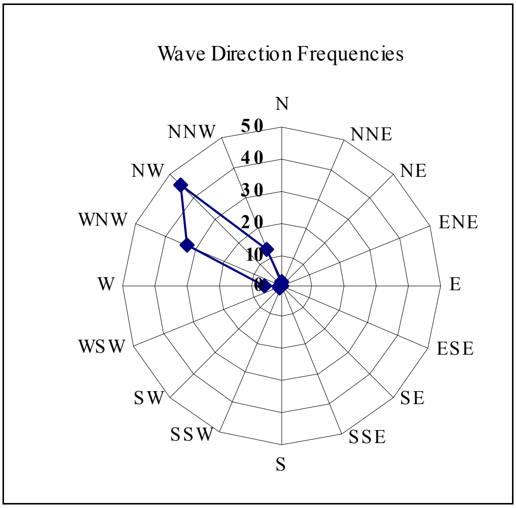

Figure 2: Wave direction frequencies in the Portuguese West coast.

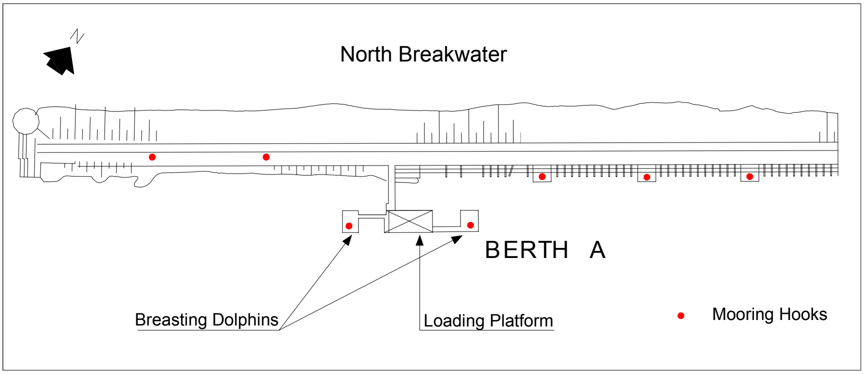

Figure 3: Sketch of berth "A" oil terminal mooring layout.

The North breakwater, which protects berth “A” from the direct action of waves, was constructed over an old submerged breakwater and during extreme storm events is submitted to waves that may exceed 20m in height with periods that may reach 25s (in high water depths). Table 1 presents the significant wave height and the maximum wave height for 10 and 50 years return period. The dominant wave’s direction is the Northwest, fig.2.

2.2 Berth “A” mooring layout

The berth “A” jetty structure consists of two breasting dolphins and a loading platform. Each breasting dolphin is equipped with a pneumatic fender and double mooring hooks, which serves, respectively, to absorb the berthing energy and to secure the spring lines of the ship. The remaining terminal mooring hooks are situated on the North breakwater superstructure, as sketched in figure 3.

2.3 Ships demanding berth “A” oil terminal

The berth “A” facility was designed to accommodate tankers up to 100 000dwt carrying crude oil and various refined products. According to table 2, berth “A” is used by a relatively wide range of vessels. In the period of time between January 2003 and March 2004, the biggest ship that berthed in berth “A” had an overall length of approximately 250m and a draught of 13.5m.

Table 2: Number of tankers that demanded berth A by gross tonnage categories between January 2003 and March 2004, source Galp Energia.

Gross Tonnage	0 - 20000	20000 - 40000	40000 - 60000	> 60000
Number	55	12	54	1

3 Berth “A” oil terminal operational conditions

The inoperativeness of berth “A” oil terminal is a real problem that Leixões Port Authority has been facing in the last years. The actual situation originates costs and security risks that are important to minimize in order to improve the oil terminal profitability.

Analysis of the records supplied by Galp Energia, between 1990 and 2003, shows that berth “A” inoperativeness reached in that period of time an annual average of 23%. The inoperativeness is higher in the months of January and December, reaching in average 50% of the days, fig. 4. Figure 5 presents the evolution of the number of days of inoperativeness in the same period of time.

A detailed analysis of the records shows that, in general, berth “A” is operational when the deep water wave height is less than 2.5m and for wave periods between 7s and 15s. The berth is inoperative predominantly for wave heights higher than 2.5m and wave periods between 8s and 20s.

In what concerns wave direction, it could be seen that the inoperativeness of berth “A” occurred mainly to waves approximately perpendicular to the North breakwater.

An exhaustive description of the berth "A" operational conditions can be found in the study "Operational conditions on the oil terminal at Leixões Harbour, Porto, Portugal, IHRH - FEUP/IST" [2], in which this paper in based on.

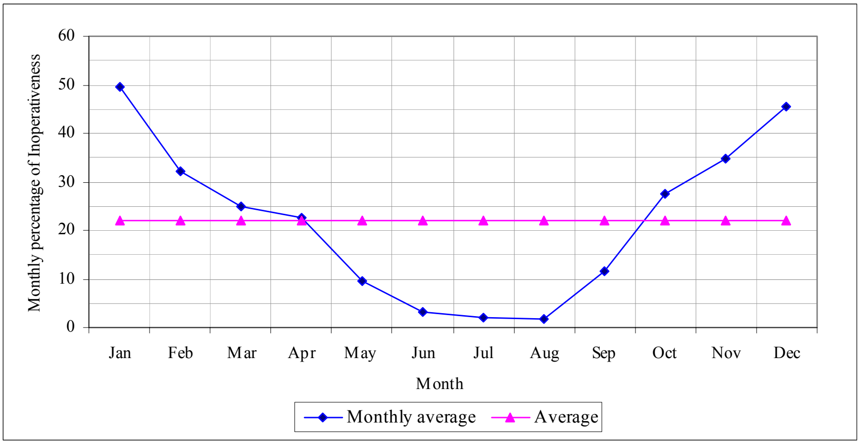

Figure 4: Monthly average of berth "A" inoperativeness between 1990 and 2003.

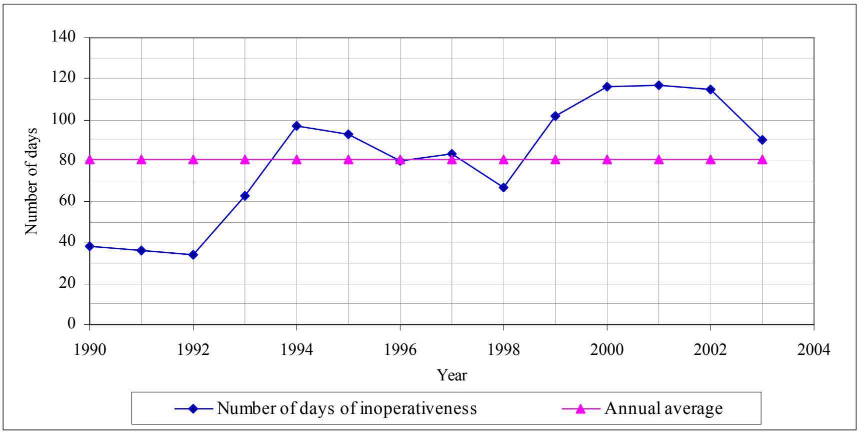

Figure 5: Number of days of inoperativeness of berth "A" by year between 1990 and 2003.

4 Causes of berth "A" inoperativeness

4.1 North Breakwater overtopping

The North breakwater overtopping plays an important role in the berth "A" operational and security conditions. It is responsible for the worsening of wave conditions in the region of berth "A" and it makes difficult to access berth "A" through the breakwater to release the ship mooring lines in emergency situations. Prototype quantification of the amount of water that overtops a breakwater as well as its range is difficult and expensive. However, results of physical model tests can give a general idea of this amount of water, in spite of some scale effects.

The results of the 2D physical modelling of existing North breakwater structure with the actual bathymetry, extracted from IHRH-IST [2], are presented in figure 6 to several incident wave conditions. These results were obtained with 2D regular waves and allow obtaining a general idea of the actual overtopping magnitude. Figure 6 shows that for high wave height and high wave periods, during high tide (+4.0m CD), the breakwater overtopping is significant. Tests with irregular waves are being carried on.

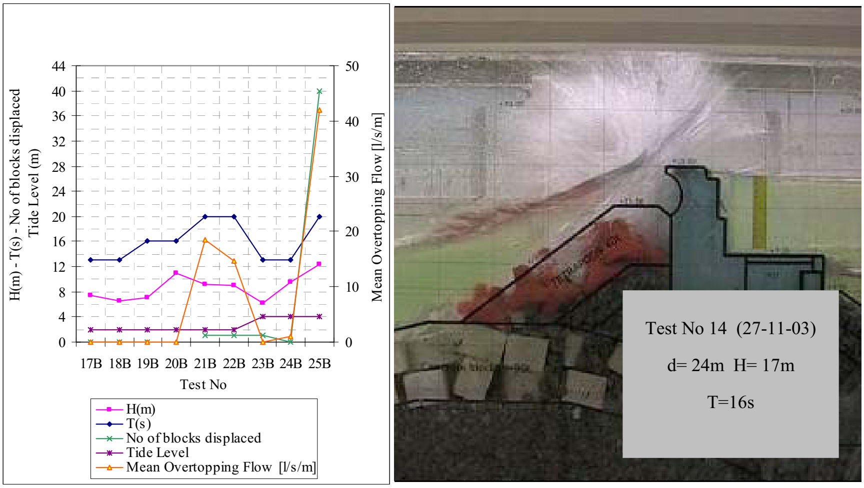

Figure 6: Results of the physical modelling of the existing breakwater with the actual bathymetry, to several wave conditions.

4.2 Current and sediment transmission thought North breakwater

The analysis of bathymetry evolution, in the surrounding area of berth "A", fig.7, shows a preferential accumulation of sediments in a band adjacent to the inner breakwater toe, in contrast with a lower and approximately uniform accumulation of sediments in the rest of the basin.

The sediment deposition near the inner breakwater toe does not progress, as would be expected, from the breakwater's head inward, and there were not detected morphologic marks of a sediment transposition process near the breakwater's head. This lead to the supposition that sediments, induced by water movement, could be crossing the breakwater core. This supposition is supported also by ship pilots that refer the visualisation of water and sand flows coming from the breakwater, at the stern of the ship, during adverse sea conditions.

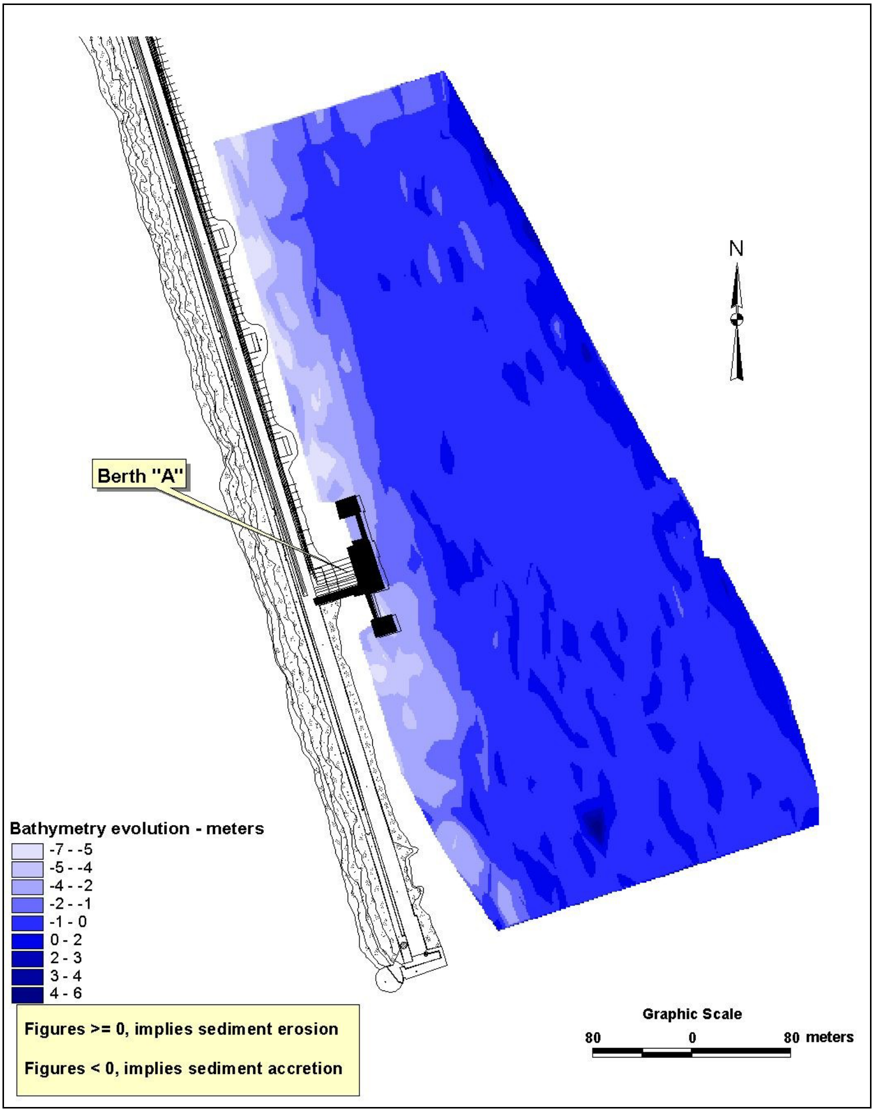

Figure 7: Bathymetry evolution, in the surrounding area of berth “A”, between 3 November 2001 and 8 February 2002.

It is not possible to accurately determine the permeability conditions of the North breakwater structure, however the presence of the 90t cubic blocks layer of the old submerged breakwater, fig. 8, is enough to conclude that the structure is very permeable to sediments as well as water currents.

This situation gives rise to an increase of dredging frequency as well as localized current in the vicinity of the oil terminal that worsen the moored ship motions conditioning oil terminal operational and security conditions.

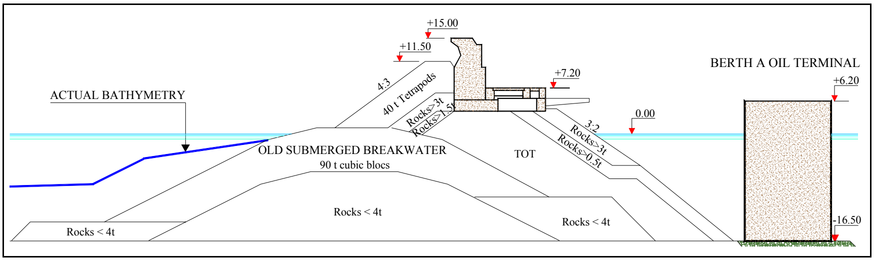

Figure 8: Cross section of the North breakwater, at the berth “A” oil terminal, with the actual bathymetry.

4.3 Characteristics of existing mooring and fendering systems

The operational and security conditions of port terminals are significantly influenced by the amplitude of moored ship motions. Regarding this, a well designed fendering and mooring system can effectively contribute to the reduction of ship motions, improving loading/unloading operations efficiency and frequency.

A moored ship submitted to dynamic marine environmental forces can experience six different types of motion. The influence of each motion in the operational conditions depends, among other factors, on ship characteristics. For large oil tankers, the horizontal plane motions (surge, sway and yaw) are the ones that most contribute to berth operations efficiency and security [3].

The influence of fender and mooring system characteristics to the reduction of moored ship motions is only effective to horizontal motions, that are also the ones that most influence operational conditions of an oil terminal [4].

OCIMF [5] presents some rules that berth structures and mooring system, used by very large crude carries - VLCCs, should obey. These rules can be used as an indication to the analysis of Berth “A” mooring system layout. Figure 9 sketches the ideal mooring system layout for VLCCs according to OCIMF.

The OCIMF [5] presents also the following rules to mooring of tankers in jetty structures:

- The mooring system should be arranged as symmetrically as possible about the midship point of the vessel, in order to ensure a good load distribution.
- The breast lines should be as parallel to the ship’s hull as possible, while spring lines should be perpendicular.
- Head and Stern lines aren’t necessary as long as bollards were located in convenient positions.
- The vertical angle between the line and the horizontal should not exceed 30º, although 25º would be preferable throughout the entire range of loaded conditions.
- The mooring lines should be all of the same material, diameter, composition and, if possible, the same length, especially the ones that are in the same direction, to obtain an equal distribution of forces.
- It should be used the same type of tail for the same type of mooring line.

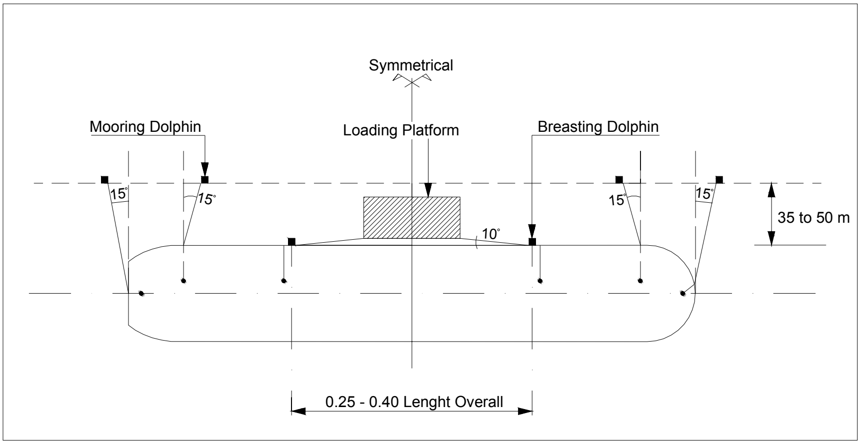

Figure 9: Ideal VLCCs berth, adapted from OCIMF [5].

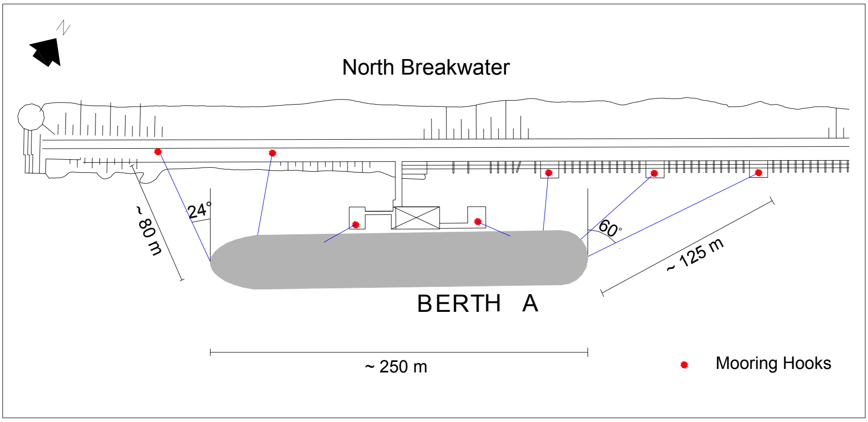

Figure 10: Mooring arrangement of an oil tanker moored on berth “A”.

In figure 10 is sketched the mooring line arrangement for an oil tanker of 250 m length, the biggest that used berth “A” from January 2003 to March 2004. Analysing the mooring arrangement sketched in figure 10, based on OCIMF recommendations, some differences can be observed. The mooring arrangement is not completely symmetric and the horizontal angles between some mooring lines and the berth are bigger than recommended. Nevertheless, it should be understood that OCIMF recommendations are general, and so some changes can be made to adapt the mooring layout to particular conditions. In spite of this, some upgrades can be de made in order to improve berth operational conditions. Pretensioning the breast lines, in order to pull effectively the vessel against the fenders, will allows the use of the fender friction characteristics in the reduction of ship motions, especially for surge motions. This happens because the hydrodynamic damping of the surge motion is very small. Therefore the friction of the fenders plays an important role in limiting the ship surge motion.

The introduction of quick release mooring hooks together with multi-point computer based mooring line tension monitoring system would allow the quick release of the ship in emergency situations and a better control of the ship behaviour.

The recoiling characteristics of a fender, directly related with the amount of energy that is transmitted to the ship after each impact, are decisive either during the berthing, contributing to quicker immobilization of the ship, or when the ship stays moored. The pneumatic fenders installed in all berths of the Leixões oil terminal and in other oil terminals all over the world have a typical high recoiling behaviour, Janssen [6].

According to Nikerov [7], mentioned by Bruun [8], the cone type fenders have a good recoiling behaviour (they reflect about 50% of the energy) but its weakness lies in their relatively low resistance against shear forces.

4.4 Proximity to the breakwater's head

The location of berth "A" could also be presented as a possible cause to the hydrodynamic and operational problems of the berth due to excessive wave diffraction currents around the breakwater's head. In order to investigate the influence of diffraction currents at the port entrance as well as other local effects, such as, refraction, shoaling and reflection, two distinct numerical simulations were carried out, one at the IHRH-FEUP and the other at the CEHIDRO. In these numerical simulation several wave condition were tested.

The results of the numerical simulation performed at the IHRH-FEUP agree with the ship pilot reports and show that, during high tide (+4.0m CD), waves of 2.5m in height may be expected in the surrounding area of berth "A", to certain wave conditions [2]. Figure 11 presents the wave heights in the harbour entrance area, for waves coming from the West direction with a peak period of 19s and a significant wave height of 13.0m.

4.5 Long period waves

The presence of long period waves could originate resonance of the mass of water near berth "A" leading to stationary waves, which are especially problematic to ships berthed near the node points, due to the large horizontal motions of these points. Resonance can also occur if the period of these waves is close to the natural period of oscillation of the moored ship originating therefore large ship motions.

In the region of Leixões Harbour two ranges of long period waves can often occur: the first one with periods ranging from 2 to 5 minutes and the second one with periods ranging from 15 to 20 minutes. On berth "A" some accidents with moored vessels have occurred, which can be associated to long period waves. In 21 and 22 of January 1974 a tanker of 137 000dwt experienced surge motions of 10 to 15m and sway motion of 3 to 4m. The assistance of two tug boats reduced the motions amplitude to 8 and 2m and after to 5 and 1m respectively. During this event 5 mooring lines were broken. The analysis of the wave records in that period shows the presence of waves with periods ranging from 2 to 4 minutes and heights of approximately 50cm.

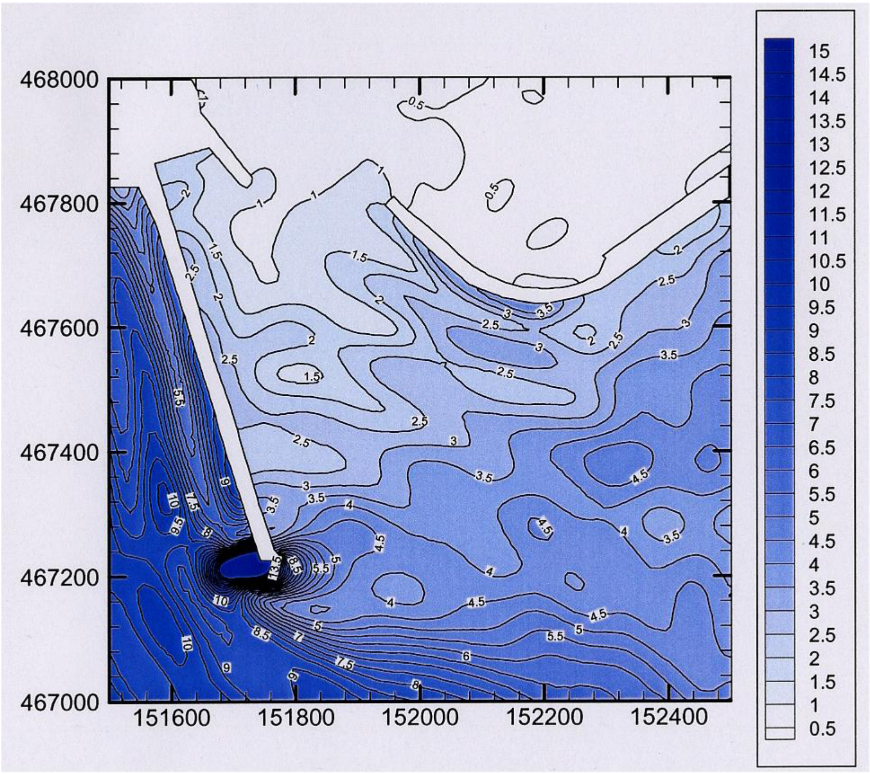

Figure 11: Wave heights in meters at the harbour entrance [2].

Some studies refer that the mass of water in the region of berth "A" can experiment resonance to wave periods in the range of the long period waves that reach the Leixões Harbour, and this resonance is compatible with a node region in berth "A". Besides, pure non-resonance reflection can occur between the two breakwaters, fig. 1.

In this way, long period waves can worsen the wave conditions near berth "A" due to the possibility of resonance of the water mass near berth "A" and the pure non resonance reflection of waves between the two breakwaters. These waves can also originate resonance of the system vessel/mooring lines/fenders.

5 Conclusions

The operativeness of berth "A" oil terminal is affected by the conjugation of several factors. The North breakwater overtopping, the current transmission through the breakwater core, the characteristics of the existing fendering and mooring systems, the wave diffraction around the breakwater's head and the long period waves are factors that contribute to the adverse wave conditions in the surrounding area of berth "A".

Some studies have been done with the aim of improving berth "A" operational conditions, whose proposed solutions can effectively contribute to the reduction of berth "A" inoperativeness, which reach, in average, 23 % of the days along the year.

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