SHIP MANOEUVRE PATTERNS TO PREVENT PROPELLER SCOURING EFFECTS

by

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ABSTRACT

Nowadays, vessels are bigger in size and are forced to operate in relatively smaller harbour areas. The propulsion systems of Ro-Ro and Ro-Pax are getting closer to the soil of the docks, due to their increase in ship and propulsion capacity and generating erosion and stability problems to harbour's structures. Moreover, Ro-Ro and Ro-Pax vessels, which serve regular services, have high docking frequencies. The most significant effect from propeller induced current can be found during manoeuvring situation in restricted waters due to the magnification caused by harbour structures. Therefore, the combination of docking frequencies along with the increase in ship dimensions can cause severe damages both to docking structures and basin manoeuvrability. The main problem is not only the damages to harbour structures but also the reduction in harbour basin depth caused by the sedimentation of the eroded sediment, with important consequences on the operability of the basin. This paper further analyses manoeuvre patterns to understand the effects of the resulting eroded sediment using Automatic Identification System (AIS) data. Results of scouring processes caused by manoeuvres of a particular Ro-Pax vessel without the help of a tugboat are described. The aim of this contribution is to analyse ship manoeuvre patterns and design new manoeuvres of a regular maritime service to minimize their effects on erosion and sedimentation and avoid adverse impacts resulting from ship manoeuvring. We can conclude that the used method, based on the study of a particular case starting from the reproduction of the manoeuvre, becomes adequate to establish the relation between the scouring forcing and its generator, which is the ship's manoeuvre near the docking.

1. INTRODUCTION

According to United Nations Conference on Trade and Development (UNCTAD) annual report (2017), over 80 per cent of global trade by volume and more than 70 per cent of its value is being carried on board ships and handled by seaports worldwide. The evolution of shipping industry over the last decades has led to growing structural and operational problems, in particular, for quays and harbours designed to host ships with lower drafts. Nowadays, port authorities are seeking ways to adopt existing infrastructures to meet the changing demand of the market. The increase in capacity, size, power and propulsion of vessels linked to high docking frequencies of regular services are the main causes of morphodynamic sea bed changes in harbour basins. This is producing two different effects: scouring effects near the structures affecting their stability and, on the other hand, sedimentation of the scoured material in other areas of the basin. This reduces the average depth and may affect vessel's

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manoeuvring capabilities (turning and stopping abilities) due to the change of hydrodynamic forces. Moreover, new range of propulsion types (e.g. propellers, bow-thrusters, podded propulsors, azimuthing thrusters, waterjets) can also increase the scouring action. Several ports present problems related to the scouring and sediment deposition (e.g. BERG & MAGNUSSSON, 1987; CHAIT, 1987; FUERHRER, POHL & RÖMISH, 1987; HAMILL, JOHNSTON & STEWART, 1999; HAMILL, RYAN & JOHNSTON, 2009; MUJAL COLILLES, 2017; STHOKKING, JANSSEN & VERHAGEN, 2003). DOMINGO (2014) concluded that the highest erosion problem comes from regular vessels, excepting tugboat and pilot operations. Ro-Ro and Ro-Pax vessels, due to their characteristics and operational needs, are especially relevant when talking about scouring action. These vessels usually perform short voyages, so they berth and unberth frequently, at the same harbours and quays.

Most of the research published about the prediction of the maximum scouring action produced by ships propellers has been carried out in laboratories, using physical models with a single propeller at bollard pull condition (CHIEW & LIM, 1996; HAMILL, 1987; HONG, CHIEW & CHENG, 2013; MUJAL-COLILLES, 2018; SCHOKKING, JANSSEN & VERHAGEN, 2003; STEWART, 1992). MUJAL-COLILLES et al. (2017) use all the pre-existing formulations to compare their results with a real case and conclude that most of them are far from reality when applied to a particular real case. Therefore, further investigations using twin propellers, more similar to the real Ro-Ro or Ro-Pax stern configuration and different manoeuvers assessment is clearly needed in order to give harbour authorities tools to prevent this increasing problem.

A particular case of study was performed by LLULL et al. (2018) who used an Acoustic Doppler Velocimetry fixed close to the docking area combined with Automatic Identification System (AIS) data and found that it is possible to obtain the geographical position and orientations of the vessel when the current is maximum and, consequently more harmful. LLULL et al. (2018) concluded that, although the existing formulae to predict scouring actions yield results far from reality, they can still be used as a qualitative tool to know where the maximum scouring depth will occur. The propeller action can be studied as a consequence of the manoeuvring patterns, which, in turn, can be obtained through AIS data analysis (AARSATHER & MOAN, 2009; CASTELLS et al., 2017). Therefore, the study of the manoeuvre and its reproduction can be used to obtain the evolution of parameters directly related with the scouring action for every particular case depending on vessel type, ship location during the berthing and unberthing manoeuvres and met-ocean conditions. From the simulation of specific manoeuvres, main parameters of the propellers can be obtained (thrust power, speed propeller and pitch/diameter ratio propeller). Considering these parameters and the existing formulae in maritime engineering proposed by PIANC (2015) and R.O.M 2.1-11 (2012), the efflux velocities, the axial velocities along the propeller and the maximum bed velocities can be calculated.

The present contribution aims to reproduce a set of manoeuvres from AIS reports of a real Ro-Pax vessel, analyse ship manoeuvre patterns and design new manoeuvres of a regular maritime service. Results will help harbour authorities and ship's masters to reduce the impact on erosion and sedimentation resulting from ship manoeuvring.

2. METHODOLOGY

This study combines different set of data. First, the use of the AIS data from the vessel of the selected harbour area. AIS data is obtained to reproduce ship manoeuvres and identify manoeuvring patterns. Once the data is obtained, it is analysed with the bathymetric surveys to establish the relation between the manoeuvring patters and the scouring and sedimentation effects of the harbour basin. Considering the formulae from literature, new alternative manoeuvres are proposed with the aid of Transas NTPro 5000-v-5.35 simulator to reduce the scouring action.

2.1 Automatic Identification System

The AIS is an automatic tracking system for identification and location of vessels by exchanging data via VHF communication to other nearby vessels (IMO, 2003). The use of AIS data permits to understand the effect of changes to the fairway and vessel manoeuvring. The Automatic Identification System is a valuable source for ship manoeuvring information and analysis. The analysis of this data can be employed to generate statistics of patterns during the docking and undocking manoeuvring and estimate scouring induced by vessel propeller in harbour basins. Scarce work has been done to apply AIS to analysis on the scale of manoeuvres in a constrained area. The trace of a vessel position obtained from

AIS can be transformed into a digital image. The AIS data frames are stored in an Excel database for easy management and extraction. Excel file is converted to KML. KML is a file format used to display geographic data in applications such as Google Earth or Google Maps.

For research purposes, The Port Authority provided AIS data reports for the period of June 2016 and January of 2017 for the selected area. The AIS information received contained mainly, time, latitude, longitude, speed over ground (SOG), and course over ground (COG) and Rate of Turn. The presented data will be, therefore, anonymized as much as possible.

2.2 Bathymetric surveys

Periodic bathymetric surveys were carried out with a multibeam system SeaBeam1185, Elac Nautik, Germany in the selected area. The blanking distance from the floating line was 0.65m and data was recorded at 180 kHz with a ship speed ranging from 3 to 5 knots. The data acquisition average error was around 0.1m due to an upper layer of mud within the harbour basin of an estimated thickness of 0.5m. Geological studies performed by the harbour authorities yield sediment characteristics below the mud layer of d_{50} =0.3mm and d_{90} = 1.0 mm, normal sizes for a harbour located in a deltaic zone. Figure 1 plots bathymetric data of a real harbour basin with a mean depth of -12m above sea level (asl) where the evolution of berthing depth and profiles of the harbour basin from June 2015 to March 2017 (last bathymetric survey carried out by the harbour authority).

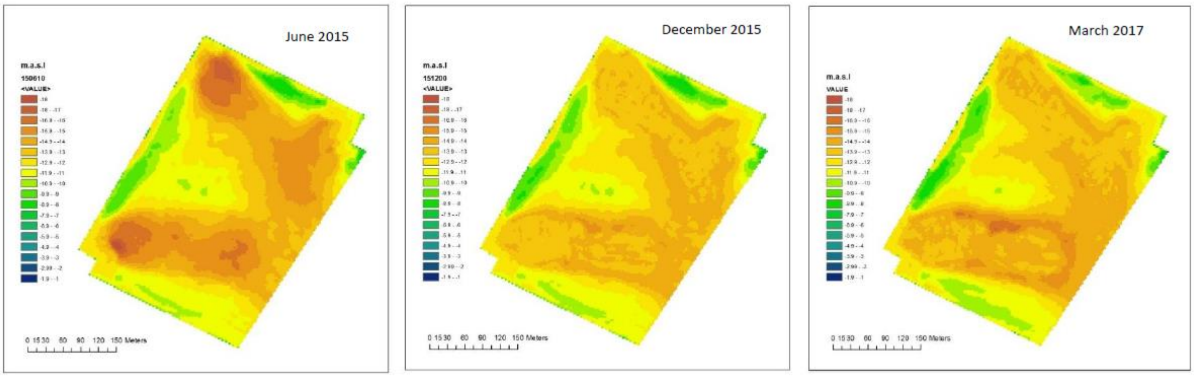

Figure 1: Evolution of the bathymetry along the harbour

As can be seen in Figure 1, the profiles in the North and West quays (see Figure 2) show holes of up to 5 m compared to the mean depth of -12m asl. Parallel to the scouring action, a sedimentation is of the order of 2 m in the west, north and south quays and in the middle of the harbour. In June 2015, harbour authority decided to dredge the areas with a lower depth in the harbour basin. As can be observed, a new hole is generating in the SW area of the harbour.

2.3 Manoeuvre simulator

The use of a manoeuvre simulator is useful to both reproduce the manoeuvre and test alternative manoeuvrings in a simulator with controlled conditions. The aid of real-time full mission bridge simulator Transas NTPro 5000-v-5.35 identifies the main parameters of a manoeuvre with positioning data obtained from AIS of the same area and can identify which manoeuvring behaviour is acceptable to reduce the effect of the toe scouring induced by vessel propeller.

3. CASE STUDY

The effects of ship manoeuvring are analysed in a specific area. A detailed study of the docking and undocking manoeuvres is conducted considering one Ro-Pax vessel which serve regular service at the same dock. Vessels particulars are very common among the Ro-Pax vessels, regarding both dimensions and propulsion. The dimensions of the case study vessel are: 225 m of length, 30 m of beam and 55000 GT. The vessel has two controllable pitch propellers and two bow-thrusters. The engine power of four main engines is 55440kW and the power of each bow-thruster is 1850 kW. The draft of the vessel is 7 m. To know the effect of propellers in the harbour basin it is important to know the AIS position with respect the propellers position (150 m forward).

The location (case study area selected) of the Ro-Pax vessel with a daily frequency is at the SW corner (West Quay) (see Figure 2). The effect of other vessels docking and undocking in the same area is not considered. With the aim of being conservative, this research is focused only with the manoeuvrings of this Ro-Pax vessel.

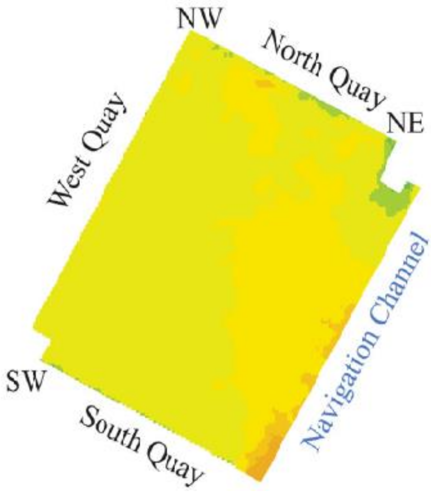

Figure 2: Case study docking area

The total AIS manoeuvres reports are 20 during June 2016, July 2016 and January 2017. Figure 3 shows an example of the AIS information: speed, rate-of-turn and position with an accuracy of about 30 seconds.

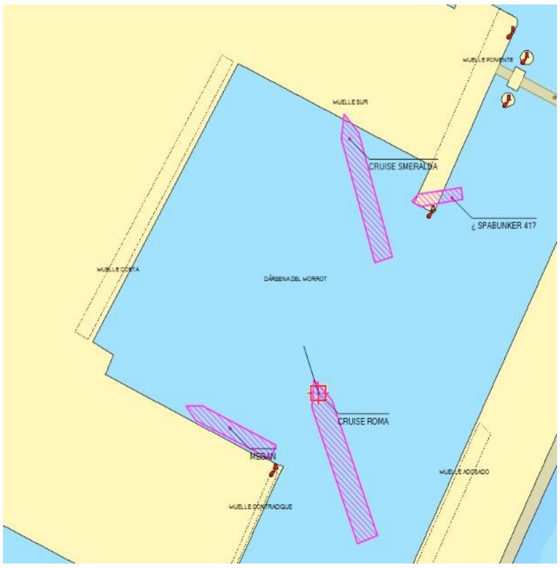

Figure 3: Case study area with AIS position information (1st July 2016)

In order to analyse manoeuvres, expected weather conditions must be known. In the present research two different weather conditions are considered: calm weather conditions (June and July 2016) and bad weather conditions (January 2017) (see Table 1).

Manoeuvre/Data	Wind speed (knots)	Wind direction	Significant wave height, Hs (m)
Docking. 08/06/16	6.5	205	0.3
Undocking. 08/06/16	2.1	280	0.19
Docking. 17/06/16	7.7	222	0.51
Undocking. 17/06/16	5.4	248	0.49
Docking. 19/06/16	4	142	0.37
Undocking. 20/06/16	4.3	231	0.24
Docking. 01/07/16	6	211	0.43
Undocking. 01/07/16	4.1	296	0.36
Docking. 06/07/16	6	222	0.44
Undocking. 06/07/16	2.6	249	0.26
Docking. 12/01/17	5.3	269	0.78
Undocking. 13/01/17	21.1	303	0.75
Docking. 14/01/17	12.1	304	0.37
Undocking. 15/01/17	14.3	299	0.34
Docking. 17/01/17	1.1	273	1.62
Undocking. 18/01/17	6	23	1.42
Docking. 20/01/17	23	47	2.7
Undocking. 20/01/16	21.8	54	2.58
Docking. 23/01/17	12.3	32	2.42
Undocking. 23/01/16	10.5	307	1.59

Table 1: Weather information of selected manoeuvrings obtained from Puertos del Estado website (http://puertos.es)

As can be seen in Table 1, in calm weather, the maximum wind speed is 7.7 knots with a significant wave height of 0.51 (17^{th} June) and in bad weather, the maximum wind speed is 23 knots with a significant wave height of 2.7 m (20^{th} January).

3.1 Manoeuvres description

The ship manoeuvring process is represented as a sequence of basic manoeuvres, being the basic subdivision of manoeuvre patterns between constant course and course changing manoeuvres. The ship manoeuvres pattern in calm and heavy weather has been identified. From AIS data, track manoeuvres can be displayed in the docking area.

Figure 4 shows tracked arrival manoeuvres during calm and bad weather conditions. The starting point of the entrance manoeuvre pattern is the track line in the middle of the navigational channel with a vessel's course of 20º and speed of 6.5 knots. At the harbour entrance of the docking area, the speed is reduced to 5 knots and the vessel alter the course to her port side (320º). When the vessel is in the middle of the docking area, the speed is slow and vessel is turning about its own centre of rotation until 40º. At this point, the vessel starts to go astern and the bow thrusters are used to position the bow with a degree precision.

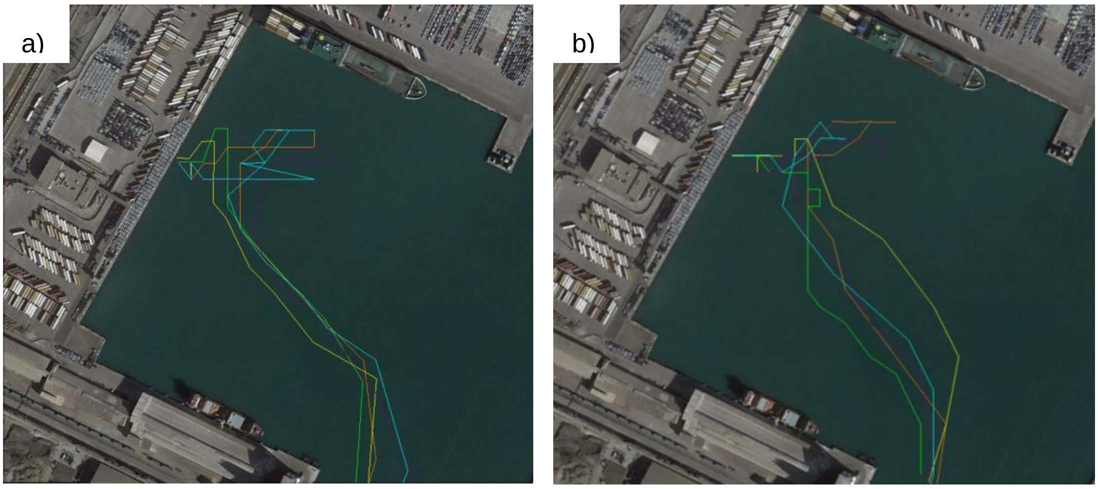

Figure 4: West quay docking manoeuvres scenario (a) Calm weather (8th June (blue), 17th June 2016 (orange), 19th June 2016 (purple), 1st July 2016 (yellow) and 6th July 2016 (green)). (b) Heavy weather (12th January 2017 (blue), 14th January 2017 (orange), 17th January 2017 (purple), 20th January 2017 (yellow) and 23th January 2017 (green)

All entrance manoeuvres follow the same pattern with some variations. In calm weather, the turning circle around its own centre of rotation in the middle of the docking area is smaller during approaching manoeuvres of 1st and 6th of July and the manoeuvring period takes less time than the others (16 minutes and 14 minutes respectively). Only one manoeuvre (20th January 2017) required tug assistance due to bad weather.

Figures 5 and 6 show the Course over Ground and Speed over Ground of ten arrival manoeuvring considered in calm weather and bad weather. Only the manoeuvre of 1st of July varies compared with the rest of manoeuvres.

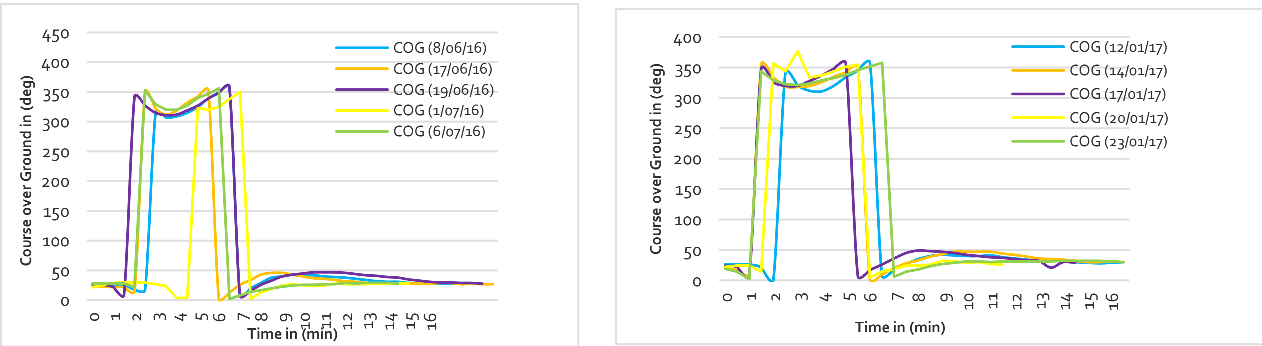

Figure 5: Course over Ground (COG) for entrance manoeuvrings considered in calm (left) and bad (right) weather

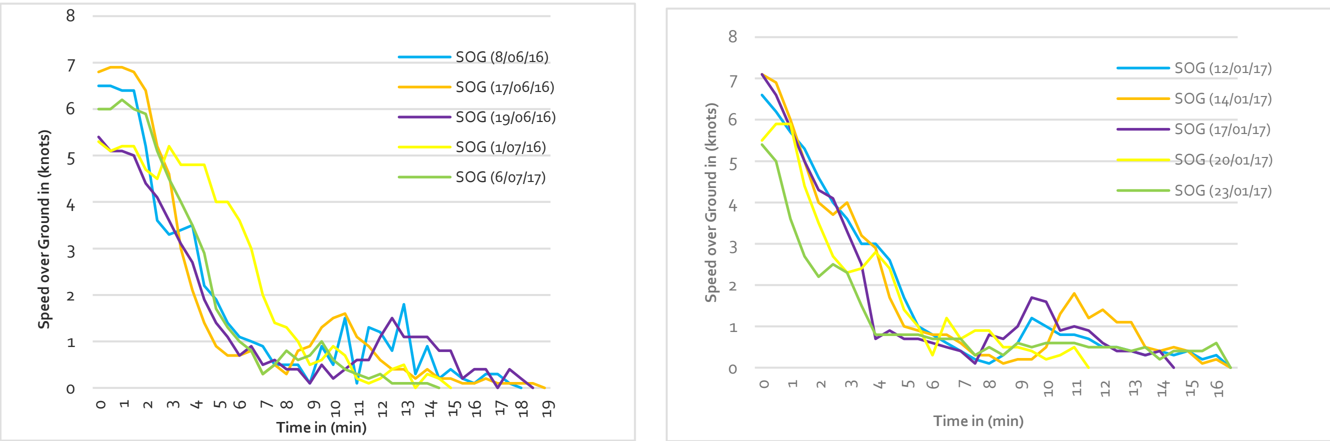

Figure 6: Speed over Ground (SOG) for entrance manoeuvrings considered in calm (left) and bad (right) weather

The departure manoeuvres pattern in calm and bad weather is easier and faster than the arrival manoeuvres (see Figure 7). When departing from the west quay, vessel has to move away from the quay while initially remaining in parallel with the quay. Such a movement is produced by the bow thrusters and the main propellers. When the vessel has moved away 30 m, the vessel starts to turn to starboard and speed increases to 2 knots. At the end of the turn, the new and steady course is 200º and the speed of the vessel will reach 6 knots at the navigational channel.

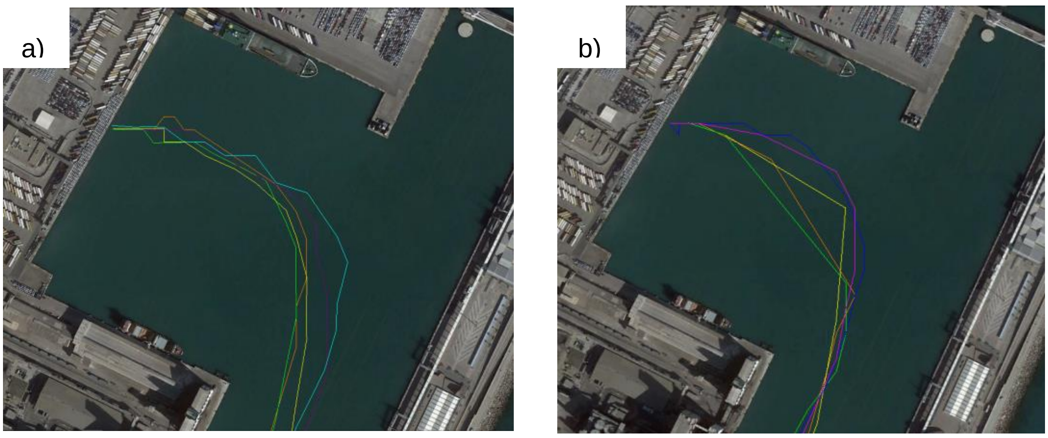

Figure 7: West quay undocking manoeuvres scenario (a) Calm weather (08/06/16-blue, 17/06/16-orange, 20/06/16-purple, 01/07/16-yellow and 06/07/16-green) (b) Bad weather (13/01/17-blue, 15/01/1- orange, 18/01/17-purple, 20/01/17-yellow and 23/01/17-green)

Figures 8 and 9 show the Course over Ground and Speed over Ground of ten departure manoeuvring considered in calm weather and bad weather. Only the manoeuvre of 1st of July varies compared with the rest of manoeuvres.

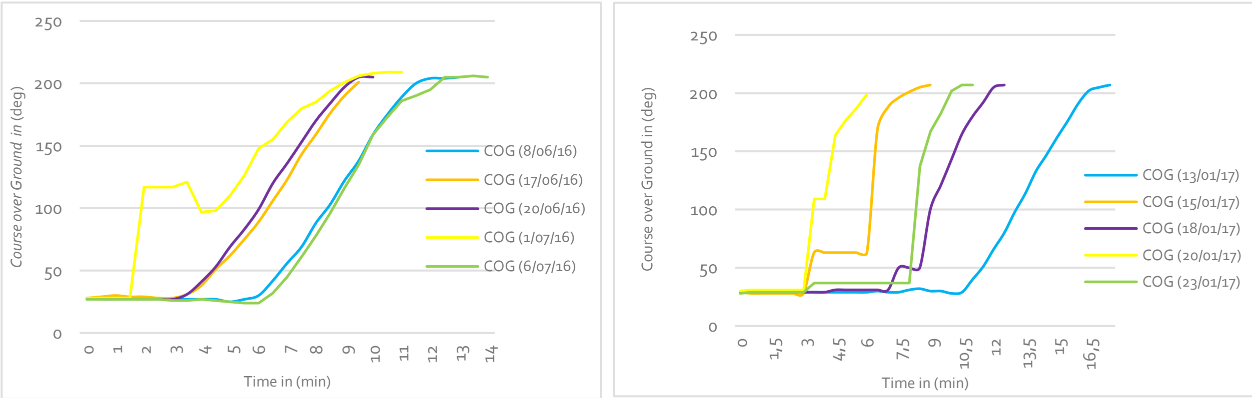

Figure 8: Course over Ground (COG) for departure manoeuvrings considered in calm (left) and bad (right) weather

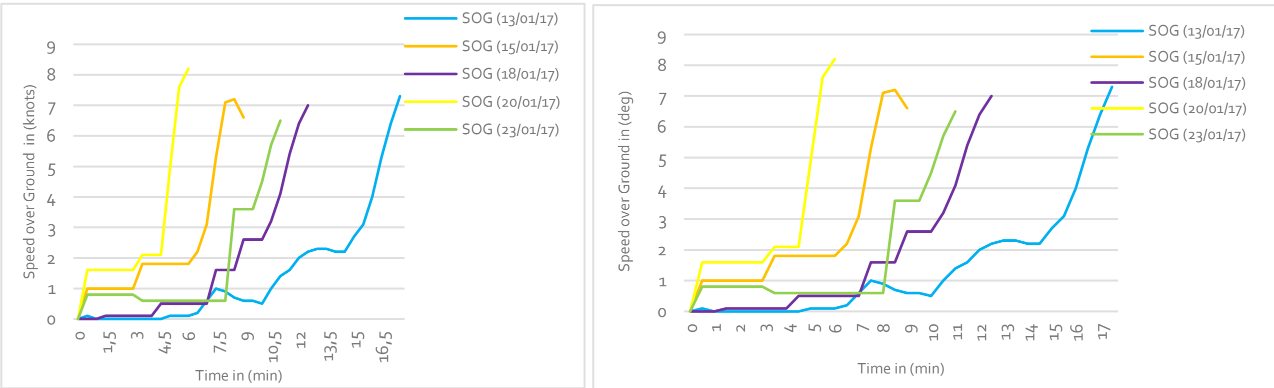

Figure 9: Speed over Ground (SOG) for departure manoeuvrings considered in calm (left) and bad (right) weather

4. RESULTS

The analysis of ship manoeuvres is important to understand the effect of changes of course and speed to prevent propeller scouring effects and to assess harbour authorities. This section will identify the main parameters (approach/departure course angle (COG), number of turning manoeuvres, approach/departure ship's speed (SOG) and period of time) of a manoeuvre using the positioning data obtained from AIS of the same ship and in the same area.

4.1 Entrance manoeuvring

Figure 10 shows mean parameters of docking manoeuvring (COG and SOG) in both conditions, calm and bad weather. The approach to harbour is modelled as a section with constant course followed by a Rate of Turn manoeuvre to change the course for the entry into the harbour.

The total average entrance manoeuvring period takes about 16.2 minutes. After 2 minutes of manoeuvre, the speed is reduced drastically and takes 7 minutes to reach 1 knot. The time of the turning manoeuvre is around 5 or 6 minutes and the period of time to reach the quay is about 8 minutes.

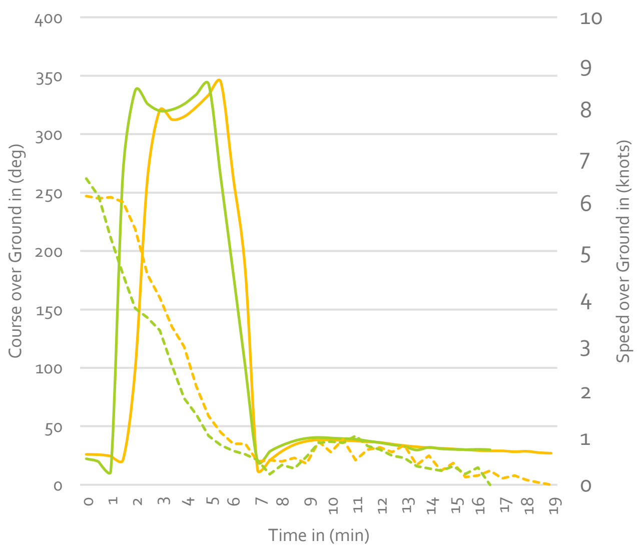

Figure 10: Mean Course over Ground (COG – continuous line) and Speed over Ground (SOG – dashed line) for ten arrival manoeuvrings in calm weather (yellow) and bad weather (green)

Bad weather manoeuvres are shorter (around 1.5 minutes) compared with calm weather ones due to the orientation of the quay and the direction of the wind considered. The manoeuvre with tug takes 9.5 minutes. Even though the speed is very similar in both cases, the course of the vessel in bad weather conditions turns before to the port side.

4.2 Departure manoeuvring

Figure 11 shows mean parameters of undocking manoeuvring (COG and SOG) in both conditions, calm and bad weather. The departure to harbour is modelled as a parallel movement to the quay followed by a Rate of Turn manoeuver with final straight course on the navigational channel.

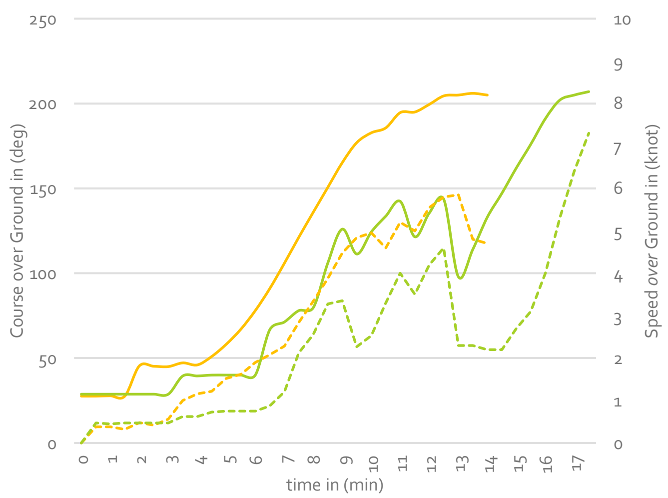

Figure 11: Course over Ground (COG - line) and Speed over Ground (SOG – dashed line) for ten departure manoeuvrings in calm weather (yellow) and bad weather (green)

In calm weather, manoeuvres are more stable compared with bad weather due to the influence of wind at low speed. The departure manoeuvre is shorter than the arrival manoeuvre and is around 8 minutes. The period of time to move away from the quay is around 3.5 minutes and then starts with the evolution circle. The total average entrance manoeuvring period in calm weather takes about 7.8 minutes and in bad weather is 9.6 minutes. The manoeuvre with tug is shorter and takes 5.5 minutes.

The results from the AIS data processing showed the vessel entering the harbour with two turn approaches and the vessel departing only with one turn.

4.3 Influence of manoeuvring to scouring processes

To identify the influence of the manoeuvring described in the previous section with the scouring processes, it is necessary establish the relation between scouring forcing (observed in the bathymetric surveys) and its generator, which is the ship's manoeuvre pattern near the docking. Figures 12 and 13 show bathymetric surveys in the west quay and in the north quay of the harbour during the period between years 2015 and 2017.

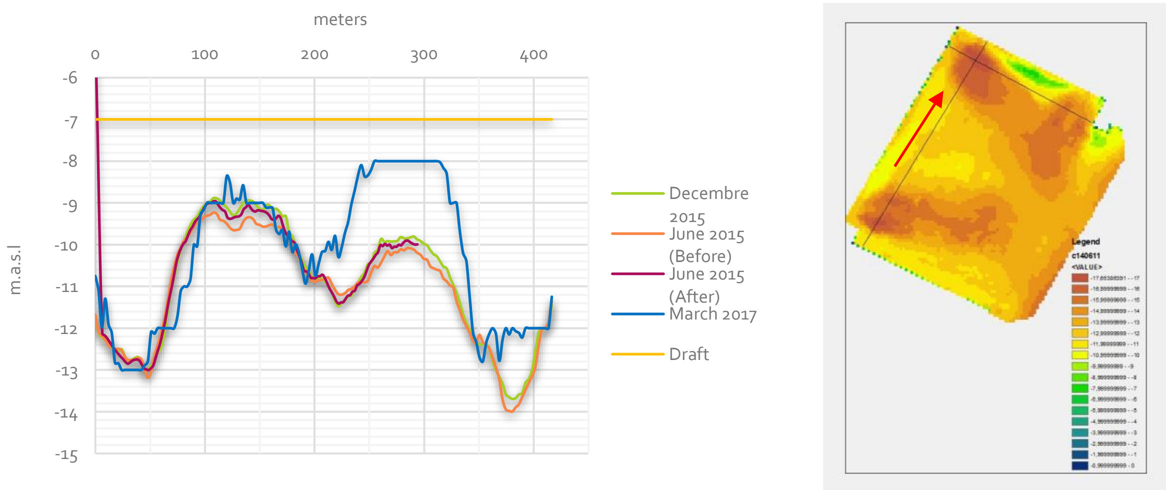

Figure 12: Evolution of the bathymetry along a section parallel to the west quay, from south to north

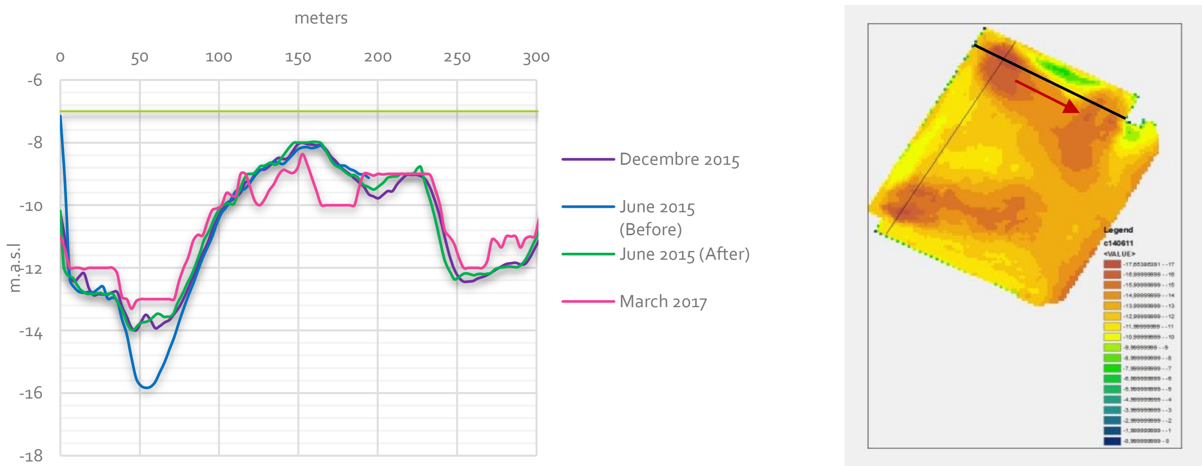

Figure 13: Evolution of the bathymetry along a section parallel to the north quay, from west to east

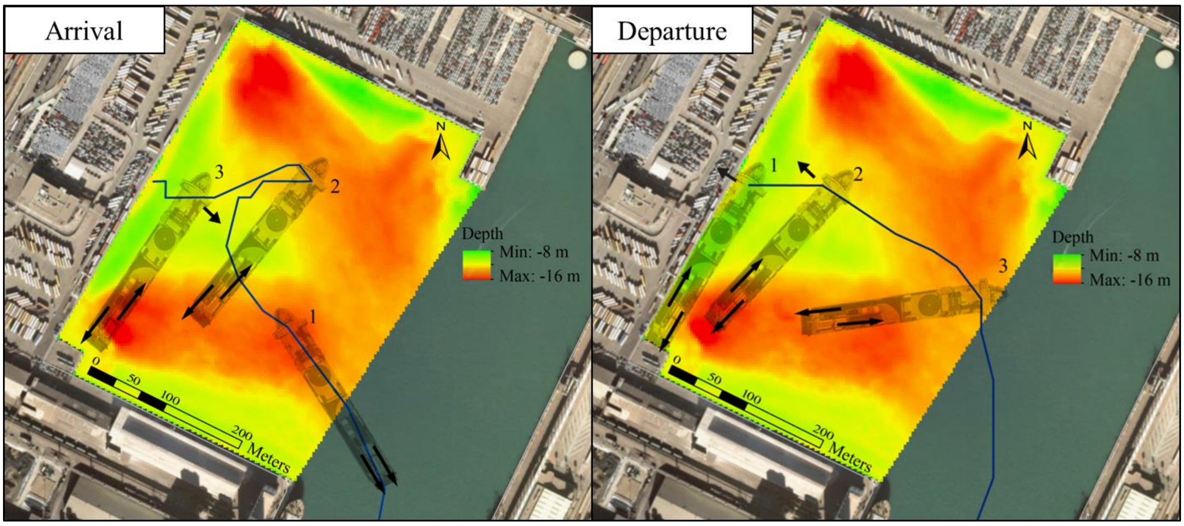

Figure 14: Representation of the arrival and departure manoeuvres

Figure 14 shows the representation of the manoeuvring patterns described in the above section. There is a clear influence of the manoeuvring with the scouring process when the vessel is berthing (Figure 14 left). When the vessel is turning around its own centre of rotation, the position of port propeller is ahead and the starboard propeller is astern (the first generating a wash towards the aft and the second, generating it inversely). It can be seen that the propellers track follows the scouring area in the SW harbour area. In addition, the bow thrusters are generating wash outwards. The reproduction of the unberthing manoeuvre (Figures 14 right) shows that the vessel moves parallel to the quay with the starboard propeller ahead (generating wash towards the aft) and the port propeller astern (generating a wash towards the bow) and the bow thrusters are generating wash inwards. The maximum scouring effect is when the main propellers are located near the SW corner, with holes of up to 5 m compared to the mean depth of -12 asl. Additionally, the sedimentation area is located below the bow thruster.in the west quay.

4.4 Influence of shallow waters

Shallow waters can seriously affect navigation and manoeuvring in these areas. Manoeuvring properties are particularly important in shallow water. Due to squat caused by increased velocities under the vessel, a combination of a mean bodily sinkage plus a trimming effect can produce unstable motion and decrease of course keeping ability. According to QUADVELIEG & COEVORDEN (2003) the vessel should have enough course stability and tuning ability to fulfil the IMO requirement (IMO 1993) with respect the overshoot angles and turning circle dimensions in shallow water. The criteria should be fulfilled in water depths above sea level (asl) larger than 1.3 times the draught (T) of the vessel ($Depth_{asl}/T>1/3$). If the draft of the vessel considered is 7 m, considering the IMO criteria, the water depth should be higher than 9m. From Figure 1, there are some critical areas closer to the West, North and South quays and in the middle of manoeuvring area, where the water depth-draught ratio could be lower than 1.3 (green areas).

In the section parallel to the west quay (Figure 12), there is a clear area situated between 80 and 110m from the SW corner where the $Depth_{asl}/T$ ratio is lower than 1.3 in several bathymetries analysed. Moreover, in March 2017 another shallow water can be found between 230 and 330 m from the SW corner. It could be the effect of wash generated by bow-thrusters.

In the section parallel to the north quay (Figure 13), there is a clear area situated in the middle of the quay, between 90 and 160 m from the NW corner where the $Depth_{asl}/T$ ratio is lower than 1.3 in bathymetries analysed.

A critical green area can be observed in the middle of the harbour area, see Figure 1. In this area, the vessel is manoeuvring at slow ahead or slow astern speed and shallow water can produce unstable motions and can disturb the course turning ability of the vessel.

4.5 Alternative manoeuvres

In order to reduce the effect of the toe scouring induced by vessel propeller, alternative docking and undocking manoeuvres with the same ship and in the same navigation area are assessed. Due to the vessel characteristics and the manoeuvring harbour area, there are some limitations to define new alternative manoeuvres. Thanks to the relative large clearance of tugs, the berthing and unberthing manoeuvres for larger vessels will often use tug assisted (HAWKSWOOD et al., 2014). Authors have reproduced alternative manoeuvres with the aid of Transas NTPro 5000-v-5.35 simulator. Two alternative berthing manoeuvres and two alternative unberthing manoeuvres are proposed.

The alternative berthing manoeuvres are: one manoeuvre with the assistance received from two tugs (without ship propulsion system) and one with the assistance of one tug. Two tugs assistance manoeuvre is shown in Figure 15 (left). When the vessel is in the central area of the harbour, the first tug is pushing at the starboard bow and the aft tug is on the port side. This will enable the vessel to complete a swing with a bow to port (anticlockwise). When the vessel is just off the berth, the tugs are pushing the ship onto the berth. Sometimes, the use of two tugs is impractical, in such cases, other alternative manoeuvre is proposed with the assistance of one tug at the aft part with the help of bow-thruster, see Figure 15 (right).

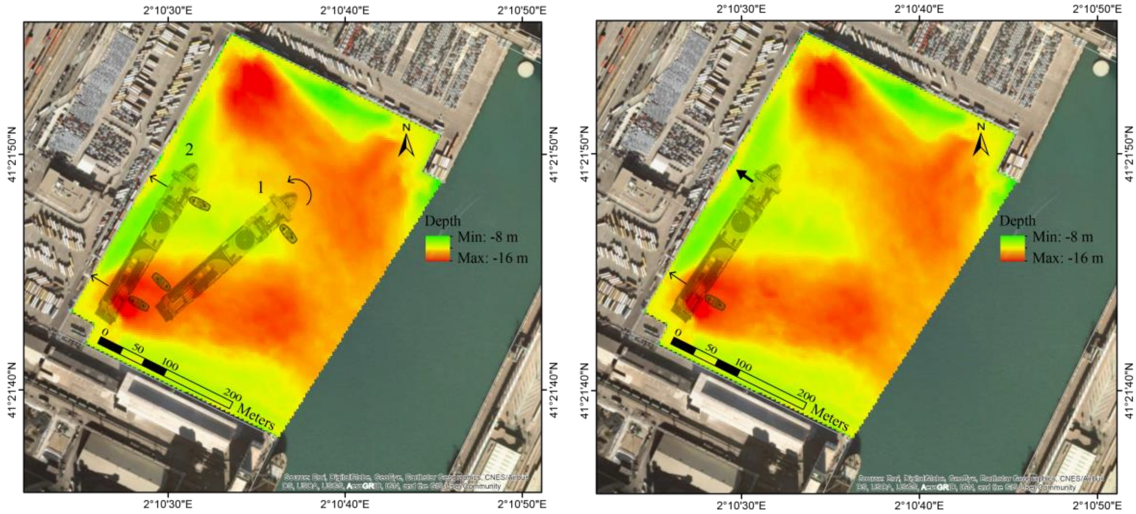

Figure 15: Representation of alternative berthing manoeuvres with tugs

The main objective of alternative undocking manoeuvres is seek to move the vessel from the quay walls so that the vessel does not get sucked onto the quay with the ahead movement. Two means of manoeuvring the vessel while moving her away from the quay are proposed: producing the transverse force by tugboats external to the vessel or using one tug and the bow thruster. Two tugs assistance manoeuvre is shown in Figure 16 (left). When the vessel is unberthing with the assistance of two tugs, these are used to pull the ship off the berth. The vessel will be pulled nearly parallel to the berth to avoid either end from making contact with the berth. Once the vessel is safely clear form the berth, swing movement will start. Alternatively, with the help of bow-thruster, one tug aft can be sufficient for unberthing, see Figure 16 (right).

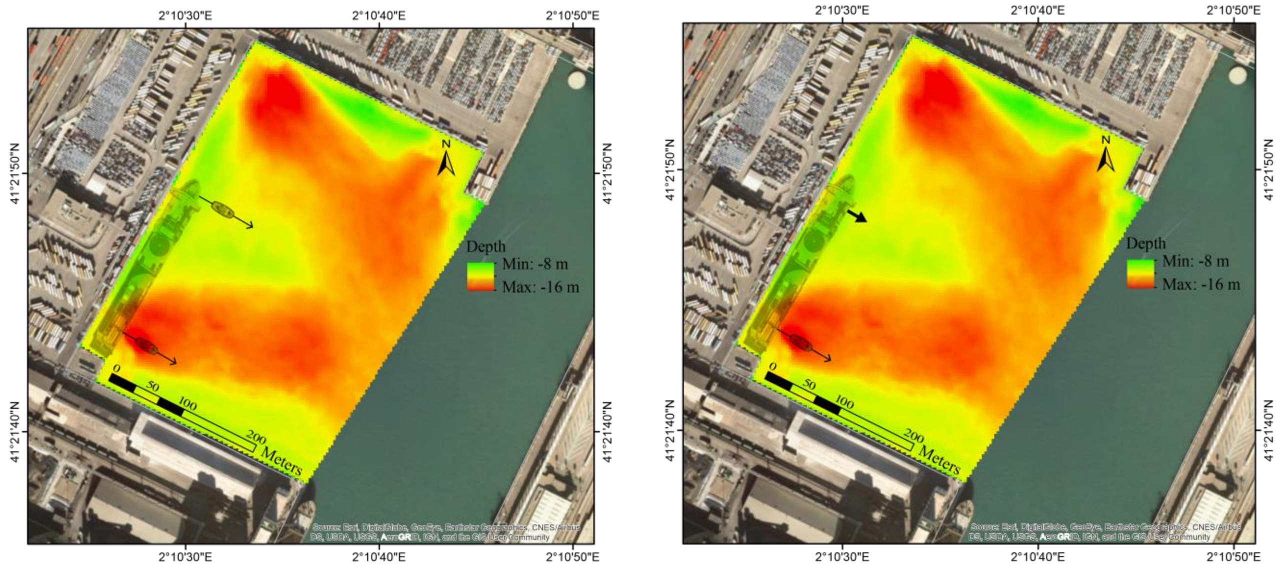

Figure 16: Representation of alternative unberthing manoeuvres with tugs

The manoeuvre without tugs, controlling the speed of the main engine and using mooring lines is difficult. Speeds analysed in the above section are adequate, because the vessel requires a minimum powering. Lower speeds should affect the manoeuvrability abilities, because the rudder is not effective.

5. CONCLUSIONS

The use of AIS is an easily available source of information about the manoeuvring vessel behaviour and a useful tool to prevent propeller scouring effects. Results obtained in this paper show that AIS data can be used to obtain the identification of statistical manoeuvring parameters and patterns of docking and undocking manoeuvres in both calm and bad weather. Manoeuvres analysed show similar patterns in docking and undocking manoeuvres with some variations when bad weather conditions are considered.

The combination of AIS data together with bathymetric surveys of the same harbour basin shows an evident relation between the manoeuvers and the scouring depth patterns. When the vessel is unberthing, the influence of the wall is clear, causing higher damage to the structure for both the localization of the deeper point in the scouring hole and its magnitude. Moreover, the sediment eroded can settle at different locations reducing the total depth in the harbour basin and produce operational problems in the particular basin. Some critical zones have been detected.

In order to reduce the effect of the toe scouring induced by vessel propeller, alternative docking and undocking manoeuvres with the same ship and in the same navigation area are assessed and proposed. From the point of view of navigation, the use of mooring lines controlling the speed of the main engine and bow thrusters is quite difficult and the manoeuver using tug assistance is the best option. When two tugs are used, scouring action is the lowest because tugs have a relatively low drafts and the vessel propeller and bow thrusters are usually not used. However, due to the high cost, a single tug can be used reducing the scouring action as well.

The use of the bridge simulator allows to reproduce any manoeuvre of any ship in any harbour basin with any met-ocean conditions, so the results obtained can help to port authorities to make decisions to improve port management and minimise the scouring problems.

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