SUND & BÆLT

ANALYSES OF NEW ISLAND HARBOUR AT TÅRS

MANOUVRE SIMULATIONS

COWI

ADDRESS COWI A/S
Parallelvej 2
2800 Kongens Lyngby
Denmark

TEL +45 56 40 00 00
FAX +45 56 40 99 99
WWW cowi.com

SUND & BÆLT

ANALYSES OF NEW ISLAND HARBOUR AT TÅRS

MANOUVRE SIMULATIONS

PROJECT NO.	DOCUMENT NO.
A258774	A258774-HAV-RAP-02

VERSION	DATE OF ISSUE	DESCRIPTION	PREPARED	CHECKED	APPROVED
1.0	26-02-2025		ABJI	ADKE	JJU

CONTENTS

1 Project Location 7

2 Scope of study 8

3 Environmental data 10
3.1 General 10
3.2 Bathymetry 10
3.3 Water levels 11
3.4 Wind 11
3.5 Waves 13
3.6 Current 14

4 Navigation Simulations 19
4.1 Objective of the navigation simulations 19
4.2 Hardware and software 19
4.3 Main assumptions for the simulations 23
4.4 General methodology 24
4.5 Preliminary Navigation simulations 26
4.6 Workshop No. 1 28
4.7 Workshop No. 2 33
4.8 Additional simulations for Layout 3 37

5 Conclusions and recommendations 41
5.1 Manoeuvres 41
5.2 Navigation operational limits 41
5.3 Conclusions and captain remarks 45

6 References 47

APPENDICES

Appendix A Run-matrix Workshop No.2 48

Appendix B Images from Workshop No. 2 51

1 Project Location

The project site is located near Tårs (DK) in Langelandsbælt. The objective is to establish an offshore ferry harbour on an artificial island approximately 3.5 km from Lolland, out in the Langslandsbælt, which can reduce the travelling time all year round on the Spodsbjerg-Tårs crossing.

The proposed harbour location and its area is shown in Figure 1-1.

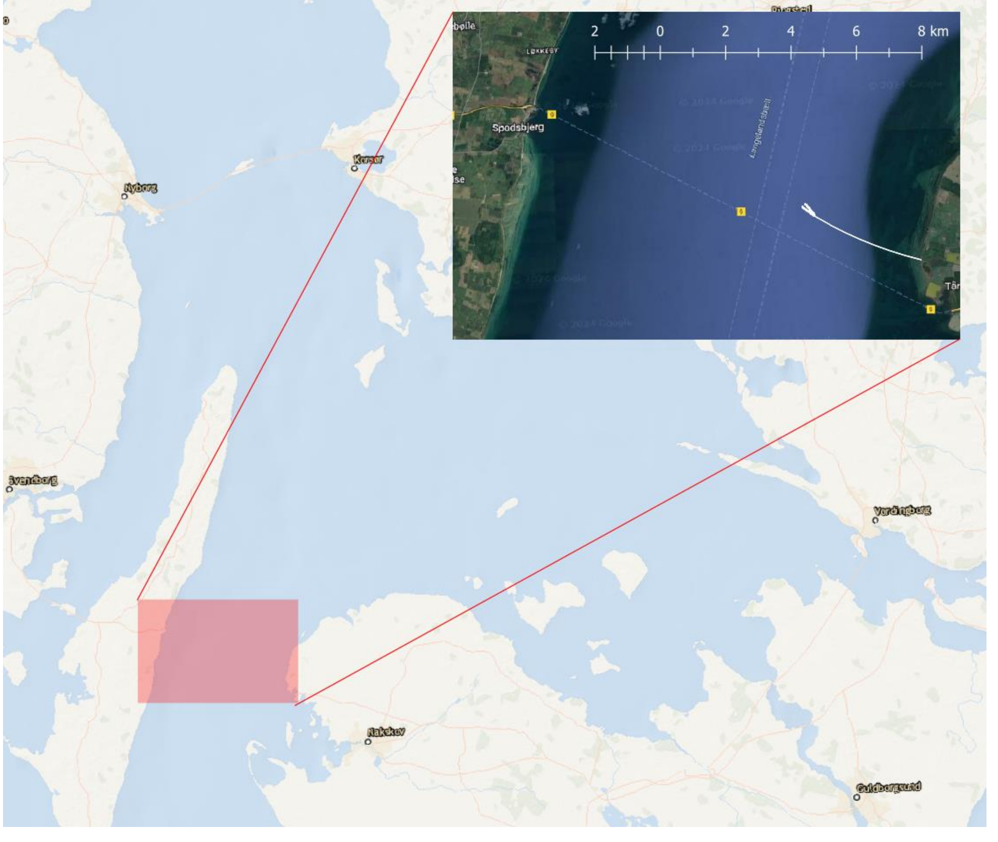


Figure 1-1 Location of Tårs Ferry Harbour in Langelandsbælt.

2 Scope of study

The purpose of this study is to assess if the proposed layouts of the harbour can facilitate safe approach and departure operations to the ferry terminal, while maximizing weather windows or operational time, through desktop simulations. Navigational simulations were carried out using the latest software package SIMFLEX V.4.12.0.1. The report presents the findings of the simulations and provides an assessment of typical approach and departure manoeuvres during different wind, wave and current conditions.

Two different harbour layouts are considered in the navigational simulations:

› Layout 2, see Figure 2-1. The harbour entrance of 60m width faces the northwest direction and the distance between entrance and back quay wall is 250m. The berth pocket/area has a 60m width to accommodate two ferry berths.

› Layout 3, see Figure 2-2. The harbour layout is identical to Layout 2 with the harbour being rotated so that the entrance faces towards north.

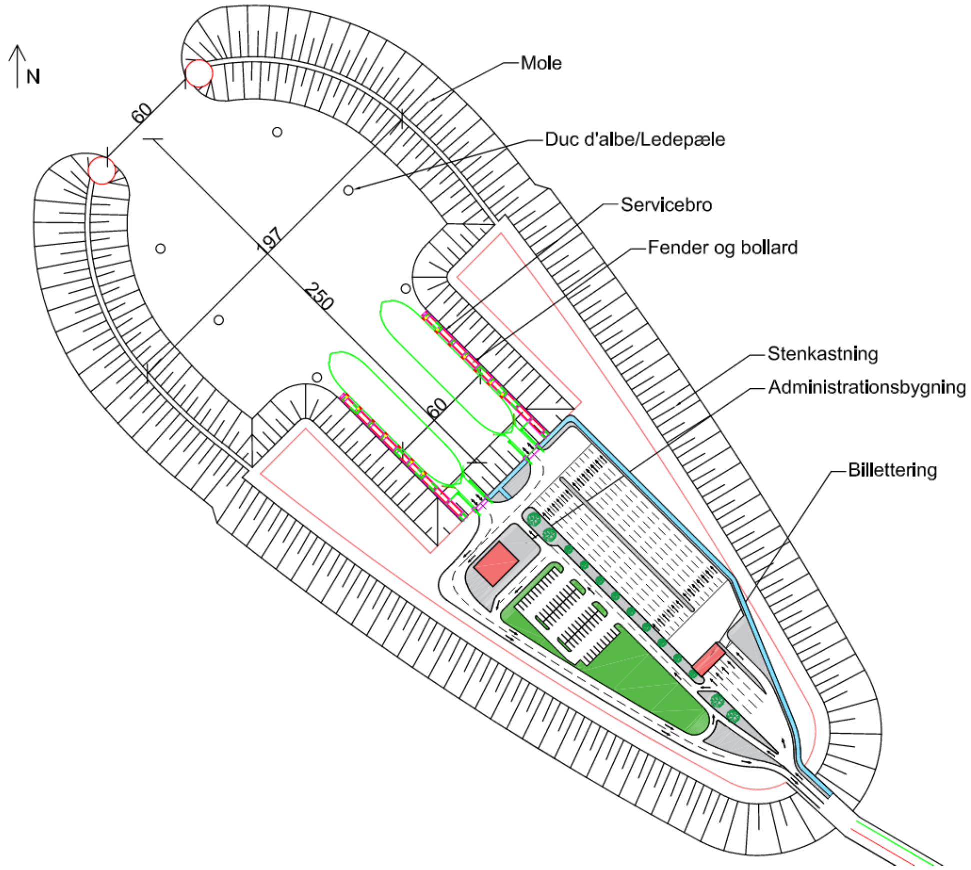


Figure 2-1 Harbour Layout 2 with the harbour being oriented towards northwest.

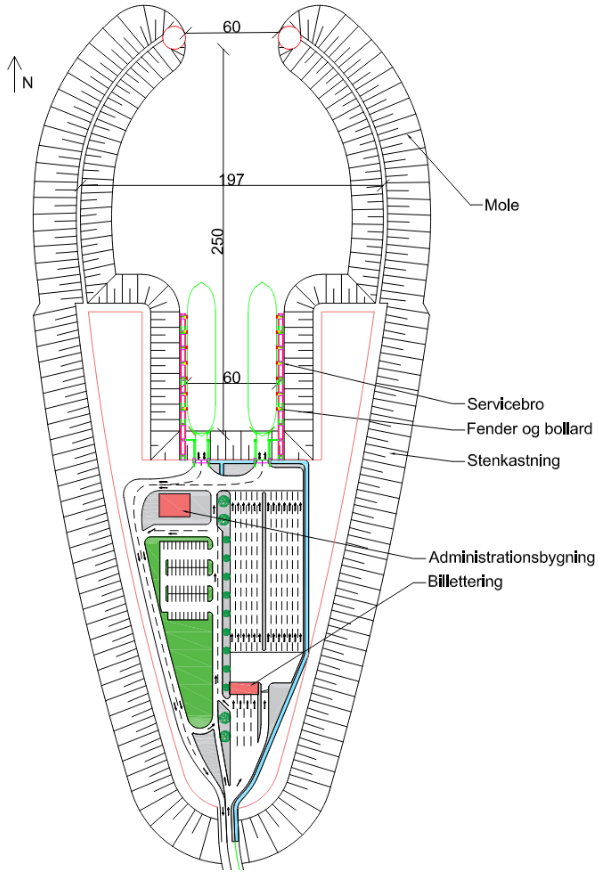


Figure 2-2 Harbour Layout 3 with the harbour being oriented towards north.

3 Environmental data

3.1 General

A summary of the metocean data used to set the run-matrix for the simulations is given below in Table 3-1.

Table 3-1 Metocean data used to set run-matrix

Parameter	Data	
	Document	Data set
Waves	Ref. /1/	MIKE 21 SW model 2003 to 2013. MIKE 21 BW model for wave propagation into the harbour
Wind	Ref. /1/	NORA3 1993-01-01 to 2023-11-29 dataset
Current	-	Data received from DHI, year 2019
Bathymetry	Ref. /1/	MIKE 21 SW model 2003 to 2013 with refined mesh at area of interest

3.2 Bathymetry

The bathymetry used for the navigation simulations is identical to what is presented in ref. /1/, shown in Figure 3-1 and Figure 3-2.

Bathymetry levels are provided in DVR90 (m CD).

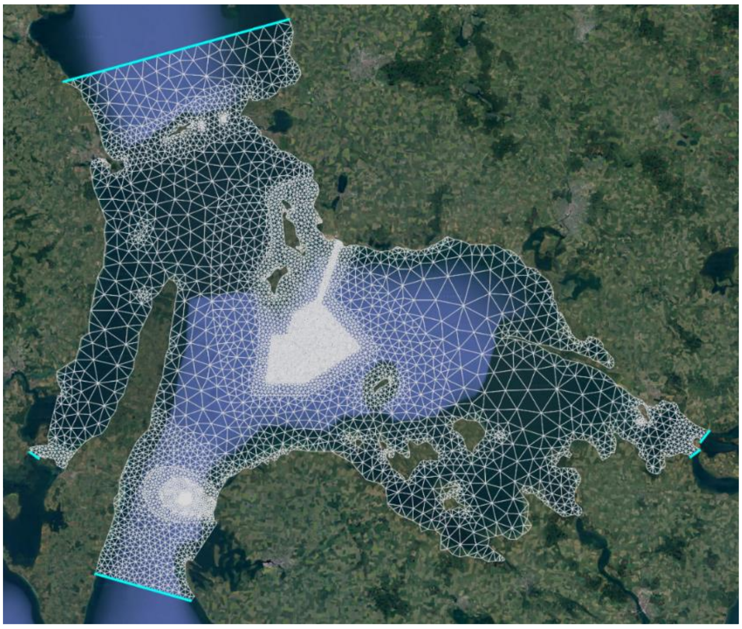


Figure 3-1 Model mesh used in ref. /1/. Boundaries shown as cyan lines.

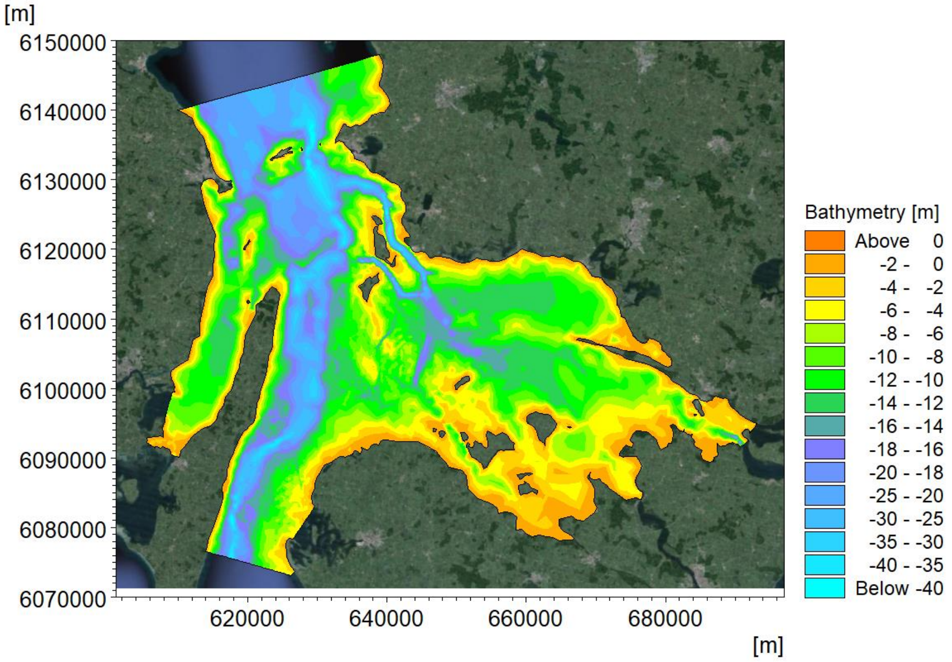


Figure 3-2 Bathymetry (m CD) used for the wave study in ref. /1/.

3.3 Water levels

Water levels are not considered in the simulations. The water level set in the simulations corresponds to 0 m DVR90.

3.4 Wind

3.4.1 General conditions

A wind rose in a point of the NORA3 wind dataset near the project site is shown in Figure 3-3. Scatter plot of the wind direction and speed as well as joint occurrence of wind direction and speed is given in ref. /2/.

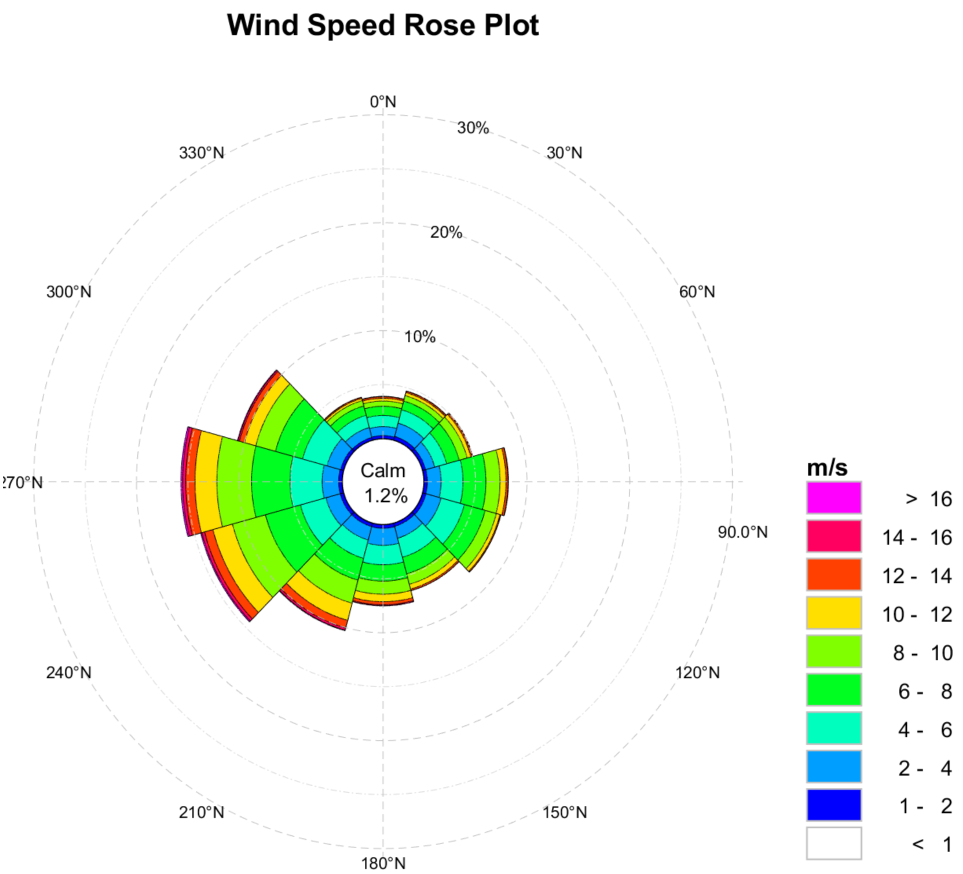


Figure 3-3 Wind rose in a point near the project site from the NORA3 dataset.

3.4.2 Extreme conditions

Extreme conditions corresponding to a 1-year return period are taken from ref. /1/ and are presented in Table 3-2.

Table 3-2 Directional extreme wind speeds with a return period of 1 year. Based on U_{10} in the NORA3 dataset. Both the extreme fit and upper confidence level including 1 standard deviation are presented. Data from 1993-01-01 to 2023-11-29.

Wind Speed (m/s)	1 year return period	
	Extreme	+1std
Omni	20.0	20.3
0°	15.5	15.9
30°	15.6	16.0
60°	15.9	16.5
90°	16.9	17.5

Wind Speed (m/s)	1 year return period	
	Extreme	+1std
120°	17.4	18.1
150°	20.0	20.3
180°	20.0	20.3
210°	20.0	20.3
240°	19.6	20.1
270°	17.4	17.8
300°	14.8	15.0
330°	14.3	14.7

3.5 Waves

Wave conditions are described in ref. /1/ and a summary of the relevant parameters for the navigational simulations are given below.

3.5.1 Normal conditions

Normal wave and extreme wave conditions are obtained by numerical wave modelling and are described in section 3.5 and 3.6 in ref. /1/. The largest waves are coming from south-southwesterly (SSW, 210-240°N) to north-northeasterly (NNE, 0-30°N) directions, with the largest waves coming from SSW.

3.5.2 Extreme conditions

Directional extreme wave conditions and associated peak wave periods with a 1-year return period are considered for the navigational simulations, see Table 3-3.

Table 3-3 Directional extreme wave conditions and associated peak wave periods (given in "()") with a 1-year return period at location P1, see ref. /1/.

MWD	H_s [m] (T_p [s])
Omni	1.6 (5.5)
0°	1.2 (4.5)
30°	1.2 (4.5)
60°	0.9 (4.0)
90°	0.7 (3.5)
120°	0.7 (3.5)
150°	0.8 (3.5)

MWD	H_s [m] (T_p [s])
180°	1.0 (4.0)
210°	1.6 (5.5)
240°	1.3 (5.0)
270°	1.1 (4.5)
300°	0.9 (4.0)
330°	0.9 (4.0)

3.6 Current

The current conditions at the project location were provided by DHI in the form of current maps for the period between 01-01-2019 and 01-01-2020. Timeseries were extracted at selected points in front of the harbour entrance, see Figure 3-4, for Layout 2 (northwest facing harbour entrance) and Layout 3 (north facing harbour entrance). Scatter plots were produced based on the extracted timeseries for the depth averaged current. An example with the area covered by the current maps is given in Figure 3-5. The current direction in the following is defined as "going towards".

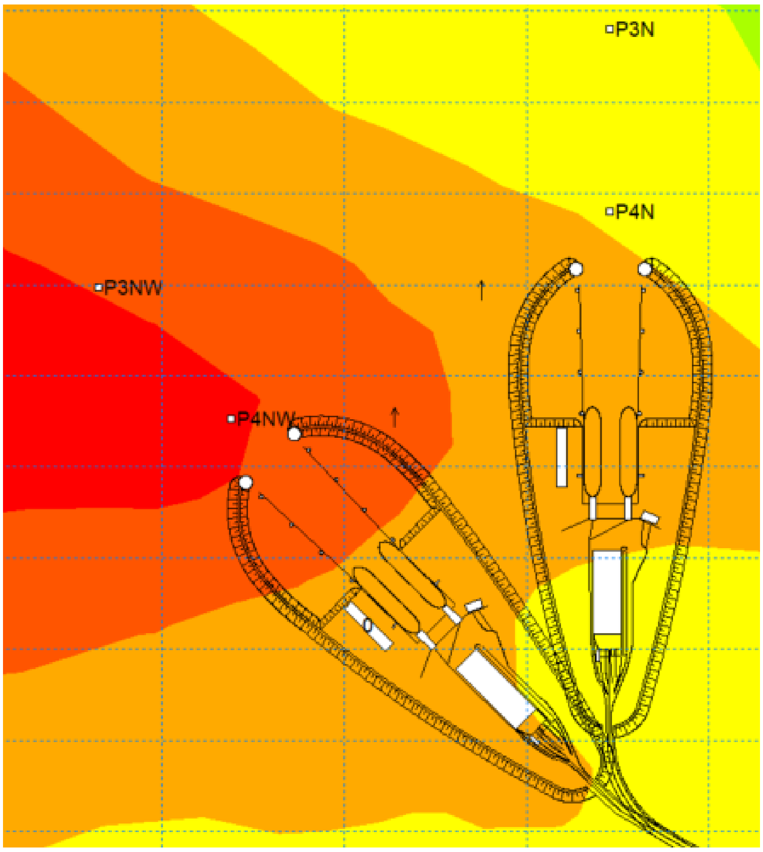


Figure 3-4 Points at which depth averaged current speed and direction are extracted.

The coordinates for the extraction points are given in Table 3-4.

Table 3-4 Coordinates of the extraction in WSG84 UTM32N.

Layout	Point No.	Easting	Northing
Layout 2	Point 3NW	625531.1	6086297
Layout 2	Point 4NW	625675.5	6086153
Layout 3	Point 3N	626091.9	6086580
Layout 3	Point 4N	626091.9	6086380

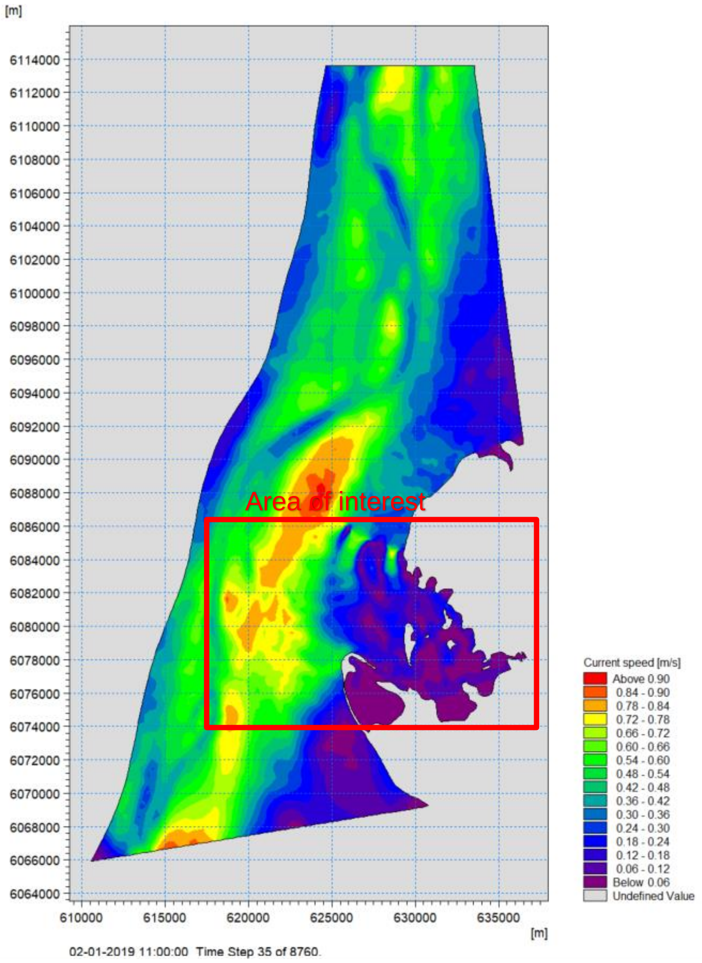


Figure 3-5 Depth averaged current map at a given timestep.

General statistics of depth averaged current speed are provided in Table 3-5.

Table 3-5 General statistics for depth averaged current speed at the extraction points.

Layout	Point No.	Min	Max	Mean	Stdv
Layout 2	Point 3NW	0	2.21	0.58	0.38
Layout 2	Point 4NW	0	2.36	0.58	0.39
Layout 3	Point 3N	0	1.71	0.40	0.28
Layout 3	Point 4N	0	1.72	0.35	0.28

Scatter plots are prepared for depth averaged current speed vs. depth averaged current direction (“going towards”).

Scatter plot for points No. 3NW and No. 4NW (Layout 2) are shown in Figure 3-6. It is observed that current speeds going towards north-northeast direction reach speeds up to 1.5 m/s with a most frequent value of approximately 0.5 m/s. Higher current speeds up to 2.3 m/s can be reached for current going towards southwest, with the most frequent current speed being about 0.5 m/s.

Scatter plot for points No. 3N and No. 4N (Layout 3) are shown in Figure 3-7. It is observed that current speeds going towards north-northeast reach speeds up to 0.8 m/s with a most frequent value of approximately 0.3 m/s. Higher current speeds up to 1.7 m/s can be reached for current going towards southwest, with the most frequent current speed being about 0.3 m/s.

There is generally no clear correlation between the depth averaged current direction and wind direction, nor between the depth averaged current speed and wind speed.

It is apparent, that the current speeds are higher outside the harbour entrance for Layout 2 compared to Layout 3, which is because of the orientation of the harbour. Furthermore, the current direction outside the harbour entrance is more southerly and northerly for Layout 2 compared to Layout 3. The current directions also show that the current is approximately perpendicular to the harbour entrance for Layout 2, which cause issues for approaching ferries.

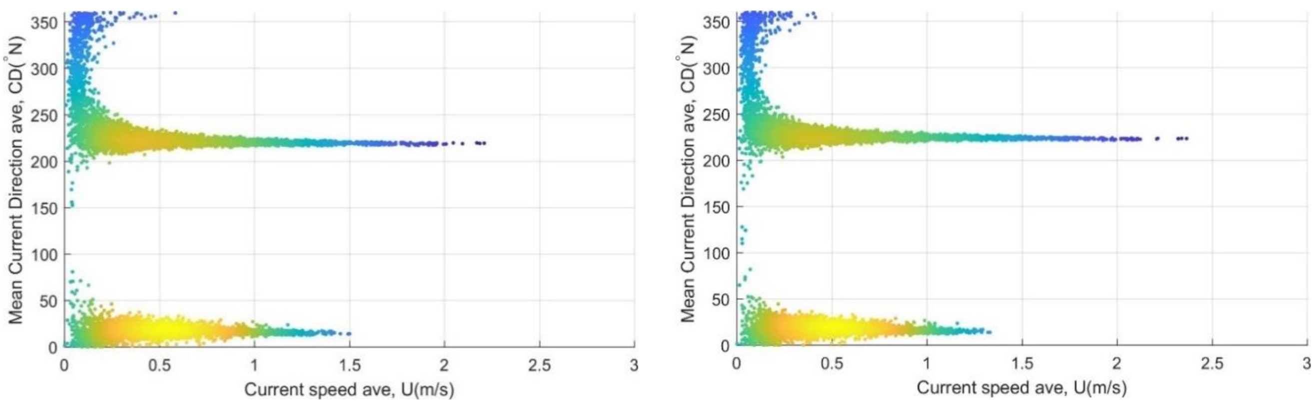


Figure 3-6 Scatter plots for depth averaged current speed VS direction (going towards) at Points No.3NW (left) and No.4NW (right).

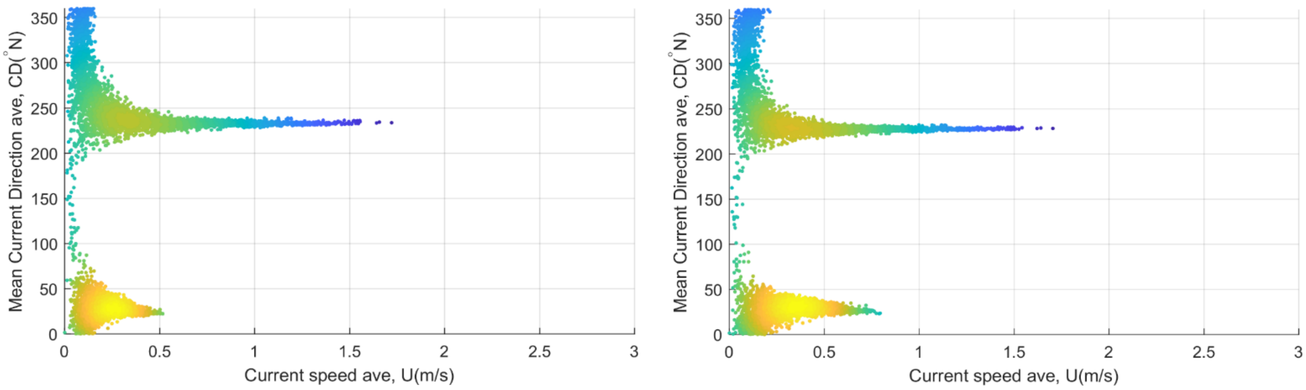


Figure 3-7 *Scatter plots for depth averaged current speed VS direction (going towards) at Points No.3N (left) and No.4N (right).*

Current maps for the main observed directions (SW and NNE) have been extracted from the current data provided by DHI at the time when the maximum values shown in the figures above occur. The current maps for an area near the harbour entrance are shown below in Figure 3-8 and Figure 3-9 f while values are given in Table 3-6

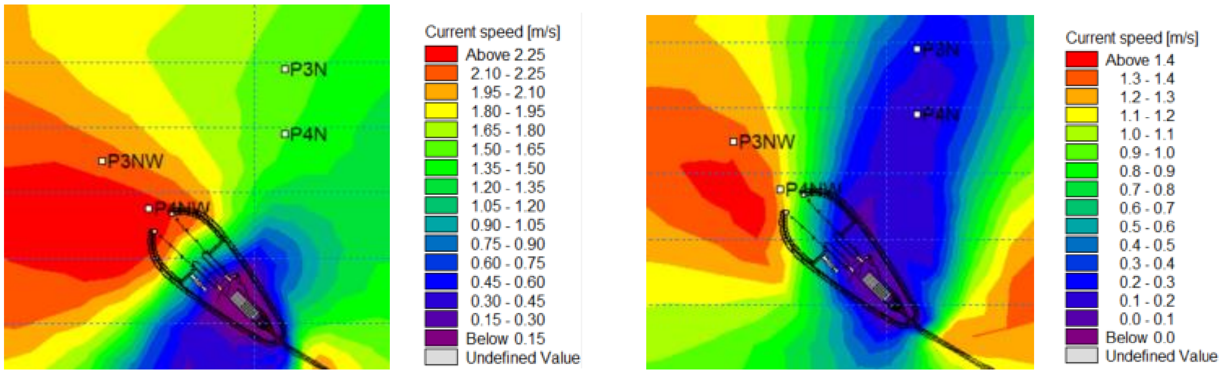


Figure 3-8 *Left: Timestep 7982 for Layout 2 with SW going current. Right: Timestep 6366 for Layout 2 with NNE going current.*

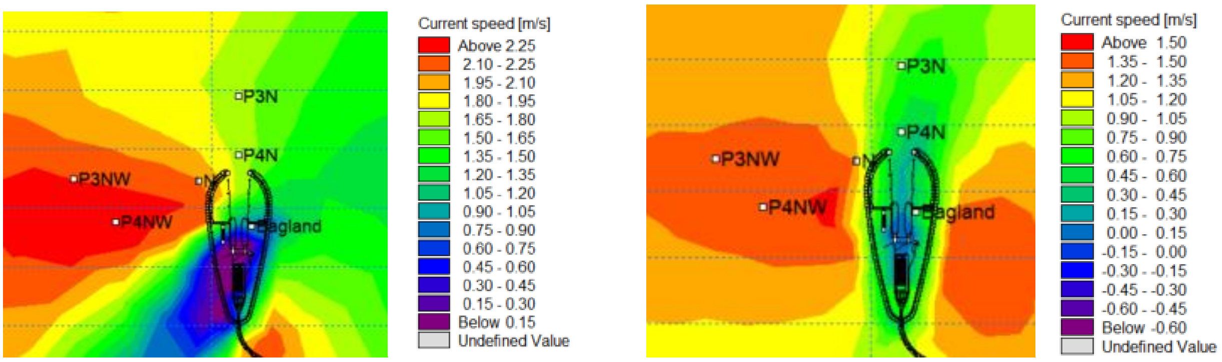


Figure 3-9 *Left: Timestep 7981 for Layout 3 with SW going current. Right: Timestep 6365 for Layout 3 with NNE going current.*

Table 3-6 *Values of depth averaged current speed and direction at extraction points selected for current maps to use in the navigation simulations.*

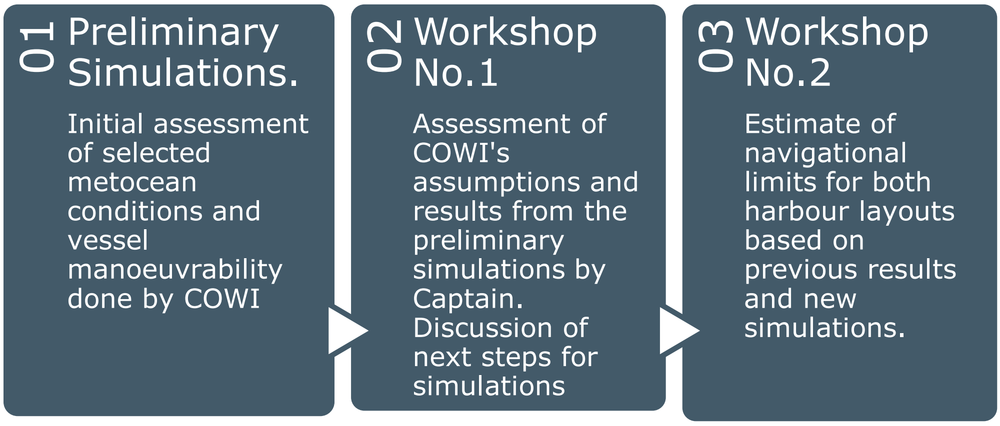
Point No.	Layout	Step in simulation	Depth averaged current speed [m/s]	Mean current direction (going towards)
Point 3NW	Layout 2	7982	2.21	SW
Point 4NW	Layout 2		2.36	
Point 3N	Layout 3	7981	1.49	
Point 4N	Layout 3		1.49	
Point 3NW	Layout 2	6366	1.71	NNE
Point 4NW	Layout 2		1.72	
Point 3N	Layout 3	6365	0.79	
Point 4N	Layout 3		0.52	

4 Navigation Simulations

4.1 Objective of the navigation simulations

The main objective of the navigation simulations is to assess the suitability of the harbour layouts and manoeuvrability under the prevailing met-ocean conditions for the design vessel.

The methodology followed for the navigation simulations setup is summarised below. A captain from FORCE Technology was involved in two manoeuvre simulation workshops carried out at COWI. The caption has 18 years of previous experience from the Spodsbjerg-Tårs ferry route.



4.2 Hardware and software

The navigation simulations are based on two separate software packages, which are part of Simflex V.4.12.0.1: The "Area Engineer" which is used to design the layout and the "Operation Control Centre (OCC)" which performs the actual real time simulation. Both software packages are developed by FORCE Technology, one of the market leaders for this type of software.

4.2.1 Area engineer

To run the simulations a numerical layout model is set up by use of the software "Area Engineer". The model includes:

› 2D or 3D geometric definition of e.g. bathymetry, fenders and other physical objects;

› Met-ocean definitions to simulate environmental effects on the ships (current, waves, wind, visibility) imported from hydraulic models if available;

› Aids to Navigation such as marks and light descriptions.

4.2.2 Operation control center (OCC)

The real time simulations are performed by the Operation Control Center (OCC). It is a state-of-the-art numerical navigation model, which simulates the effect and interaction between met-ocean conditions, and ship models and link to other external sources affecting the model ship such as push and pull tug operations. The effects are specific to each individual ship model and include:

› Wind forcing

› Current forcing

› Wave forcing

› Radar simulation

› Tug selection and handling

4.2.3 Hardware

The simulator equipment operated is composed of two stationary PC in network, three 21" monitors displaying instructor screen (OCC), the ship instruments, ship radar and ship chart plotter (ECDIS). 3D environment is shown in three additional monitors above the instructor and ship instruments.

The ship main controls (main rudder, main engines, thrusters, visual orientation) are provided via a hardware console as shown in Figure 4-1 and Figure 4-2.

Figure 4-1 Navigation simulator.

Figure 4-2 Ship main control hardware console. Top console for regular engines and bottom console for azipods (used for Workshop No. 2).

4.2.4 2D environment

A 2D environment was used for the preliminary navigational simulations and Workshop No. 1, see sections 4.5 and 4.6.

The bathymetry was generated by using the data used in ref. /1/ but the extent was reduced to the area of interest, see section 3.2.

The land area covering the artificial island was generated by using the harbour layouts shown in Figure 2-1 and Figure 2-2.

The wind and waves were input as a constant value over the entire domain.

The current was input as a map (x, y, current speed, current direction) corresponding to the time steps in the .dfsu file timeseries received from DHI which were most representative of the conditions set in the run-matrix.

4.2.5 3D Environment

A 3D environment was prepared for Workshop No. 2. The bathymetry, land, current maps and harbour layout were the same as in the 2D simulations.

Figure 4-3 3D environment used in Workshop No. 2 with the captain.

4.2.6 Ship model

A ship model with dimensions similar to the target vessel operating on the Spodsbjerg-Tårs route was used in the simulations. The model vessel is the ferry “Samsø” used between Kalundborg and Ballen which is similar to the ferries “Spodsbjerg” and “Tårs” used on the Spodsbjerg-Tårs route. The simulated vessel has slightly more conservative ship particulars, than that of the design vessel according to the captain assisting for Workshop No. 1 and 2.

Table 4-1 Ship model particulars.

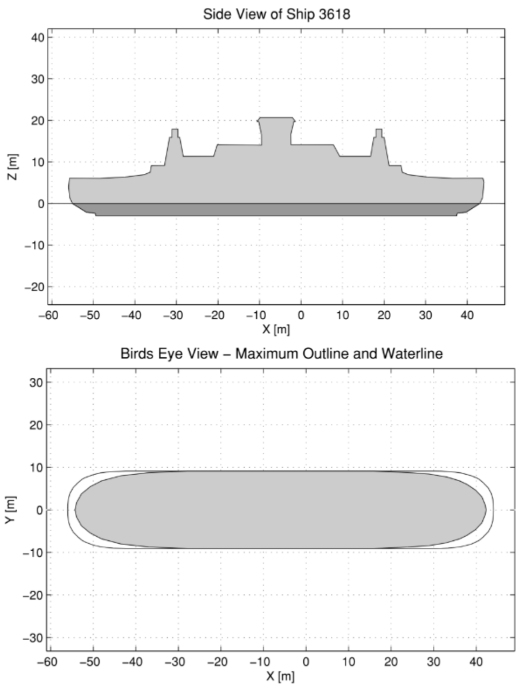
Parameters	Value	Visualisation
Ship No.	3618	
Name	Samsø	
Loading condition	Service	
LOA	99.9 m	
Beam	18.2 m	
Draft fore	2.8 m	
Draft aft	2.8 m	
4x propellers 1.6 m diameter (rudder)		
Displacement	2360 m^3	
Front wind area	309 m^2	
Lateral wind area	1051 m^2	
Turning circle, advance	3.7 Lpp	
Turning circle, tactical diameter	4.9 Lpp	

Figure 4-4 Visualisation of Samsø Ferry.

4.3 Main assumptions for the simulations

- Simulations were performed to assess the layout suitability for navigation; hence, the simulations started at a point located in the vicinity of the harbour with sufficient distance to reduce the operational vessel speed of 8 knots to a safe speed at the harbour entrance.

- Aft and forward azipods were operated independently with different power and direction.

- A safe manoeuvre is reached when the vessel enters the harbour with a safety distance from the breakwater and with a controlled speed suitable for breaking inside harbour.

4.4 General methodology

The main cases selected for navigation simulations are shown in Table 4-2.

The aim of the simulations is to test if the proposed layouts provide safe navigation conditions under the metocean conditions which allow for a desired operational time. The number of simulations is limited, and representative cases are selected based on:

- General wind speed limits for ferry, assumed as 14m/s in agreement with captain due to open waters and no lee.
- 1 year return period values for waves assumed as target operational limit.
- Maximum current speeds for (data from 2019 provided by DHI). Data are included as described in section 4.2.4.
- Scatter plots and scatter tables of the different parameters showing occurrences (note these are prepared for only one year data which is the overlap time between NORA 3 wind data and the modelled current speeds).
- Most frequent wind and wave direction were selected and will be tested for both predominant current directions.
- Cases in which wind and waves push the vessel against the harbour entrance are also tested to see if stopping distance is sufficient which coincides in general with the case with worst wave height inside basin.
- Cases with beam on wind, wave and current are tested as worst combination for harbour access.

Table 4-2 Summary of Run matrix with target limits.

Scenario No.	Layout	Case	MWD	Wind direction	H_s	Wind limit operation	Current speed depth averaged	Current direction	T_p
			[°N] From	[°N] From	[m]	[m/s]	[m/s]	[°N] Towards	[s]
1N	Layout 3	Predominant wind-wave	210	210	1.6	14	0.8	30	6
2N	Layout 3	Worst beam on loads	270	270	1.1	14	0.8	30	4.5
3N	Layout 3	Worst beam on loads	90	90	0.9	14	1.7	210	3.5
4N	Layout 3	Worst wave inside basin	0	0	1.2	14	1.7	210	4.5
1NW	Layout 2	Predominant wind-wave	210	210	1.6	14	1.5	30	6
2NW	Layout 2	Worst combination wave outside and inside basin	345	345	1.2	14	2.3	210	4.5
3NW	Layout 2	Worst beam on and current	30	30	1.2	14	2.3	210	4.5

4.4.1 Safety level marks

Safety level marks were used in Workshop No. 2 simulations. Each simulation is evaluated by safety level marks as follows:

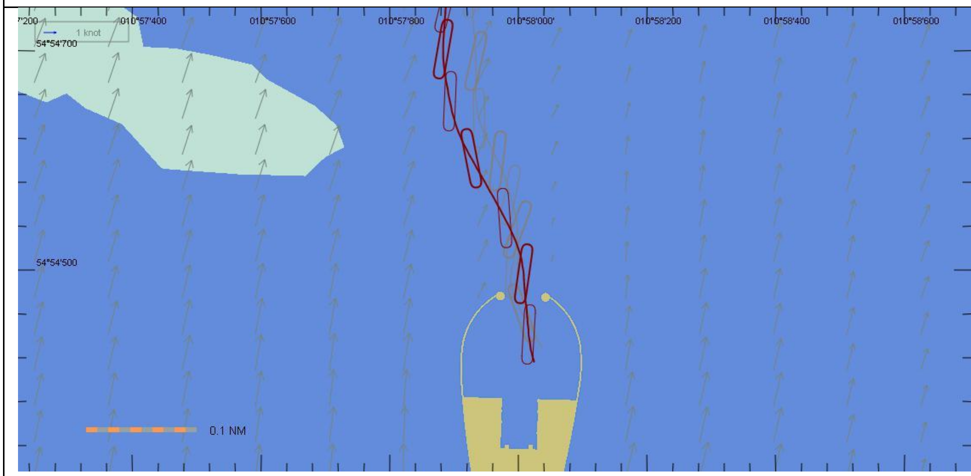
1. High, run proceeded without problems.
2. Good, run occurred without excessive use of available engine power to carry out planned manoeuvre.
3. Acceptable, engine power may have once been used to near or full capacity to carry out the planned manoeuvre.
4. Not acceptable, the use of 100 % engine power was necessary on several occasions to carry out planned manoeuvre.
5. Fail, ship grounded, collided, loss of control.

4.5 Preliminary Navigation simulations

Simulations were carried out for some of the cases in Table 4-2. Target metocean values were used. Results and comments are given below. Note that simulations for Layout 3 (north facing layout) were performed after workshop No. 1.

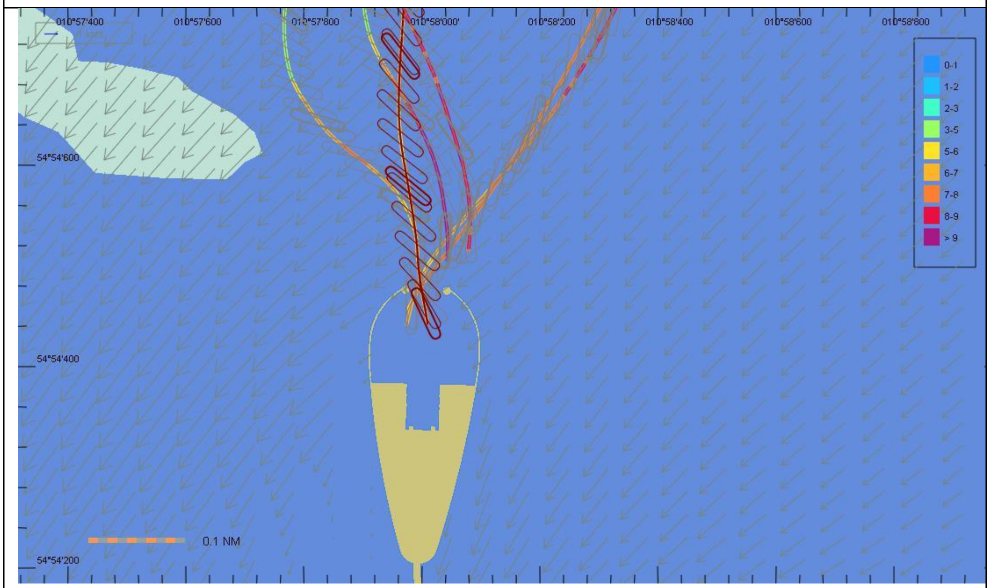
1N - Case with predominant wind-wave

Various attempts were performed ending up in a successful entrance to the harbour but at a high speed (about 5-6 knots). High speed was required to steer the vessel and avoid drifting towards the breakwater entrance.



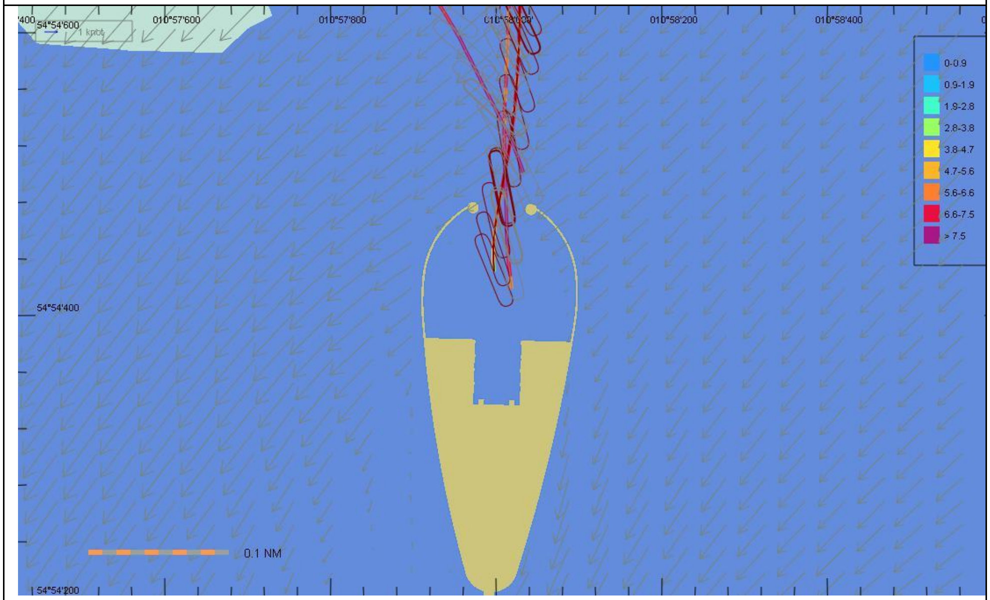
3N - Case worst current and beam on wind

All attempts except one were unsuccessful. Successful attempt seemed on the limit and also considered then as a fail.



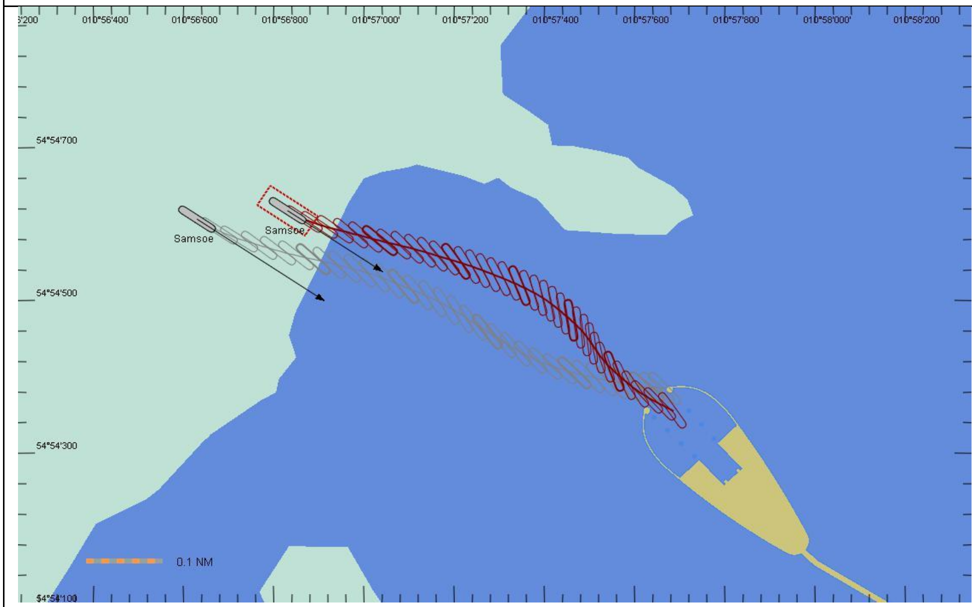
4N - Case with worst wave inside harbour (Current towards SW)

2 Attempts out of 3 were successful. The wind pushing the vessel towards the harbour makes it hard to control the vessel speed. In general, the manoeuvring was easier than for the other cases attempted.



1NW - Predominant wind-wave

Various attempts were performed ending up in a successful entrance to harbour but at a high speed (about 6 knots). High speed was required to steer the vessel and avoid drifting towards the breakwater entrance.



3NW - Case with worst current speed (SW direction) Various attempts were performed without success. The vessel was hard to steer and there was a lot of drift from the current action. Wind speed was lowered from 14m/s to 8m/s in some simulations.


The general conclusion was that the layout with the harbour facing North provided easier navigation than the layout facing Northwest direction. The high current speeds require high speed to steer the vessel which leaves little room for error at the harbour entrance. Challenges were experienced in entering the harbour and it was found that the performed navigational simulations were insufficient to conclude on the suitability of the harbour.

4.6 Workshop No. 1

This workshop was arranged as a result of the preliminary simulations for Layout 2 (northwest-facing layout). The aim of the workshop was to assess the selected metocean conditions and manoeuvring strategy used in the preliminary simulations and using a Captain from FORCE Technology to re-run the simulations to set realistic operational limits and navigation strategy.

During the workshop, an initial assessment of the influence of current and wind forces on the ferry were done by desktop assessment. The calculated forces are given in Table 4-3

Table 4-3 Calculated forces on vessel

Parameter	Force tonnes
Wind beam on	10.7
Wind long	2.4
2.3m/s Current beam	48.8 - 195.3
1.5m/s Current beam	20.8 - 83.1

The captain comments after reviewing the preliminary simulations and assessing the loads on the vessel from selected metocean conditions are given below:

- Forces on the vessels are driven by current speed.
- Wind speed of 14m/s is considered as feasible although may pose a risk if in line with current.
- Current speeds are very high, and the Pilot has doubts on vessel being able to perform manoeuvres safely.
- Two strategies are proposed for vessel arrival:
  - Strategy 1. Vessel comes from northwest and faces southern breakwater head when current comes from SW. 300 m from the entrance reverse fore azipods and use 50% power. Use aft azipods to steer and use a bit of speed on this one 30%-40%. Enter with about 4 knots then full power to stop in the fore and about 30% in the aft (aft not reversing). This can be used for current coming from the opposite direction as well directing the vessel towards the opposite breakwater head.
  - Strategy 2. Start as Strategy 1 but reverse aft azipods since the beginning of the simulation with power about 50-70% in all azipods.
- Simulations are to be performed starting with low wind and current speeds with stepwise increase after successful simulations.
- The use of pc controls rather than console makes the manoeuvring difficult and requires a different strategy than the one expected in real life. It was decided to use the first strategy although it is not a very common practice.

The simulations were carried out starting with low wind speed and current, which were increased based on simulation results and comments from the captain. This was mainly due to the pc controls making manoeuvring difficult compared to a console. Strategy 1 and strategy 2 were tested, strategy 1 being preferred as it provided better results. The cases selected for simulations were the one with predominant conditions deemed as the most representative (case 1NW) and the one with the worst conditions for entering the port with beam on wind-wave and high current speed (3NW). A summary of the simulations performed, and result is given in Table 4-4

Table 4-4 Simulations performed by Captain and results. Only NW facing layout was tested.

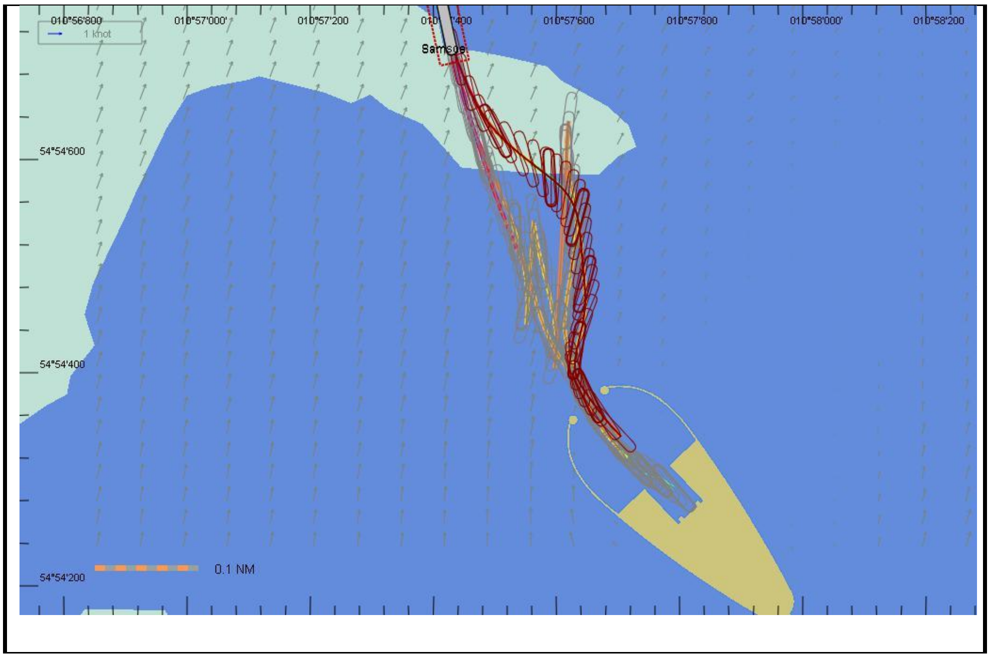
CASE	Simulation Run	MWD	Wind direction	H_s	Wind speed	Current speed depth averaged	Current direction	T_p	Comments
	No.	[°N] From	[°N] From	[m]	[m/s]	[knots] ([m/s])	[°N] Towards	[s]	[-]
1NW (Layout 2) Predominant wind-wave	1-2	210	210	1.6	6-8	1 (0.51)	NE	6	fail No.1 and ok No.2 but hard to control inside harbour
	3	210	210	1.6	6	1 (0.51)	NE	6	ok entering harbour and slow speed inside
	4	210	210	1.6	8	1.1 (0.57)	NE	6	ok entering harbour and slow speed inside
	5	210	210	1.6	10	1.1 (0.57)	NE	6	ok but unsafe distance to breakwater
	6	210	210	1.6	12	1.1 (0.57)	NE	6	problem steering, too much drift, failed simulation
3NW (Layout 2) Worst beam on and current	7	30	30	1.2	8	1.3 (0.67)	SW	4.5	failed simulation,
	8	30	30	1.2	8	1 (0.51)	SW	4.5	Successful simulation

The main conclusion after the workshop was that for more realistic results, a 3D environment and a console shall be used. The conclusion is based on the low wind speeds and reduced current when comparing to Table 4-2 for which simulations were unsuccessful.

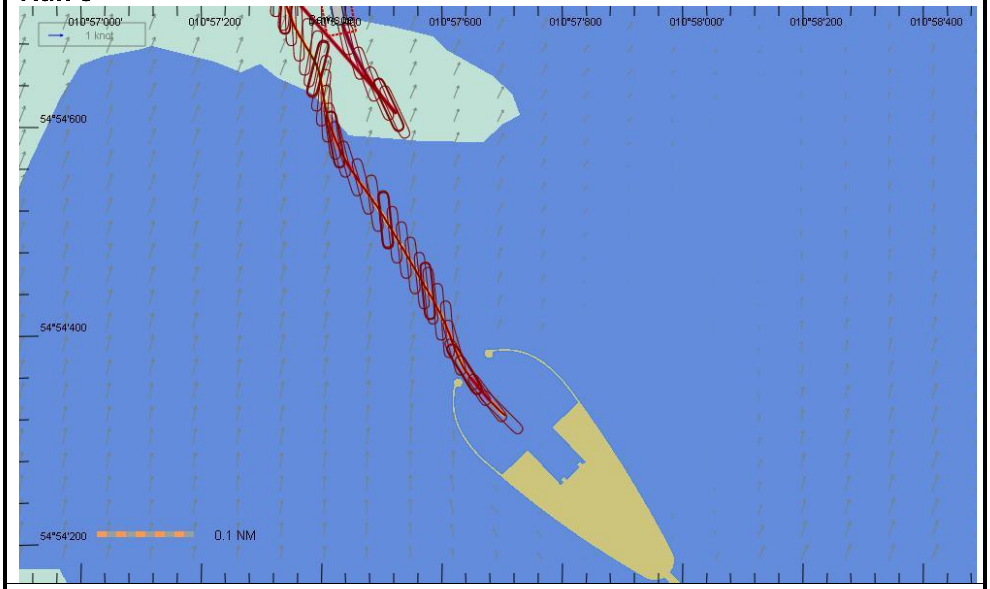
Please refer to section 5 for primary conclusions based on all workshops.

Some of the simulations performed are shown below. For simulation particulars (metocean conditions) refer to Table 4-4.

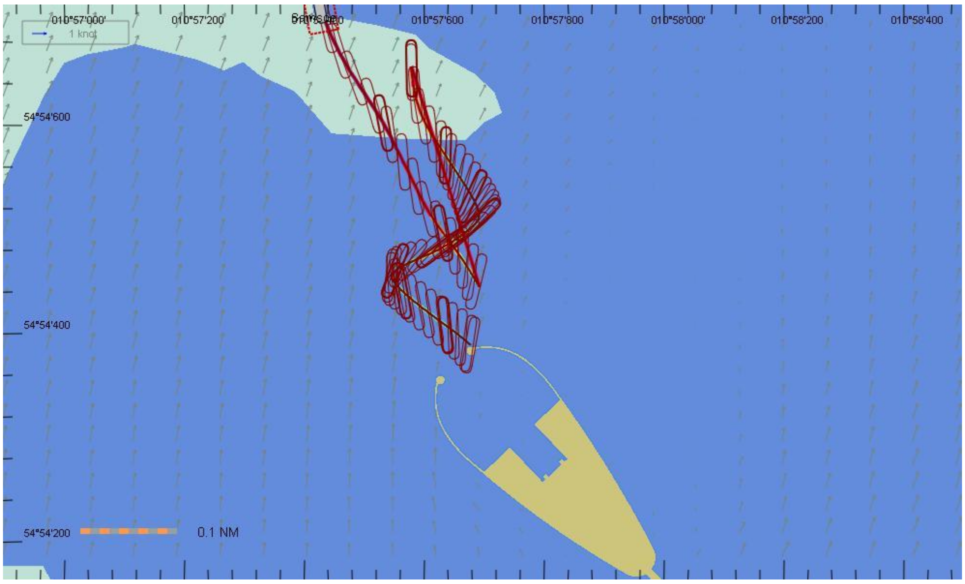
1NW Case
Runs 3-4


010°56'800
010°57'000'
010°57'200
010°57'600
010°57'800
010°58'000'
010°58'200
1 knot
Samsøe
54°54'600
54°54'400
54°54'200
0.1 NM

Run 5

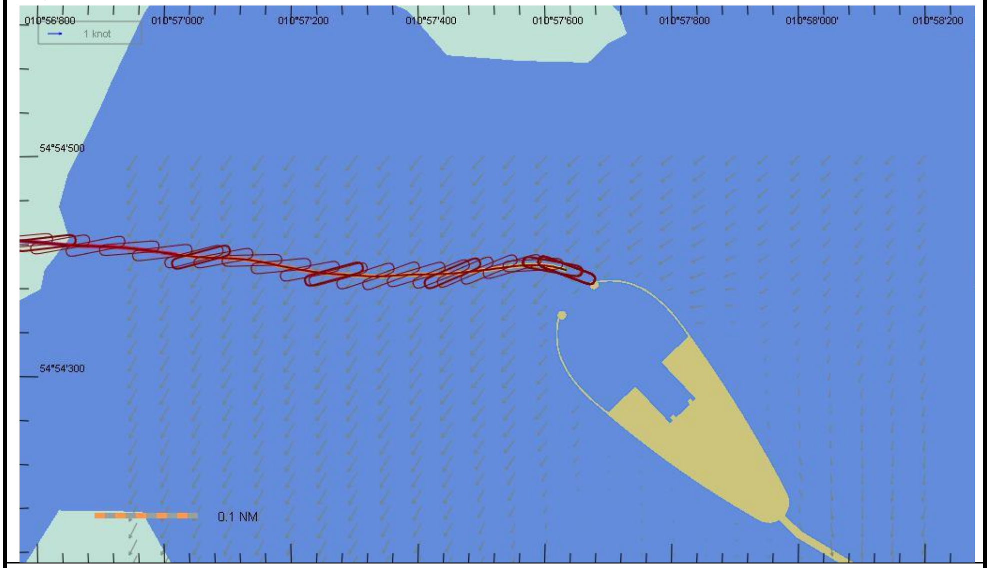

010°57'000'
010°57'200
010°57'600
010°57'800
010°58'000'
010°58'200
010°58'400
1 knot
54°54'600
54°54'400
54°54'200
0.1 NM

Run 6

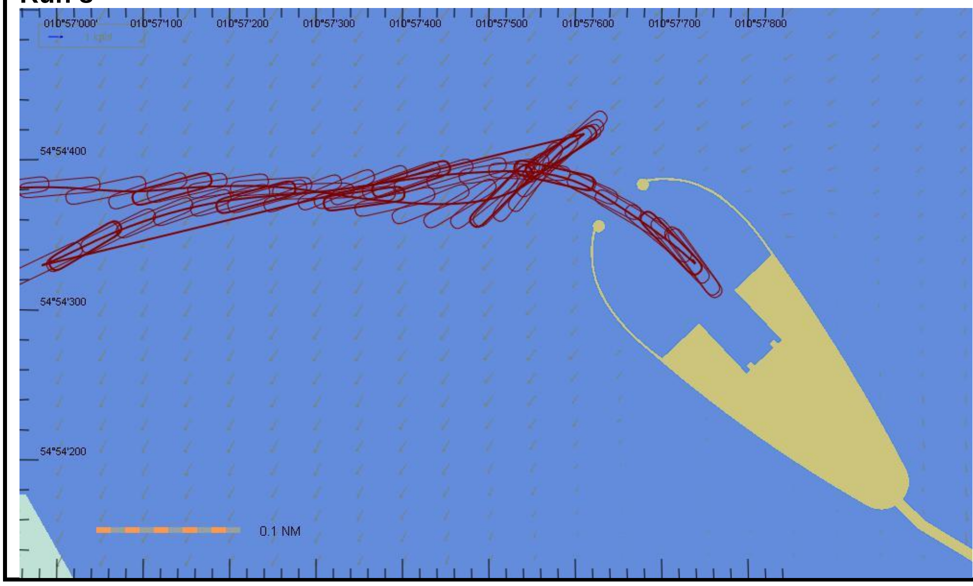

010°57'000'
010°57'200
010°57'600
010°57'800
010°58'000'
010°58'200
010°58'400
1 knot
54°54'600
54°54'400
54°54'200
0.1 NM

3NW Case

Run 7



Run 8



4.7 Workshop No. 2

Workshop No. 1 was insufficient to determine the suitability of Layout 2 with regards to approaching the harbour. An additional workshop was set up with the Captain from FORCE Technology to further assess the suitability of Layout 2, but also primarily to test the suitability of Layout 3. For Workshop No. 2 a new console, appropriate for controlling azipods, was used, see section 4.2.3, while also applying a 3D environment.

During this workshop, both Layouts 2 and 3 were checked against several combinations of metocean parameters. The Run-matrix from the workshop can be found in Appendix A. Case names below are taken from the Run-matrix from this workshop.

The preferred vessel approach strategy from Workshop No. 1 was applied.

The overall conclusion of the Workshop No. 2 and additional simulations are primarily given in section 4.8 and 0.

4.7.1 Layout 2 (northwest facing layout)

A summary of the results from Workshop No. 2 for Layout 2 is given below and in section 5.

› Runs for case 1NW were successful and desired operational limits were reached under safe manoeuvres.

› Runs for the case 2NW were on the limit for operational conditions with a distance between vessel and breakwater head of 7-8 m, which was deemed ok by the captain, but would be subjected to a different opinion depending on the crew. In this case, stopping the vessel would be hard as it is pushed by wind and waves against the quay and a more detailed assessment would be recommended as the vessel model had lower engine power than expected.

› Runs for the case 3NW were on the limit for operational conditions with the vessel entering the harbour having a gap of about 4.5 m with the breakwater head. These runs were deemed unsafe.

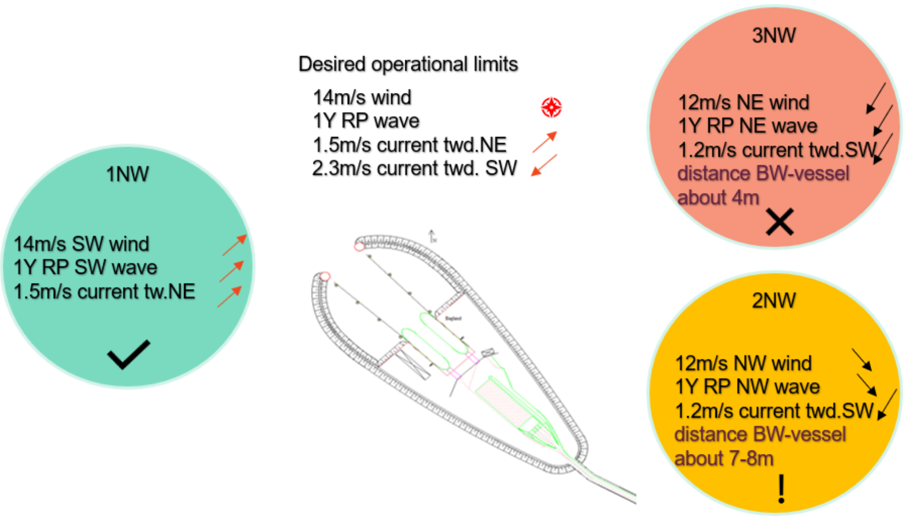


Figure 4-5 Summary of results from Workshop No.2 for Layout 2 (northwest facing layout). BW refers to breakwater head.

The swept area for all simulations is shown below in Figure 4-8.

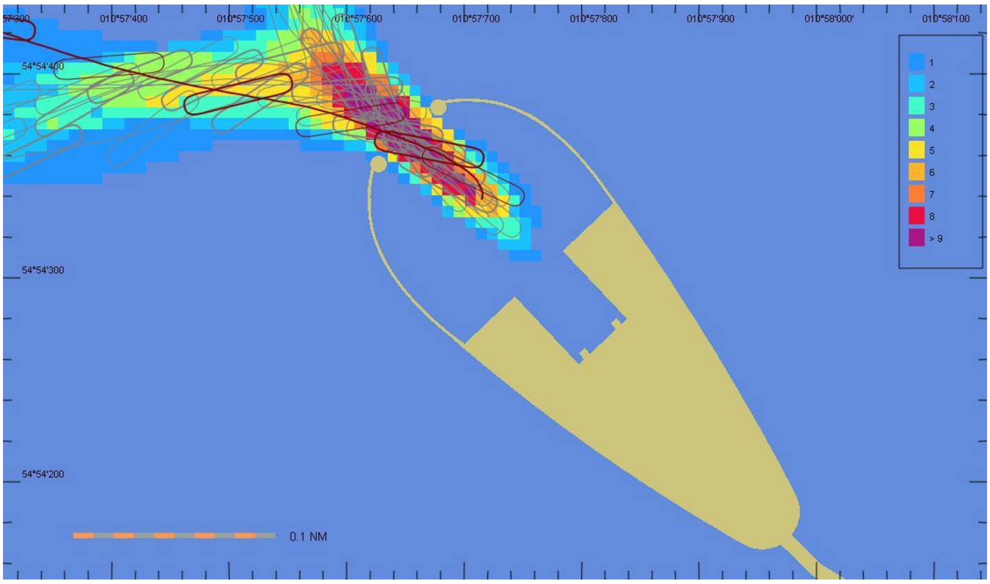


Figure 4-6 *Swept area for the simulations performed for Layout 2. Legend refers to number of simulations for which the vessel has sailed over a certain area.*

The vessel bottom speed is shown in Figure 4-9.

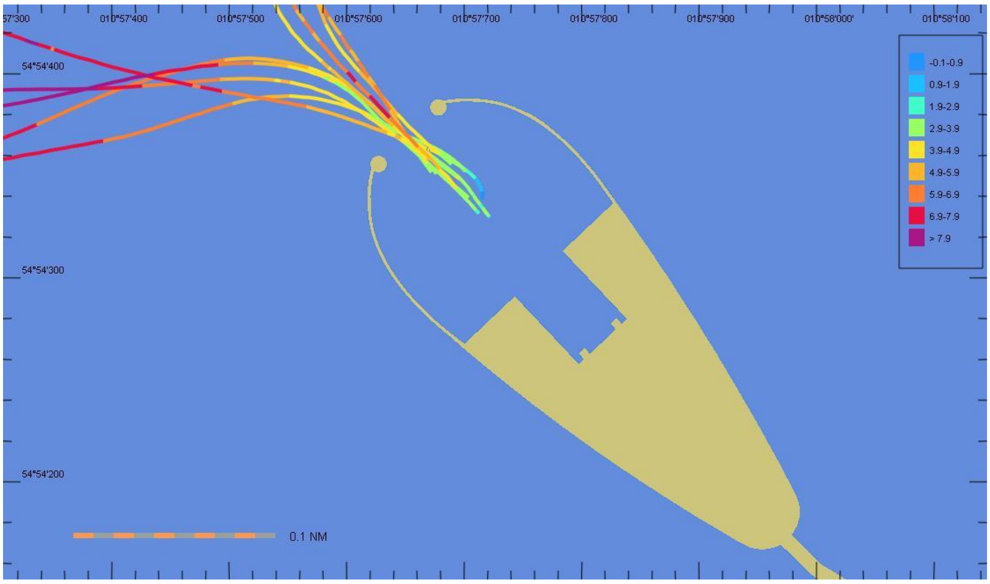


Figure 4-7 *Vessel bottom speed for simulations for Layout 2. Legend in knots.*

More details on the vessel tracks for the simulations are shown in Appendix B for Layout 2.

4.7.2 Layout 3 (north facing layout)

A summary of the results from Workshop No. 2 for Layout 3 is given below.

- Runs for case 1N were successful and desired operational limits were reached under safe manoeuvres.

- An additional case was proposed by the captain with wind and waves coming from west and current speed towards NE direction. Manoeuvres were safe and desired operational limits were achieved.

- Runs for case 3N with easterly wind and wave and current towards SW were unsuccessful with the vessel drifting and reaching the breakwater head in all simulations performed.

- Runs for case 4N with northerly wind and waves, and current towards SW were on the limit of the operational conditions according to the captain. The vessel entered the harbour but the speed and distance from breakwater could be deemed as unsafe depending on the crew.

- Vessel bottom speed at harbour entrance was in general between 4 and 7 knots depending on the conditions tested. Once the vessel was inside harbour and it was deemed that there would not be problems stopping the vessel and bringing it to berth, the simulations were stopped.

- The vessel approach strategy may not be ideal for some cases with high current speed in line with wind as the angle used to enter is too high and engines do not react fast enough or provide power enough to turn the vessel in time towards the harbour entrance.

More details on the vessel tracks for the simulations are shown in Appendix B for Layout 3.

The swept area for all simulations is shown below in Figure 4-8.

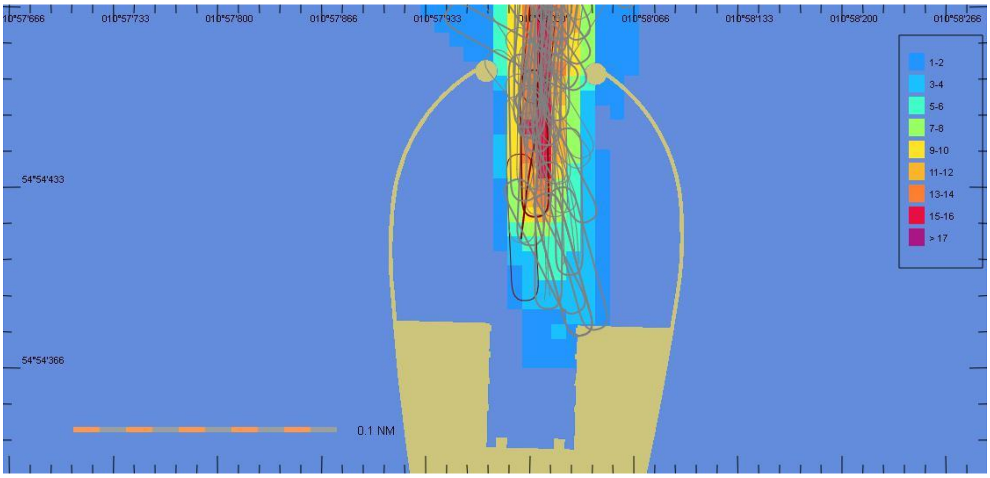


Figure 4-8 *Swept area for the simulations performed for Layout 3. Legend refers to number of simulations for which the vessel has sailed over a certain area.*

The vessel bottom speed is shown in Figure 4-9.

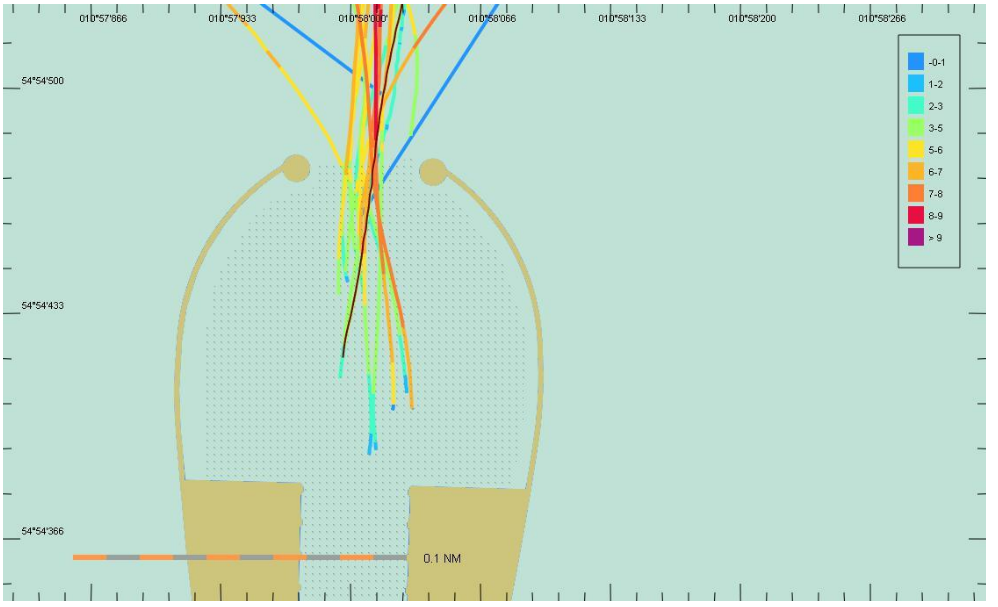


Figure 4-9 *Vessel bottom speed for simulations for Layout 3. Legend in knots.*

4.8 Additional simulations for Layout 3

In addition to the navigational simulations performed during Workshop No. 2, additional simulations for case 3N were performed to better assess the suitability of Layout 3 with regards to the navigational conditions. The additional simulations were performed by COWI. The following metocean input was applied:

- Wind coming from East equal to 10 m/s
- Waves coming from East (1Year Return Period H_s = 0.9 m and $T_p =$ 3.5 s)
- Current towards Southwest equal to 1 m/s speed

A total of 5 simulations were run without waves. Simulation run No.1 (vessel too close to breakwater) and No.4 (vessel crashing with breakwater) were considered as unsuccessful. The reason is likely to be the slow vessel speed at the harbour entrance which made the manoeuvres difficult and generated some drift hard to overcome. In the rest of the simulations, the vessel passes close to the breakwater but controlled and with about 7 m distance.

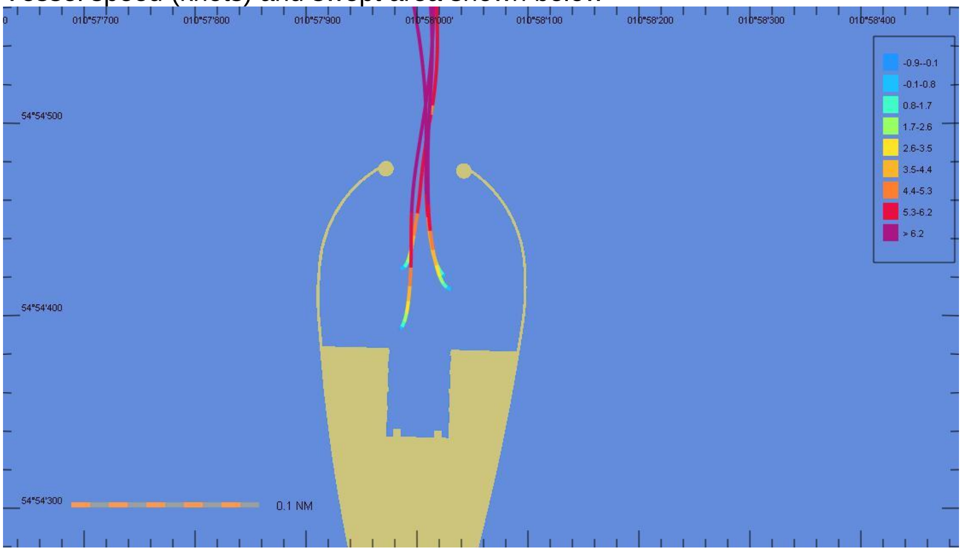
A second set of 3 simulations were run with the corresponding waves. All simulations were successful in terms of accessing the harbour with a safe speed and stopping before reaching the quay area, but the vessel drifted a lot and the distance between structures and vessel was small. A similar strategy as the one outlined in Workshop No.1 but in this case with aft azipods reversed to reduce vessel speed before the harbour entrance. In some cases, azipods were not reversed to reduce speed before harbour entrance and speed was reduced by reducing engine power. In these cases, it was easier to control the vessel at the entrance, as speed was not reduced as much as in the previous cases, but harder to stop once inside. It is recommended to test the vessel breaking capabilities before entering the harbour and to have a reduced speed when possible.

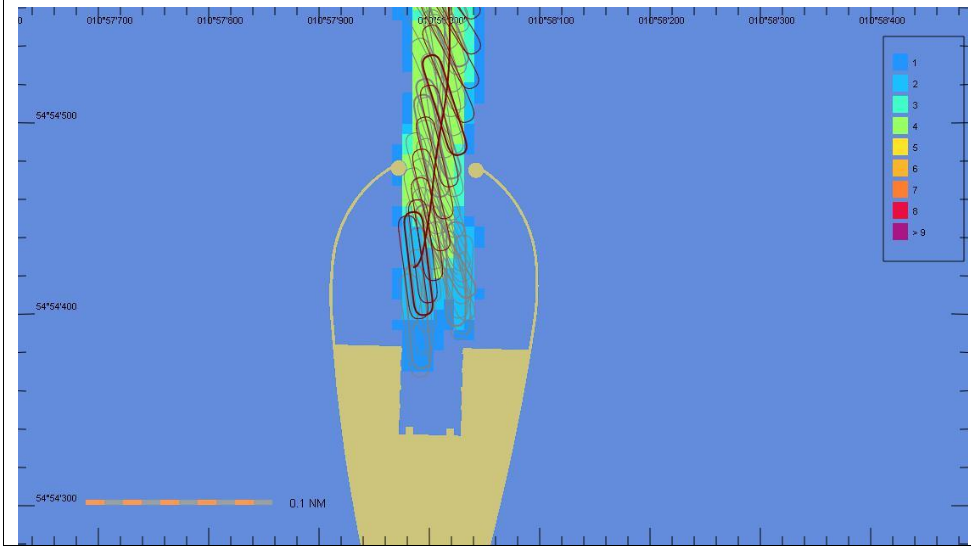
The conclusion derived from these additional simulations was that the vessel will be able to access the harbour although attention shall be put into controlling the distance between structure and vessel. It is assumed that Captains will be able to find a strategy which allows for a safe distance to structures.

Plots with vessel speed (knots) and swept areas are provided below for simulations run with and without waves.

General conditions
10 m/s wind from east
1 m/s current towards southwest

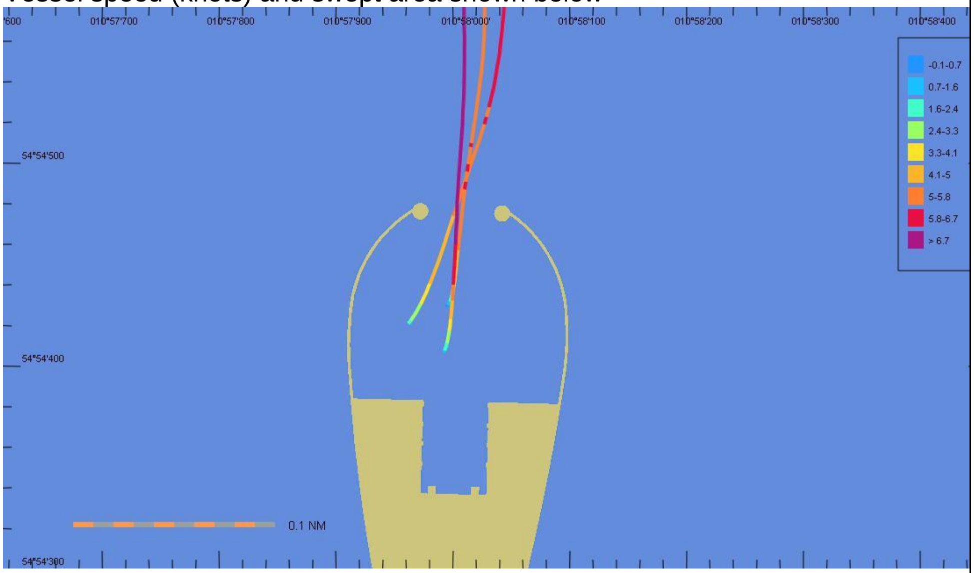
Successful runs with no waves
Vessel speed (knots) and swept area shown below

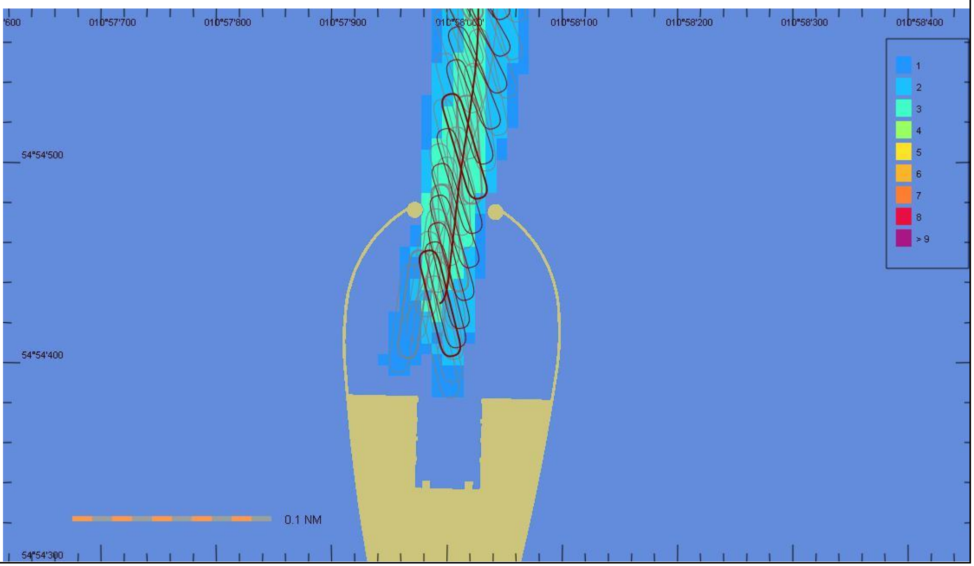




Runs with waves H_s=0.9m, T_p= 3.5s

Vessel speed (knots) and swept area shown below





4.8.1 Summary of performed simulations for Layout 3

A summary of all simulations performed for the North facing layout is given below in Figure 4-10.

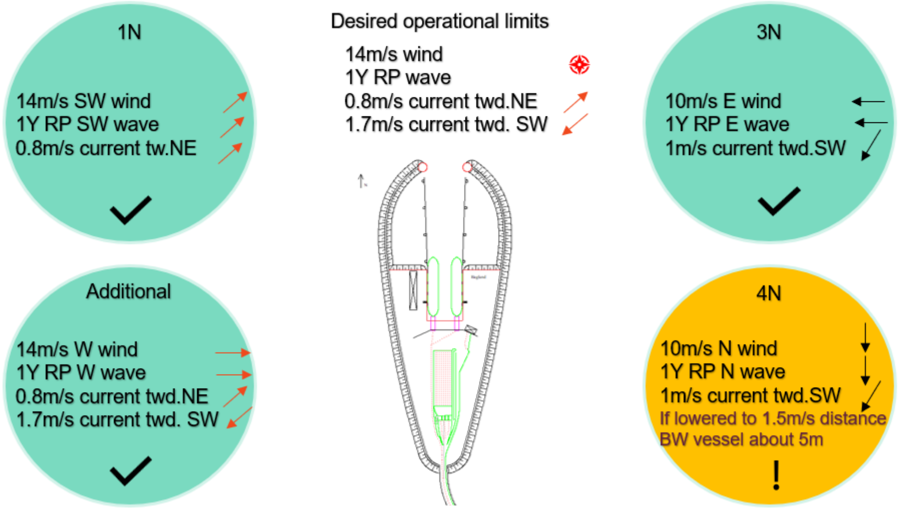


Figure 4-10 Summary of results from Workshop No.2 and additional runs by COWI for Layout 3. BW refers to breakwater head

5 Conclusions and recommendations

5.1 Manoeuvres

Based on the preliminary simulations, the two workshops with a Captain from FORCE Technology and the additional simulations performed by COWI, the arrival strategy selected is as below:

› For Layout 2 the vessel approaches from northwest and faces southern breakwater head when current comes from SW towards NE, where for Layout 3 the vessel approaches from north and faces the western breakwater. About 300 m from entrance the captain reverses the fore azipods and uses 50% power. The aft azipods are used to steer and use a bit of speed on this one 30%-40%. The ideal speed while entering the harbour is about 4 knots but can be higher in some instances. Full power is used to stop in the fore and about 30% in the aft (aft not reversing). This can be used for current coming from the opposite direction as well, directing the vessel towards the opposite breakwater head instead.

Note that strategy may be different depending on the crew. **It is always up to the captain to decide and plan safe manoeuvre.**

5.2 Navigation operational limits

The berthing and departure operational limits presented in Table 5-1, Figure 5-1 and Figure 5-2 are recommended for standard manoeuvring operations for Layout 2 (northwest facing harbour).

The berthing and departure operational limits presented in Table 5-2, Figure 5-3 and Figure 5-4 are recommended for standard manoeuvring operations for Layout 3 (north facing harbour).

Note that limits are set for a limited set of combinations of current speed/direction and wind speed/direction with associated waves. The number of simulations is especially limited for the Layout 2, which makes the limits uncertain. It is recommended to revisit these limits at a later stage of the project based on full mission simulations.

The simulations are used to set a preliminary estimates of operational limits which allow calculating an approximate downtime and highlighting the most favourable layout, see discussion in ref. /2/. The simulation scenarios were selected based on the most frequent conditions and the less favourable for navigations (for example beam on wind/current).

Table 5-1 Operational limits for Layout 2 (northwest facing layout) based on simulations.

Wind direction	90 °N to 270 °N		270 °N to 345 °N		345 °N to 90 °N	
Wave	1-Year Return Period in line with wind					
Current direction	NE	SW	NE	SW	NE	SW
Current speed	Up to 1.5 m/s	Up to 1.5 m/s*	Up to 1.5 m/s*	Up to 1 m/s**	Up to 1.5 m/s*	Up to 1 m/s**
Wind speed	Up to 14 m/s		Up to 14 m/s*	Up to 10 m/s**	Up to 14 m/s*	Up to 10 m/s**

*Assumed based on simulation limits for other cases but not simulated

**Wind speeds up to 14m/s might be achieved for lower cross current values. The max current limit for a 14m/s wind has not been evaluated

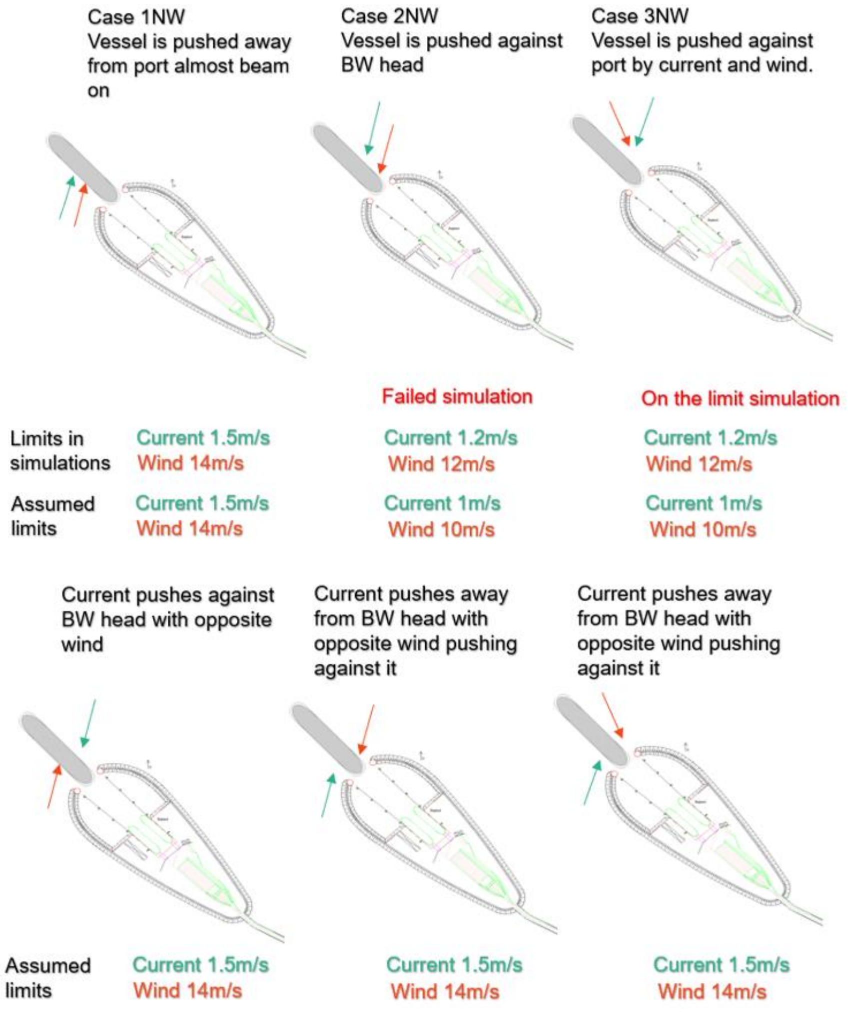


Figure 5-1 Limits found in simulations and limits assumed based on those for Layout 2.

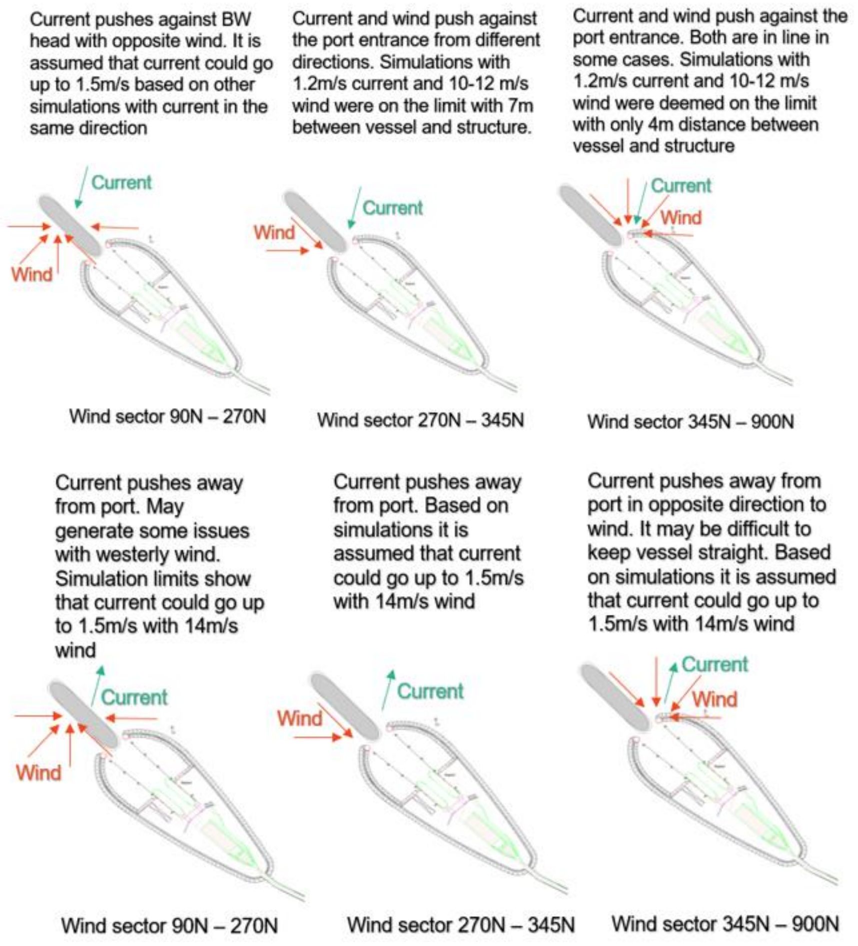


Figure 5-2 Limits found in simulations and limits assumed based on those by wind sectors (90 °N to 270 °N in left, 270 °N to 345 °N in middle and 345 °N to 90 °N in right side image) for Layout 2.

Table 5-2 Operational limits for Layout 3 (north facing layout) based on simulations.

Wind direction	120 °N to 300 °N		300 °N to 30 °N		30 °N to 120 °N	
Wave	1-Year Return Period in line with wind					
Current direction	NE	SW	NE	SW	NE	SW
Current speed	Up to 0.8 m/s	Up to 1.7 m/s	Up to 0.8 m/s*	Up to 1.2 m/s	Up to 0.8 m/s*	Up to 1 m/s
Wind speed	Up to 14 m/s		Up to 14 m/s*	Up to 10 m/s**	Up to 14 m/s*	Up to 10 m/s**

*Assumed based on simulation limits for other cases but not simulated

*Wind speeds up to 14 m/s could be achieved for lower cross current values. The max current limit for a 14 m/s wind has not been evaluated as this combination already provides an acceptable downtime.

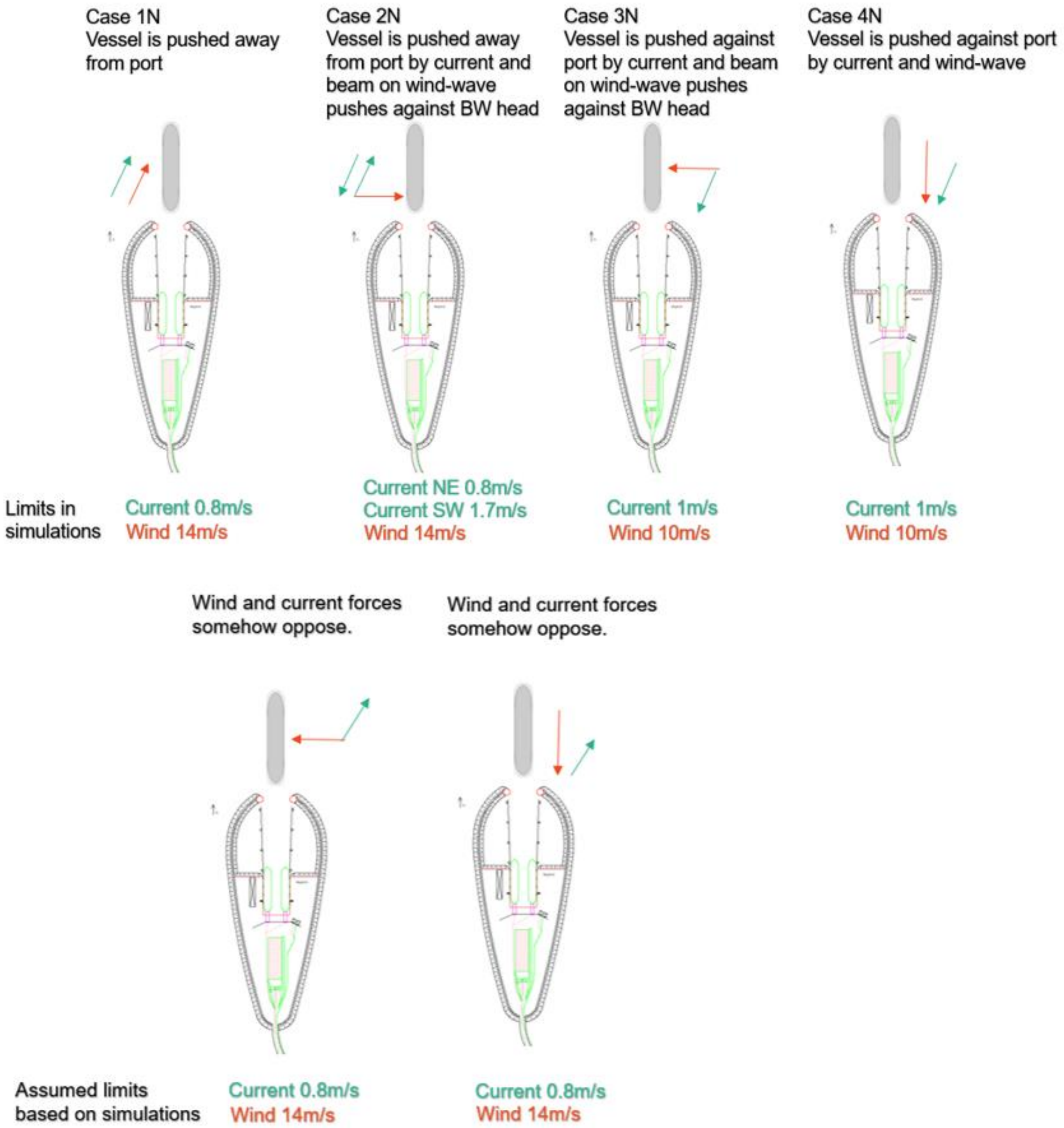


Figure 5-3 Limits found in simulations and limits assumed based on those for Layout 3.

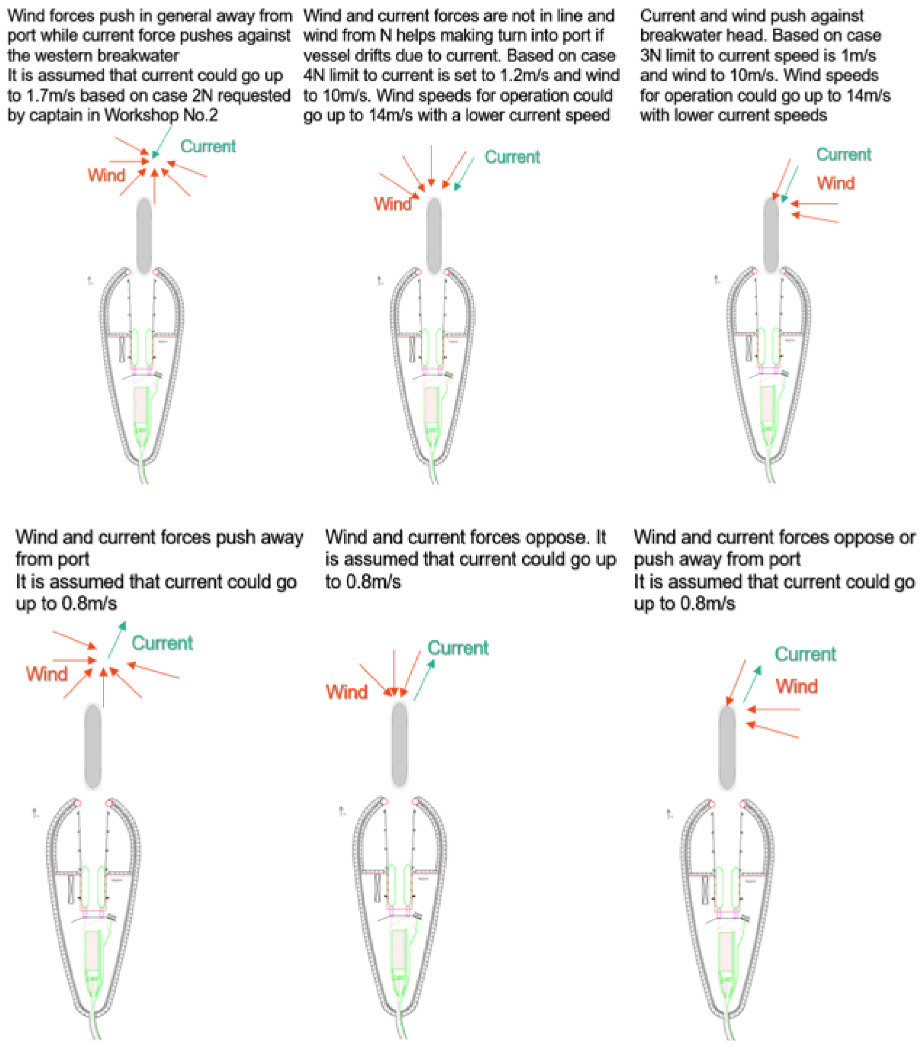


Figure 5-4 *Limits found in simulations and limits assumed based on those by wind sectors (120 °N to 300 °N in left, 300 °N to 30 °N in middle and 30 °N to 120 °N in right side image) for Layout 3.*

5.3 Conclusions and captain remarks

The captain mentioned that navigation for Layout 3 (north facing harbour) generally was easier compared to Layout 2 (northwest facing harbour). This was also expected by looking at the current speed values towards southwest direction for both layouts and because the current direction is approximate perpendicular to the harbour entrance leading to unfavourable navigational conditions.

The navigation is generally driven by the high current speed near the harbour entrance, making it challenging and on occasions unsafe to enter both Layout 2 and 3, but especially Layout 2 due to the strong cross current.

Based on the captains' comments, the performed navigational simulations and the operational limits presented in section 5.2 it is assessed that Layout 3 is most favourable with regards to approaching and entering the harbour. For assessment of the downtime based on the proposed operation limits refence is made to ref. /2/.

The captain from FORCE Technology, who performed the navigational simulations for the two workshops, made the following general remarks, where some should be considered in further studies:

- That the vessel model power being limited and below expected values for a real vessel. This implies that the **simulation results are conservative** and that the operational limits set based on these could potentially be relaxed.

- Simulations were performed for daylight scenarios. Low visibility and night simulations are recommended for future project stages along with additional simulations to better cover the range of different metocean conditions. Full mission simulation is advised.

- Captains generally use cameras on the vessel during manoeuvres, which are close to structures, to allow for safer manoeuvring, but also to better utilize the harbour entrance width. Cameras are not represented in the simulations, making the simulations conservative.

- Simulations were performed by a single captain. It is expected that during ferry operation, the captain will be accompanied by an official and manoeuvres will be discussed and assessed by two persons. This may result in a change of strategy.

- Suitable lightning is required for both low visibility, night and day navigation. As a minimum a leading light at the centre of the quay and lights along the fender line is required.

- The current harbour entrance and inner basin width should not be decreased.

- The distance between quay and harbour entrance (set as ~1.7LOA) is deemed safe for vessel stopping and berthing manoeuvres for the performed simulations. The distance shall not be reduced.

- It is suggested to install Duc d´Albes (guiding piles) inside the harbour, which can be used by the captain to guide the vessel towards the fender line and quay and to protect it from contact with the breakwater.

6 References

/1/ **COWI**
A258774-HAV-RAP-01 Wave Transformation and Tranquility
2025.

/2/ **COWI**
A258774-HAV-RAP-03 Tårs-Konceptdesign af havn og dæmninger
2025.

Appendix A Run-matrix Workshop No.2

Table A-1 shows the Run matrix used in Workshop No. 2.

Table A-1 Run matrix for workshop No.2

Scenario	Ship			Tug Assistance	Other Traffic	Manoeuver		Operator	Wind 1)		Significant Wave			Current			Current MAP	RUN No.	time	Safety Level	Remark
No.	No.	Type	Loading condition	(Yes/No)	(Yes/No)	Type	Berth	Initials	Speed (m/s)	From	Height (m)	Period (s)	From	Speed (knot)	Speed (m/s)	Going	Scaling factor	WORKSHOP	hh:mm	1-5	Pilot comments
																	NORTH FACING PORT LAYOUT				
1N	3618	Ferry	Service condition	No	No	Approcah	EITHER	Jakob Møller	8	210	1.6	6	210	1.6	0.8	30	1	1	09:21	2-3	The mathematical model is conservative. If you manage to do it here you can do it in reallife: Try to fix the speed of the vessel as it only shows in the OCC screen but not in the instrument screen (call Christian). Test brakes before entering because we need the time to reverse the thrusters. you should be able to stop this ship type in 1.5LOA length but for safety it is recommended to test brakes before entering port. Captain is reversing the aft thrusters from about 200m before port. He is not fully satisfied with vessel model as the engines should be more powerful. 80% power should do 8knots not 3-4 but the current force is no problem in this case. Controlled manoeuver and safe. the vessel is still drifting inside most likely because of the waves (not changed inside) otherwise not expect any movement .
1N	3618	Ferry	Service condition	No	No	Approcah	EITHER	Jakob Møller	8	210	1.6	6	210	1.6	0.8	30	1	1	09:49	2-3	Very conservative model. This does not reflect reality as vessel is very weak in the model
1N	3618	Ferry	Service condition	No	No	Approcah	EITHER	Jakob Møller	12	210	1.6	6	210	1.6	0.8	30	1	2	10:11	2-3	Controls are forward in 0 -30 deg full power and aft reversed to 120 50% power. Should never go ahead 100% power, only 80%. Not realistic. Wave set to 0 inside port. Could be set as an event line
1N	3618	Ferry	Service condition	No	No	Approcah	EITHER	Jakob Møller	14	210	1.6	6	210	1.6	0.8	30	1	3	10:19	2-3	No problem
Additional case requested by Captain. Modification of 2N	3618	Ferry	Service condition	No	No	Approcah	EITHER	Jakob Møller	10	270	1.6	6	270	1.3	0.7	210	0.4	4	10:36	2-3	Current is higher coming from south from captains experience. 25m from BW is down to 1knot. Need to set a mark in the middle of the port for navigation Leading Light visible in day time as well
	3618	Ferry	Service condition	No	No	Approcah	EITHER	Jakob Møller	14	270	1.6	6	270	1.3	0.7	210	0.4	5	10:46	2-3	Waves are turned to 0 inside port. Power used all the way to 100%
	3618	Ferry	Service condition	No	No	Approcah	EITHER	Jakob Møller	14	270	1.6	6	270	1.3	0.7	210	0.4	6	11:05	2-3	Waves are turned to 0 inside port. Power used all the way to 100%. You need speed to control the ferry.
	3618	Ferry	Service condition	No	No	Approcah	EITHER	Jakob Møller	14	270	1.6	6	270	3.3	1.7	210	1	23	15:35	2-3	OK AND SAFE. FULL POWER USED
	3618	Ferry	Service condition	No	No	Approcah	EITHER	Jakob Møller	14	270	1.6	6	270	1.6	0.8	30	1	7	11:12	2-3	Waves are turned to 0 inside port. Power used all the way to 100%. You need speed to control the ferry.
3N	3618	Ferry	Service condition	No	No	Approcah	EITHER	Jakob Møller	14	90	0.9	3.5	90	3.3	1.7	210	1	8	11:21	5	FAILED. REDO . COMMENT ON REAL STOPPING SPEED INSIDE PORT WILL BE HIGHER IN REALITY
3N	3618	Ferry	Service condition	No	No	Approcah	EITHER	Jakob Møller	14	90	0.9	3.5	90	3.3	1.7	210	1	9	12:21	5	Not safe. Go down in wind speed 10 to 12m/s and current to 2.5 knots
3N	3618	Ferry	Service condition	No	No	Approcah	EITHER	Jakob Møller	10	90	0.9	3.5	90	2.6	1.4	210	0.8	10	12:33	5	Change of strategy. It has not enough power to turn in the last minute after going against the current. Fail
4N	3618	Ferry	Service condition	No	No	Approcah	EITHER	Jakob Møller	14	0	1.2	4.5	0	3.3	1.7	210	1	24	15:50	5	CRASH
4N	3618	Ferry	Service condition	No	No	Approcah	EITHER	Jakob Møller	14	0	1.2	4.5	0	3.3	1.7	210	1	25	15:53	4	Able to enter but requires such high speed that probably not deemed safe by captains
4N	3618	Ferry	Service condition	No	No	Approcah	EITHER	Jakob Møller	12	0	1.2	4.5	0	2.6	1.4	210	0.8	11	12:48	4	VERY RISKY END MANOEUVER TO ENTER. THE FERRY CAN BE STOPPED MORE EASILY IN REAL LIFE.
4N	3618	Ferry	Service condition	No	No	Approcah	EITHER	Jakob Møller	10	0	1.2	4.5	0	2.6	1.4	210	0.8	12	12:54	4	IN THE LIMIT. NOT MUCH POWER IN THE SHIP CANNOT USE THE RIGHT STRATEGY. IN REAL LIFE 10m/s wind should be ok and current should not be an issue
4N	3618	Ferry	Service condition	No	No	Approcah	EITHER	Jakob Møller	10	0	1.2	4.5	0	1.0	0.5	210	0.3	13	13:04	4	With this conditions should be possible still a bit on the limit and depending on other factors such as visibility. If reduced visibility is too risky to perform.
																	NORTH WEST FACING PORT LAYOUT				
1NW	3618	Ferry	Service condition	No	No	Approach	EITHER	Jakob Møller	10	210	1.6	6	210	1.5	0.8	30	0.5	14	13:14	2-3	OK AND SAFE
1NW	3618	Ferry	Service condition	No	No	Approach	EITHER	Jakob Møller	12	210	1.6	6	210	2.3	1.2	30	0.8	15	13:23	2-3	OK AND SAFE
1NW	3618	Ferry	Service condition	No	No	Approach	EITHER	Jakob Møller	14	210	1.6	6	210	2.3	1.2	30	0.8	16	13:30	2-3	OK AND SAFE
1NW	3618	Ferry	Service condition	No	No	Approach	EITHER	Jakob Møller	14	210	1.6	6	210	2.9	1.5	30	1	17	13:58	2-3	OK AND SAFE
2NW	3618	Ferry	Service condition	No	No	Approach	EITHER	Jakob Møller	12	345	1.2	4.5	345	2.2	1.2	210	0.5	20		5	VERY CLOSE TO BW SOUTH
2NW	3618	Ferry	Service condition	No	No	Approach	EITHER	Jakob Møller	12	345	1.2	4.5	345	2.2	1.2	210	0.5	21		4	Very close to bw
2NW	3618	Ferry	Service condition	No	No	Approach	EITHER	Jakob Møller	12	345	1.2	4.5	345	2.2	1.2	210	0.5	22		4	Change in strategy for approaching angle. 7 m from BW (N). THE VESSEL REACTS WAY TOO SLOW
3NW	3618	Ferry	Service condition	No	No	Approach	EITHER	Jakob Møller	10	30	1.2	4.5	30	2.2	1.2	210	0.5	18	14:05	4	Limit with breakwater (N) . FULL POWER USED
3NW	3618	Ferry	Service condition	No	No	Approach	EITHER	Jakob Møller	12	30	1.2	4.5	30	2.2	1.2	210	0.5	19	14:13	4	Fore end of the vessel 4.5 m from breakwater so close. We should be able to do this with 14m/s in real life

The general comments from the workshop are given below:

- The initial vessel speed was set at 8 knots.
- Vessel speed at the harbour entrance was in general around 4 knots, but higher for some simulations.
- The captain commented that the engine power felt low and that in reality there would be more power available for the vessel.
- A leading light shall be included at the middle of the quay. The light shall be visible during day. Furthermore, leading lights should also be installed along the fenderline to make it easier for the captains to position the vessel for berthing.
- 100% power was required in some simulations, while in practice it is recommended to only apply 80%. This is likely linked to the potential lower engine power of the vessel model.
- The mathematical model is conservative and if one manages to enter the harbour safely in the simulations, then it is generally more than possible in real life.
- It is possible to stop the vessel in 1.5LOA length, but for safety it is recommended to perform braking tests outside the harbour before trying to enter a potential new offshore harbour.
- Night and low visibility simulations shall be performed at a later stage of the project.

Appendix B Images from Workshop No. 2

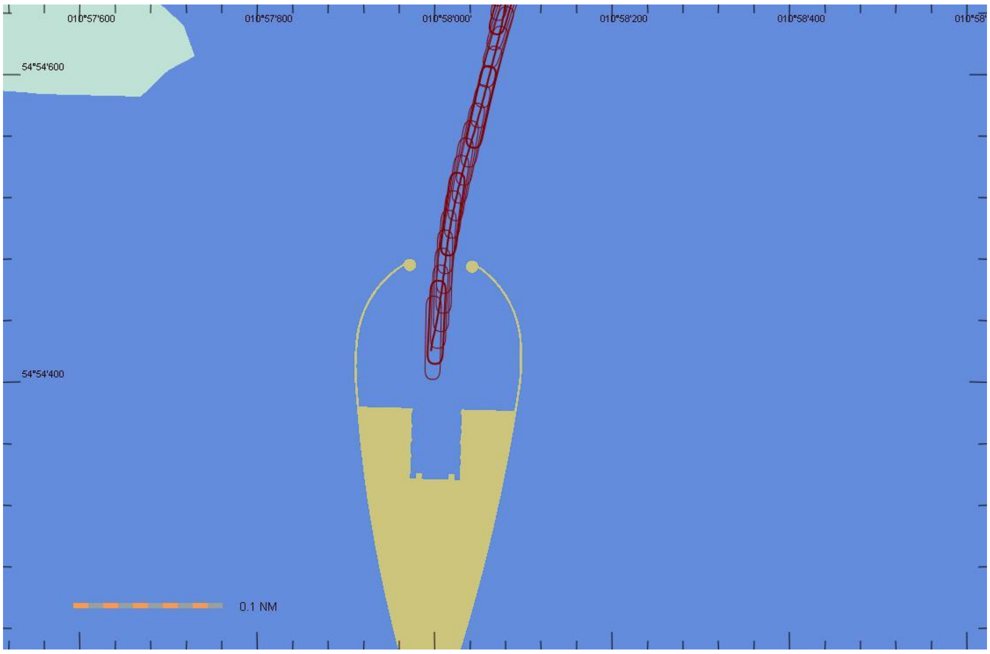


Figure B-1 Simulation No.1

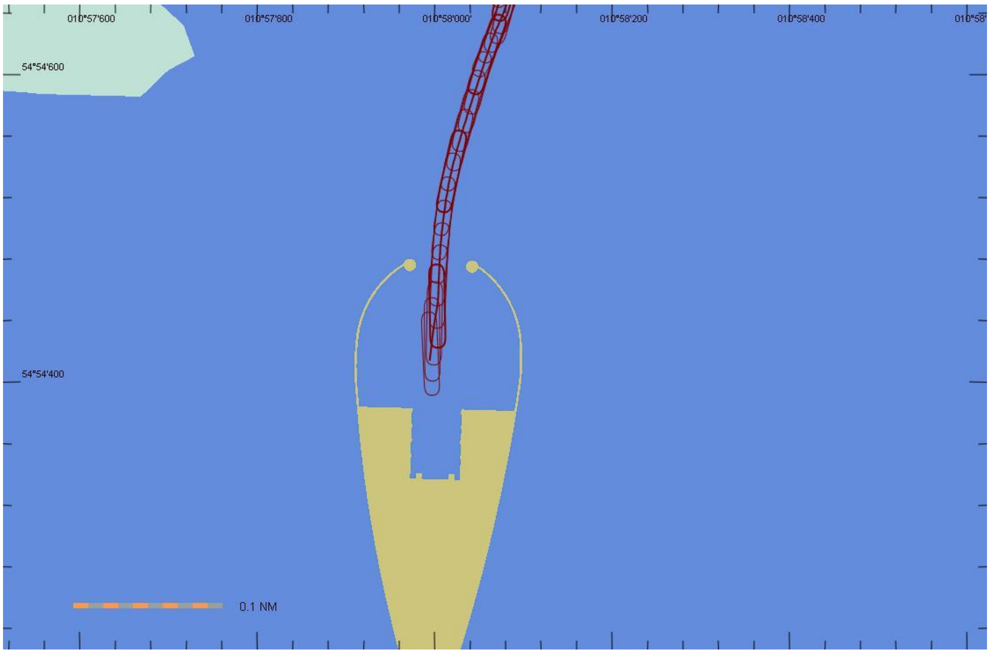


Figure B-2 Simulation No.2

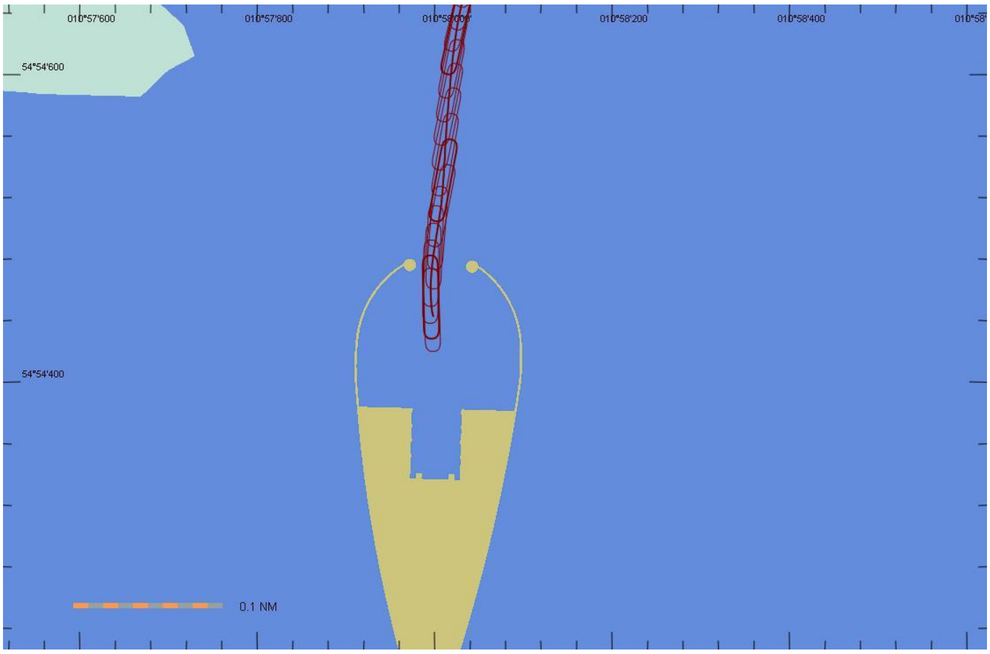


Figure B-3 Simulation No.3

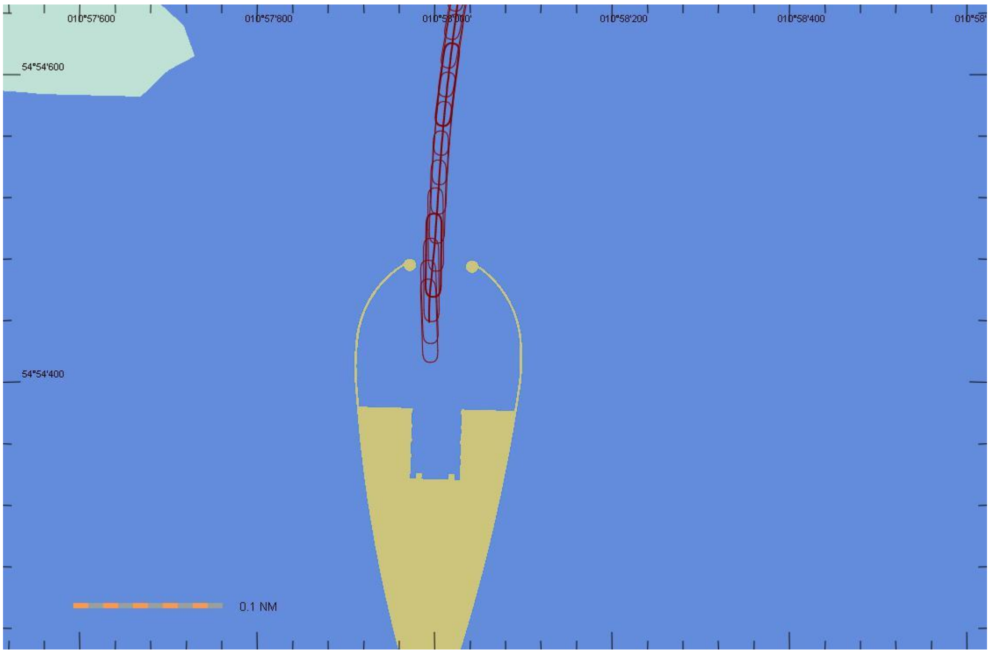


Figure B-4 Simulation No.4

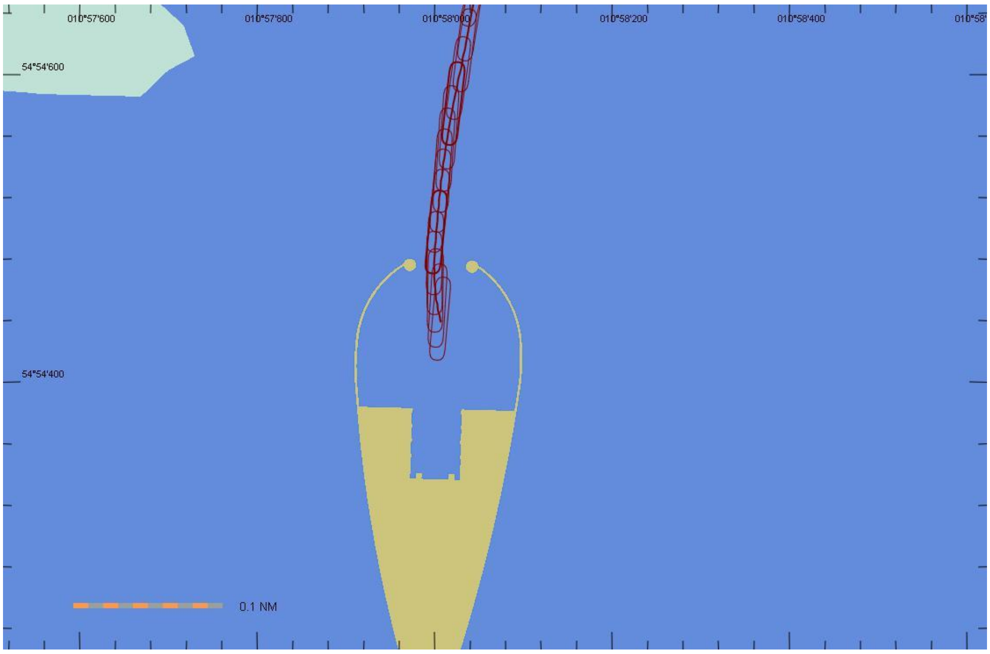


Figure B-5 Simulation No.5

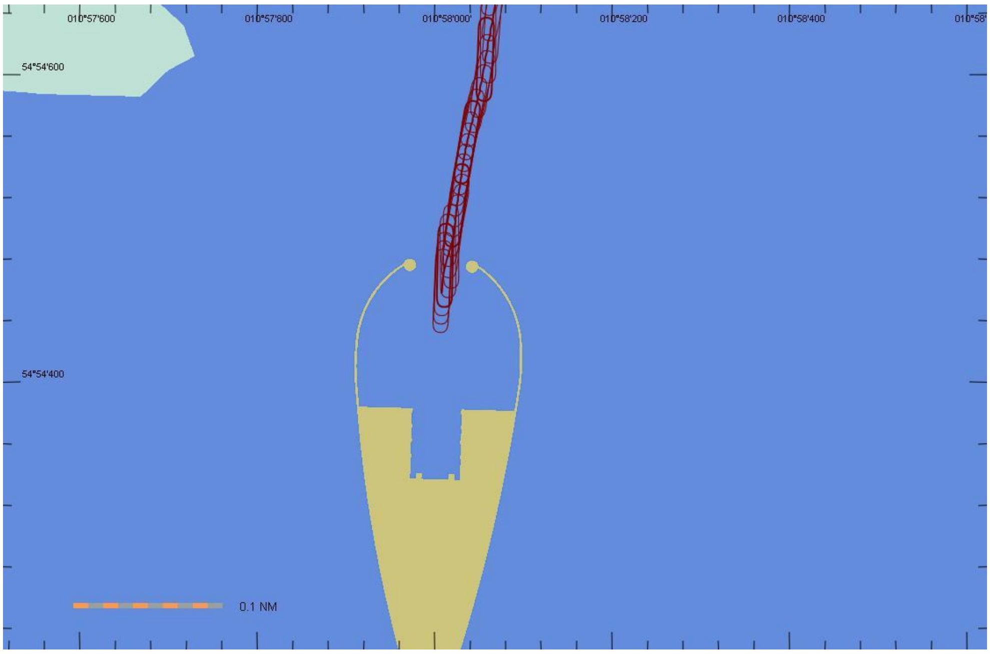


Figure B-6 Simulation No.6

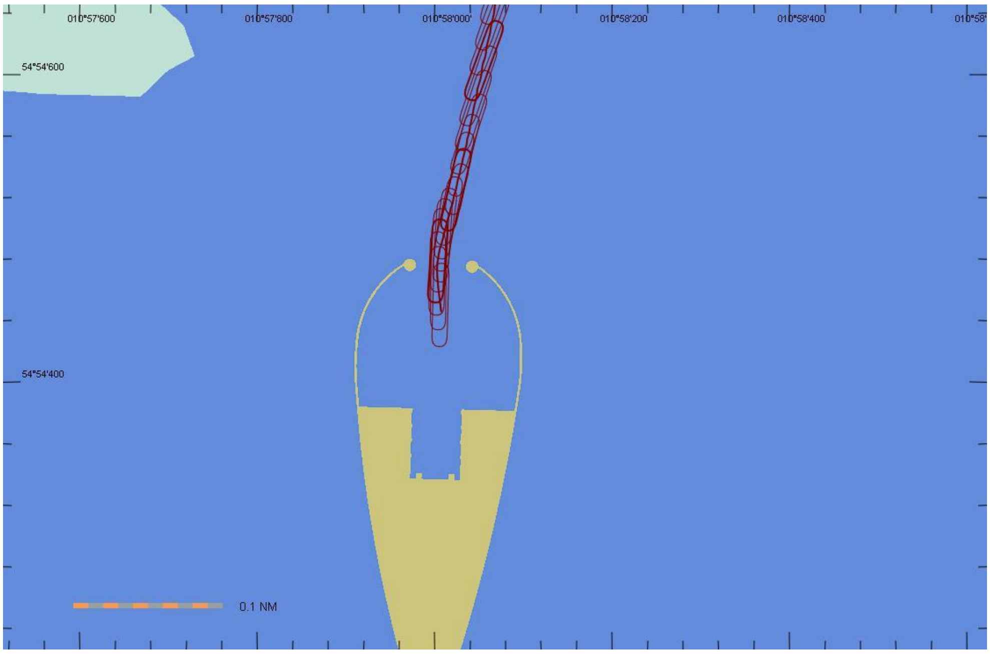


Figure B-7 Simulation No.7

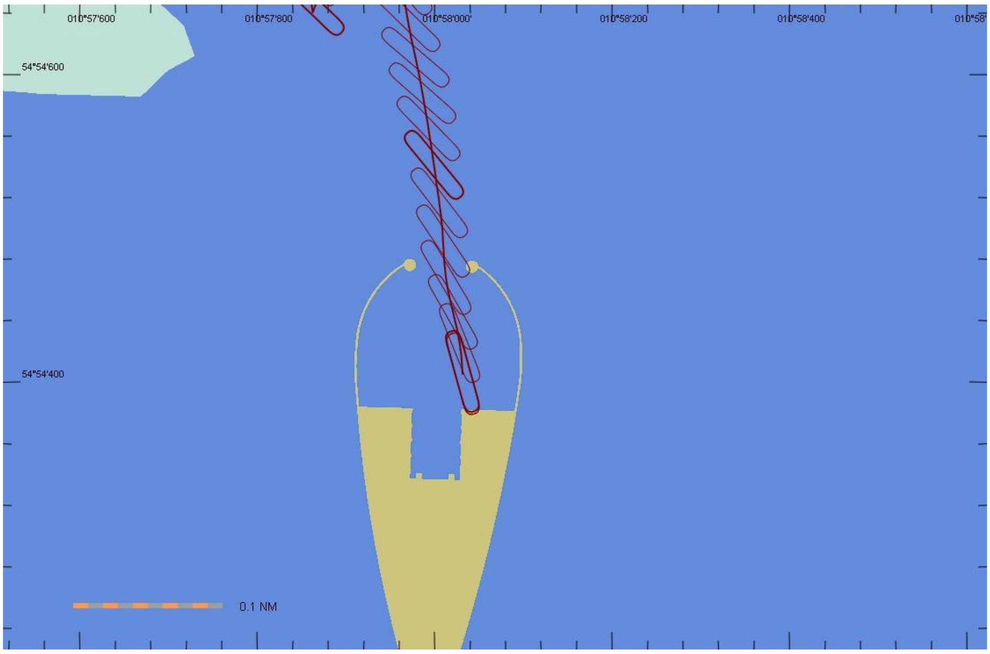


Figure B-8 Simulation No.8

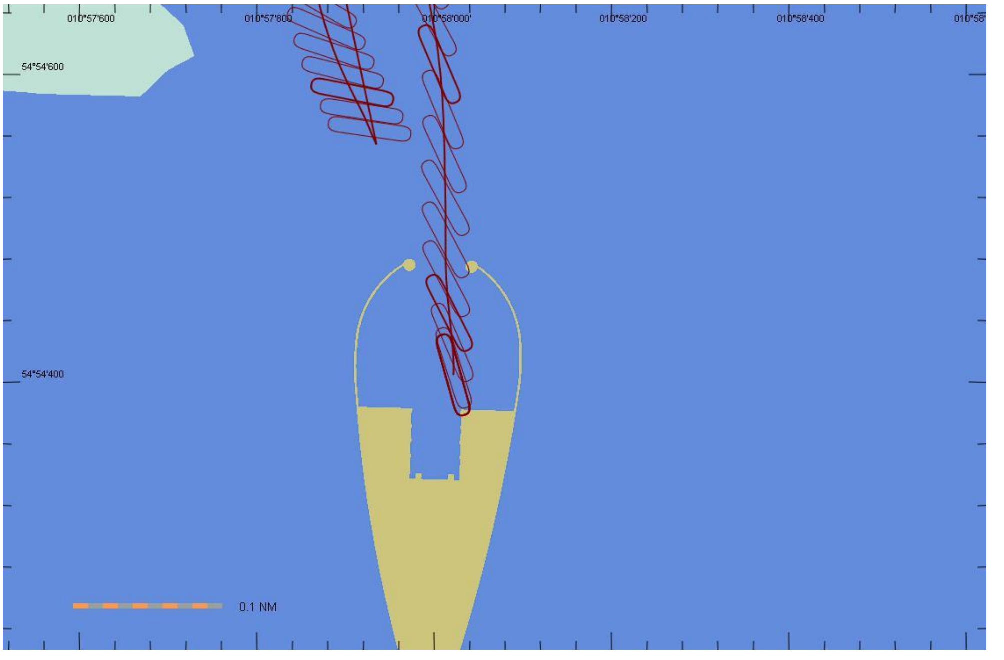


Figure B-9 *Simulation No.9*

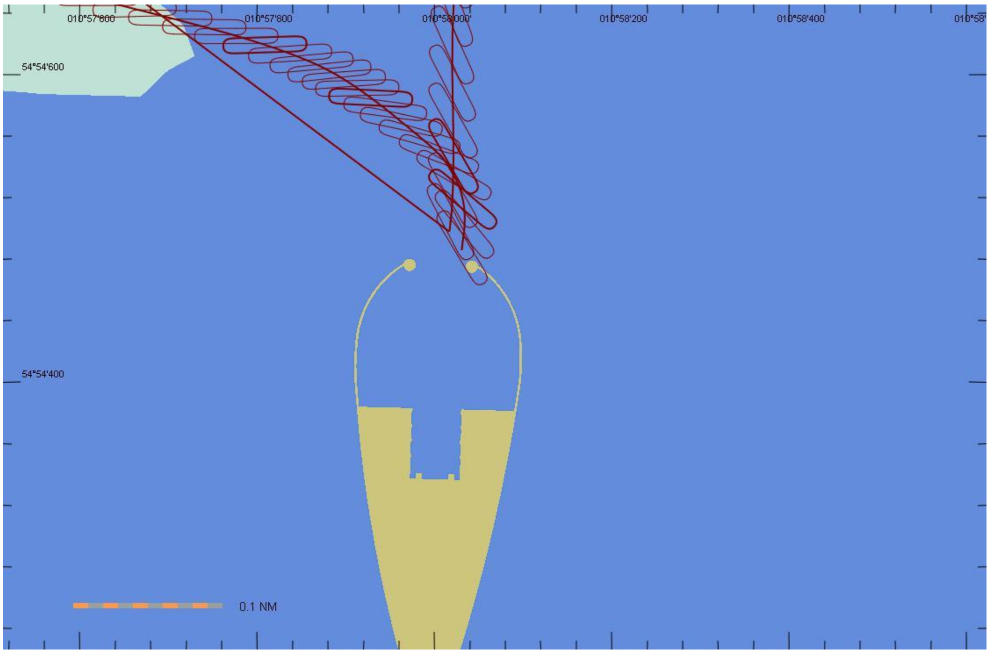


Figure B-10 *Simulation No.10*

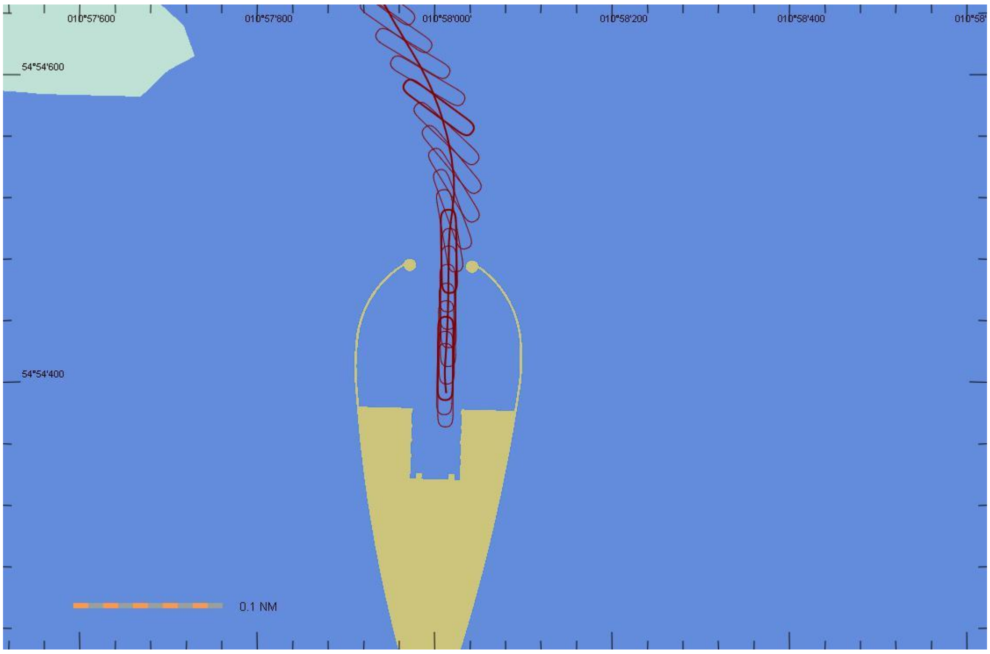


Figure B-11 Simulation No.11

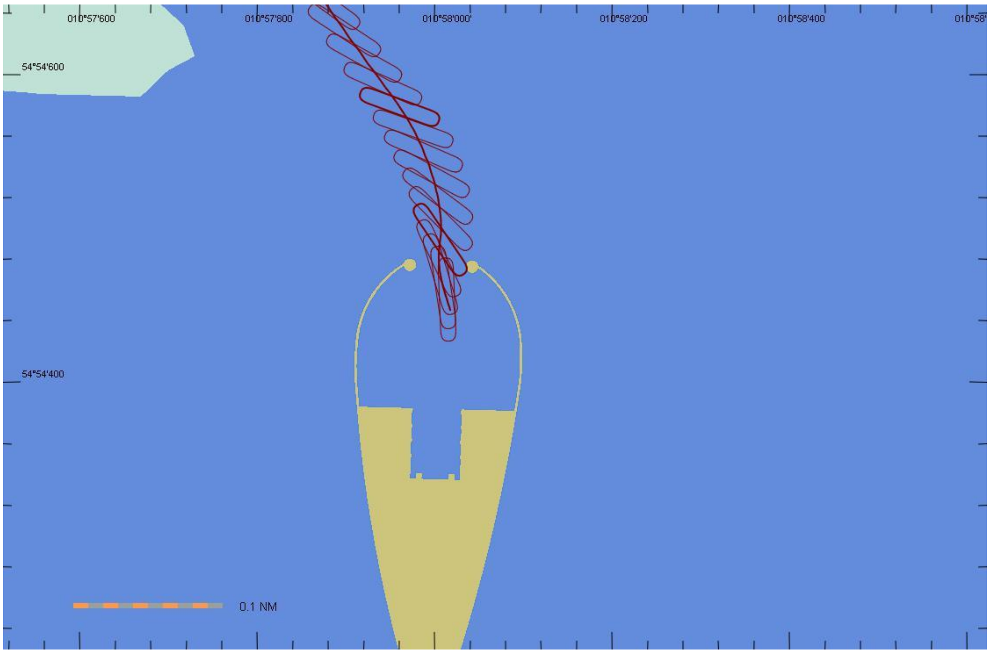


Figure B-12 Simulation No.12

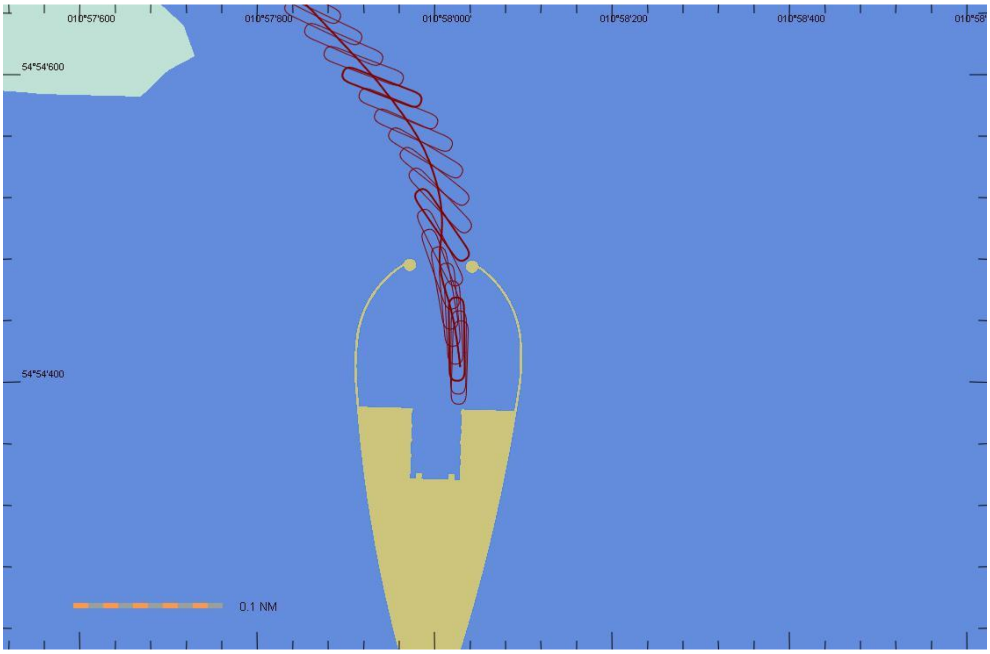


Figure B-13 Simulation No.13

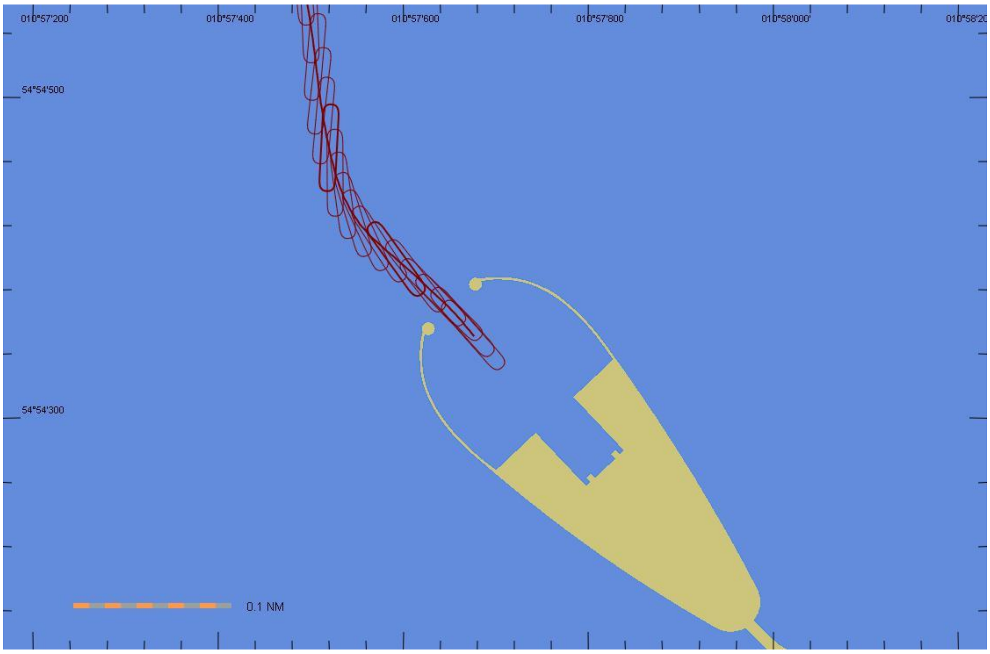


Figure B-14 Simulation No.14

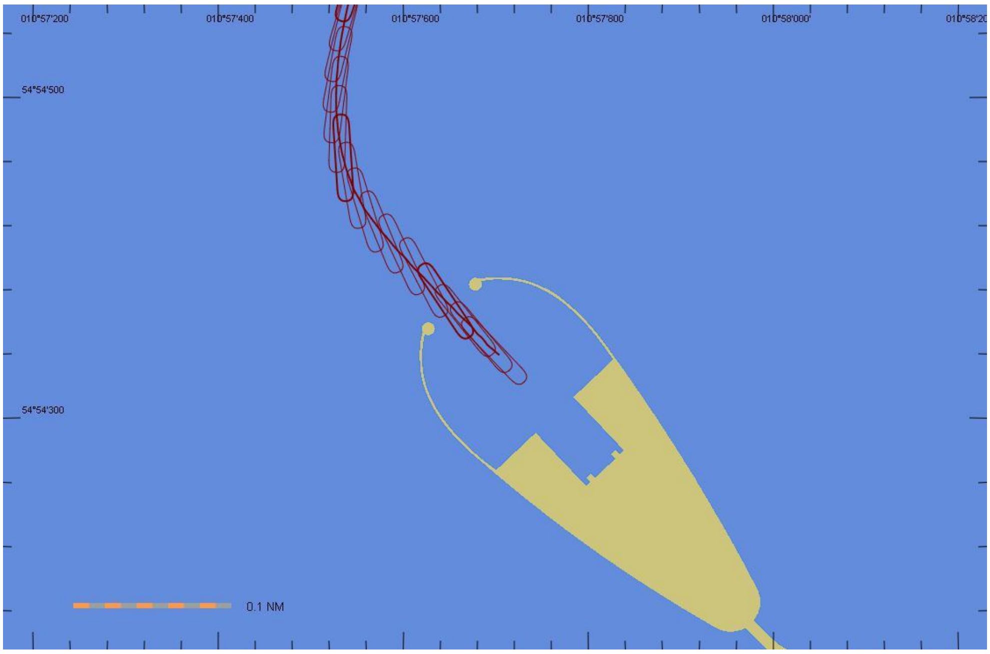


Figure B-15 *Simulation No.15*

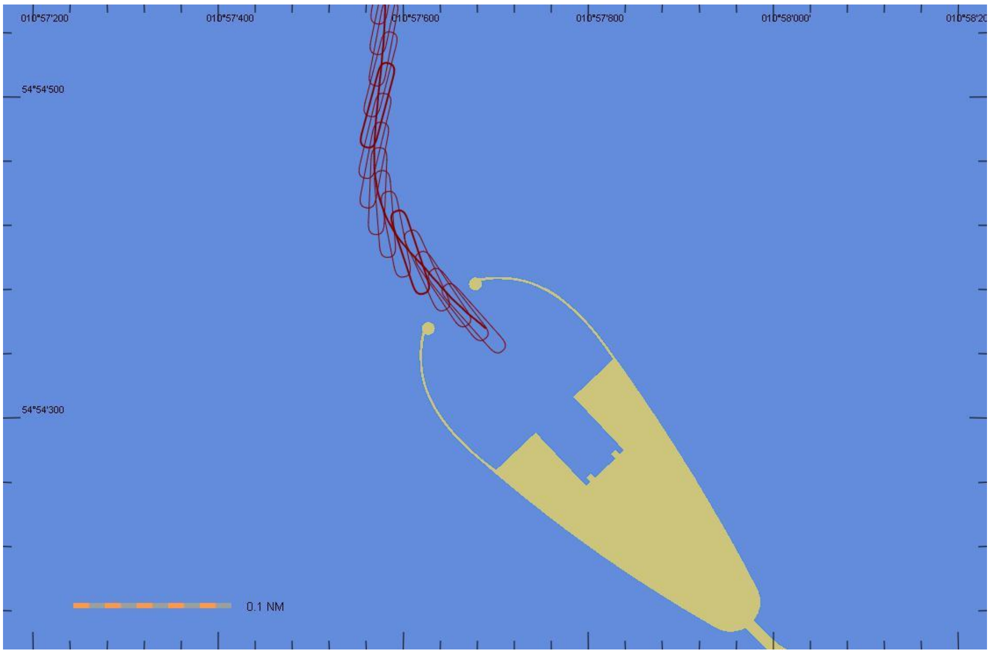


Figure B-16 *Simulation No.16*

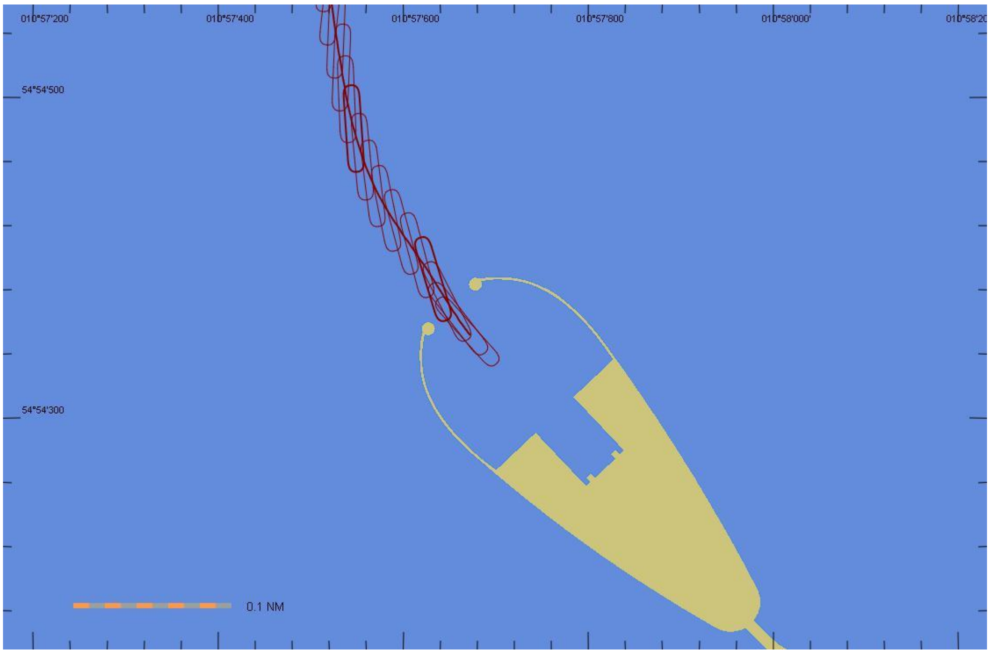


Figure B-17 Simulation No.17

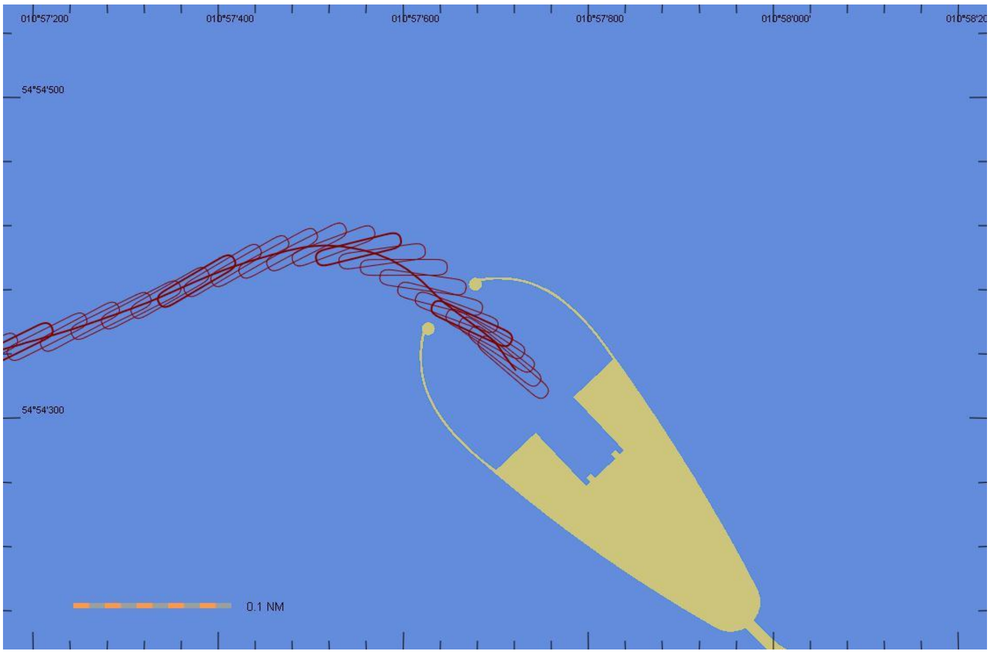


Figure B-18 Simulation No.18

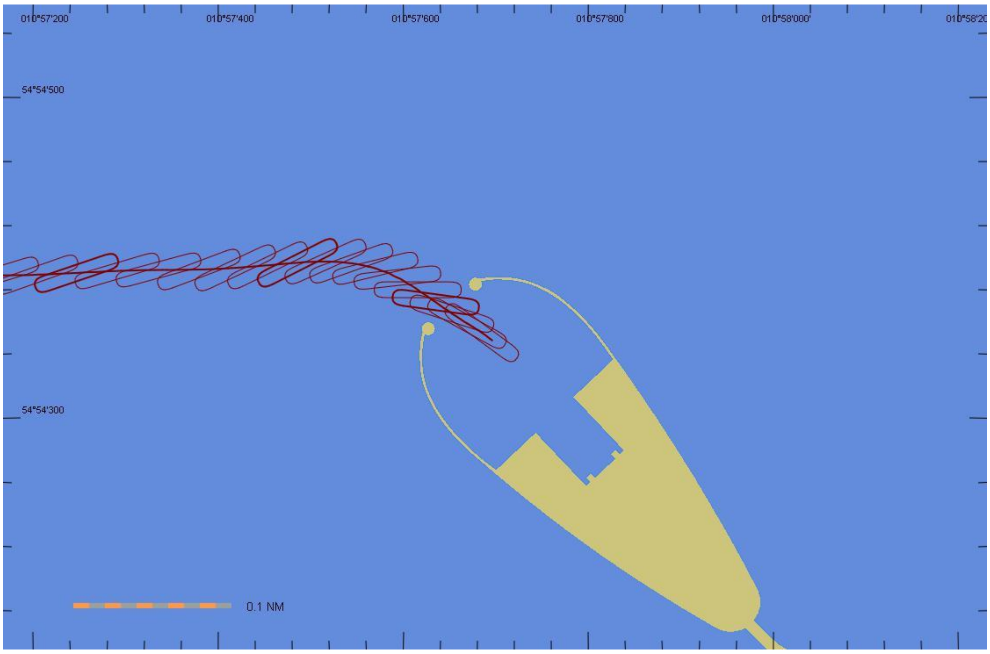


Figure B-19 Simulation No.19

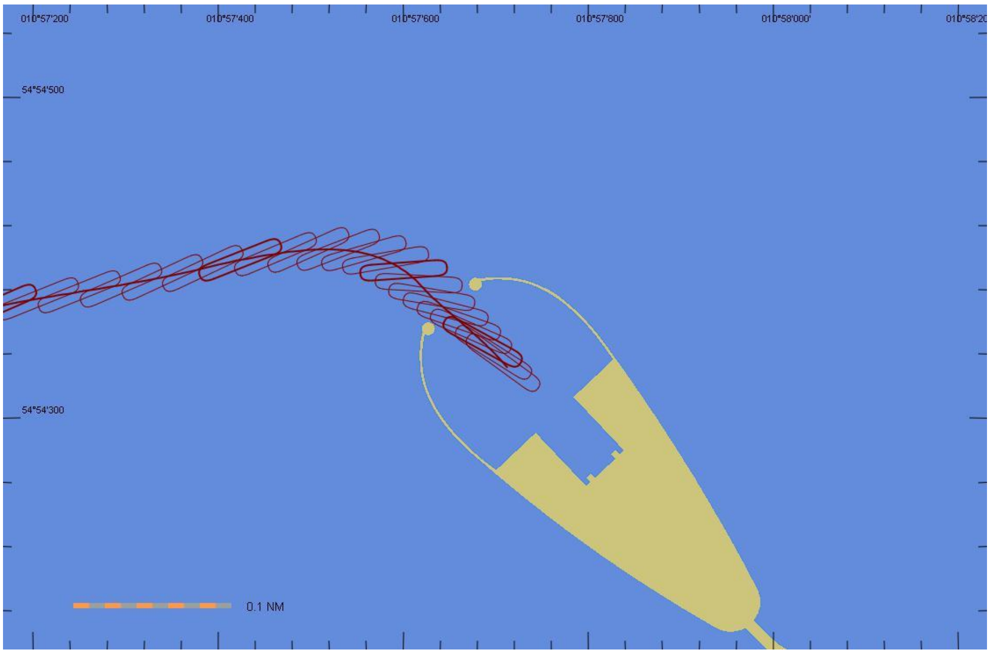


Figure B-20 Simulation No.20

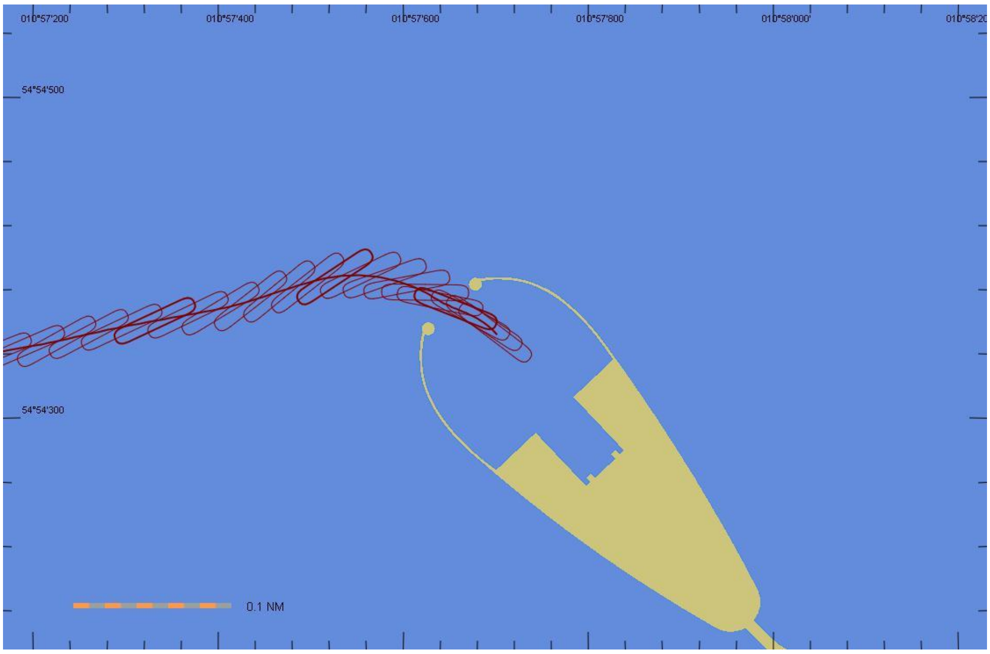


Figure B-21 Simulation No.21

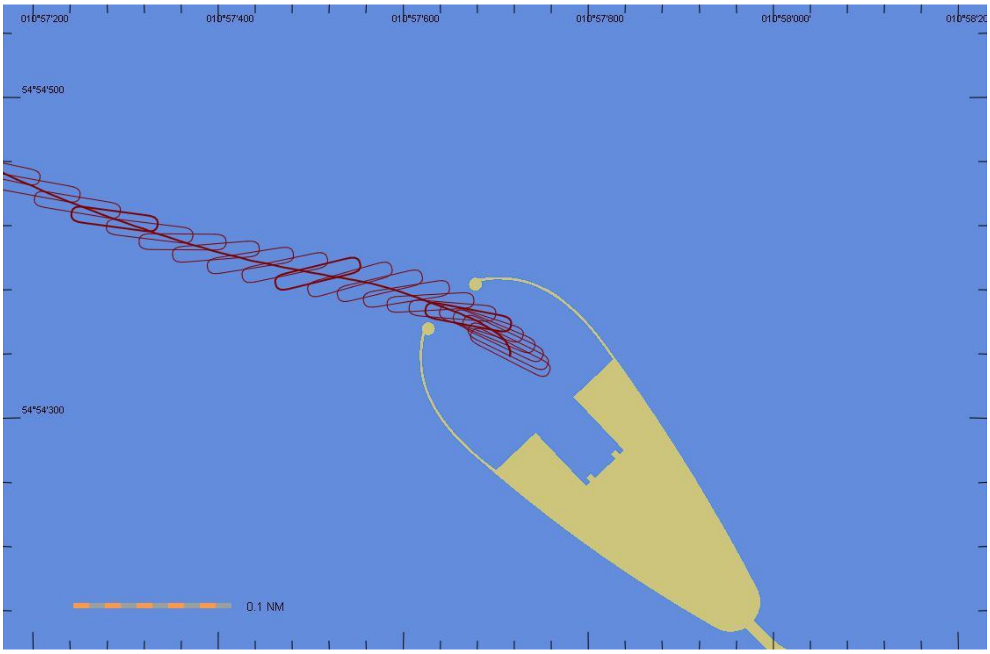


Figure B-22 Simulation No.22

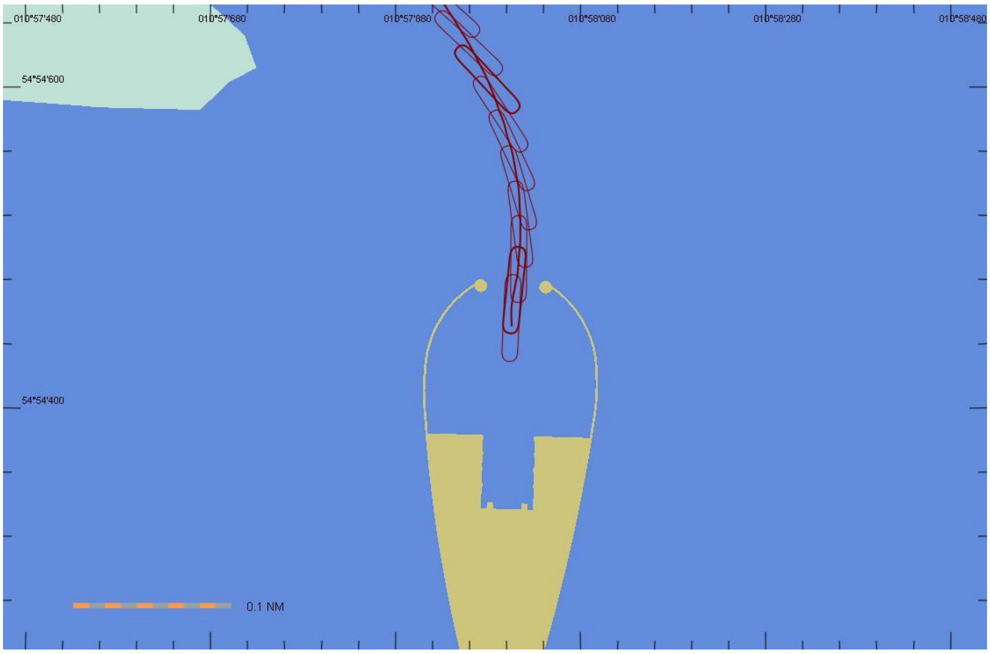


Figure B-23 Simulation No.23

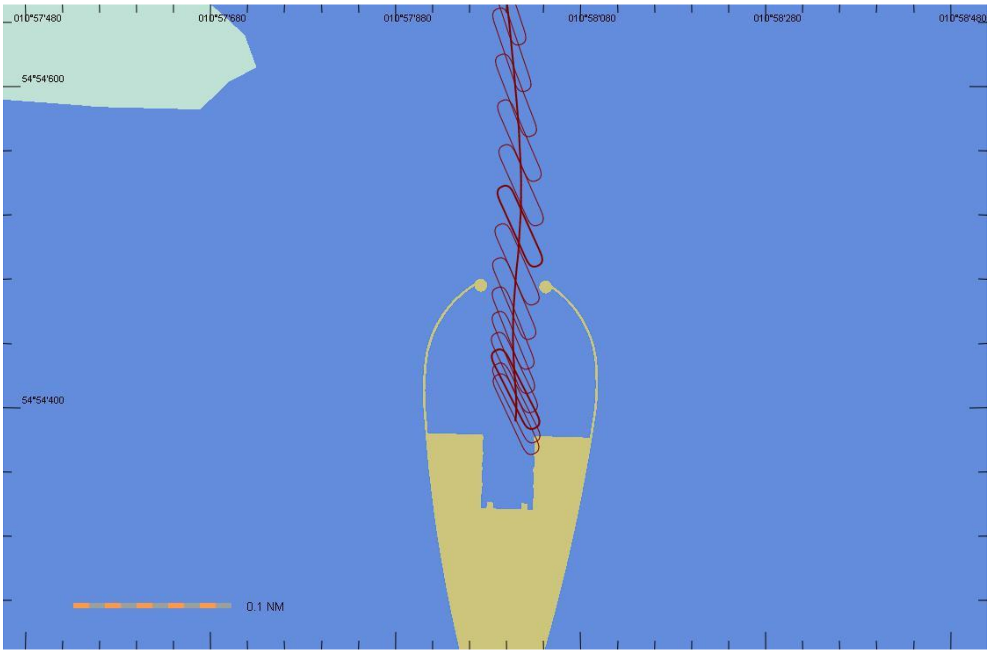


Figure B-24 Simulation No.24

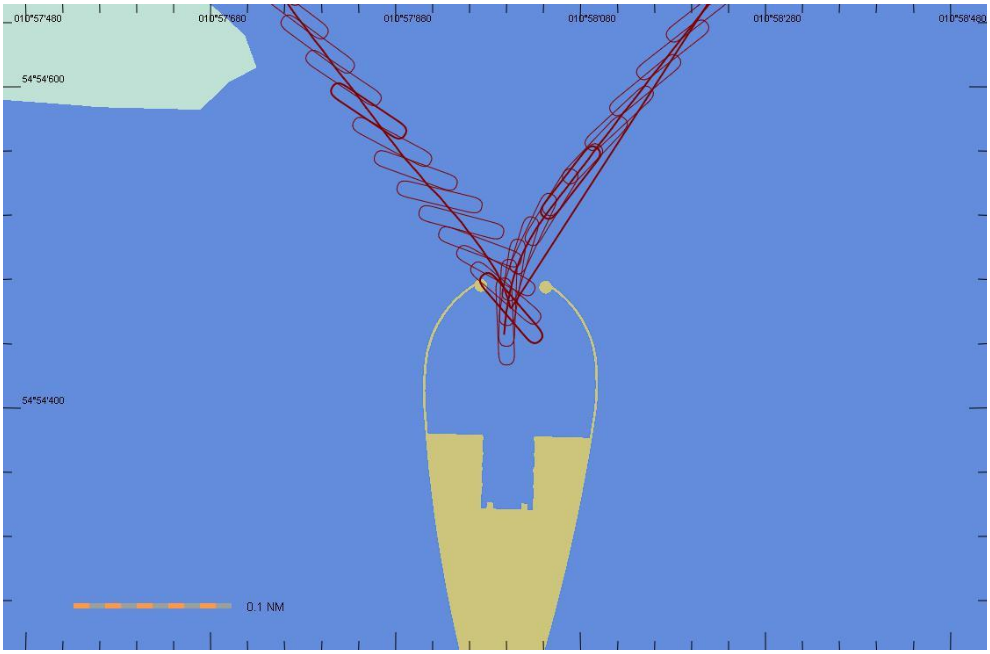


Figure B-25 *Simulation No.25*

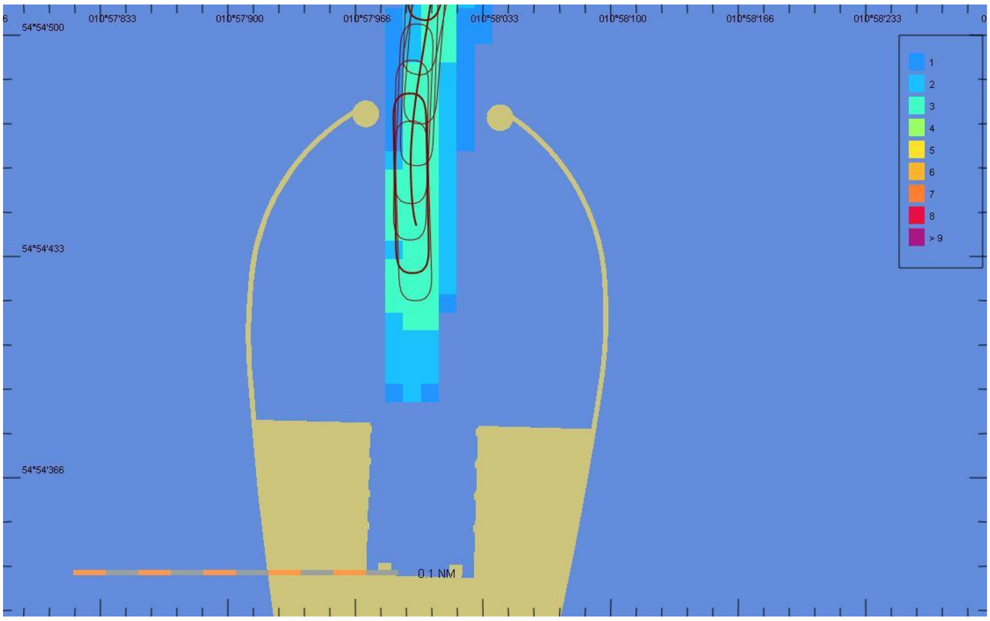


Figure B-26 *Swept area simulations 1, 2 and 3*

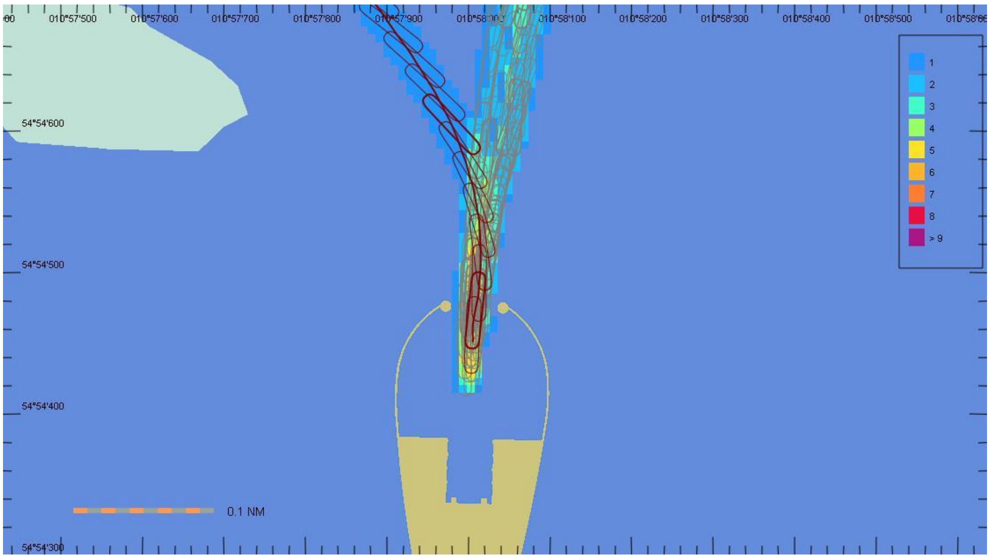


Figure B-27 Swept area simulations No. 4, 5 ,6 ,7 and 23

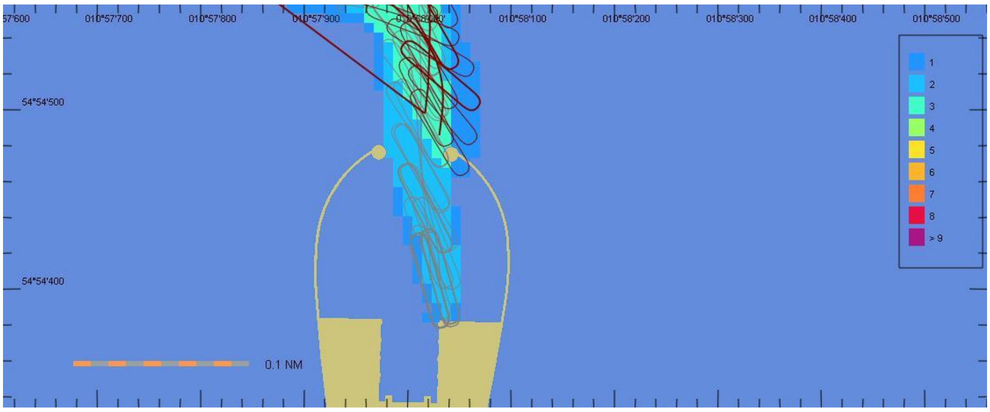


Figure B-28 Swept area simulations No.8, 9 and 10

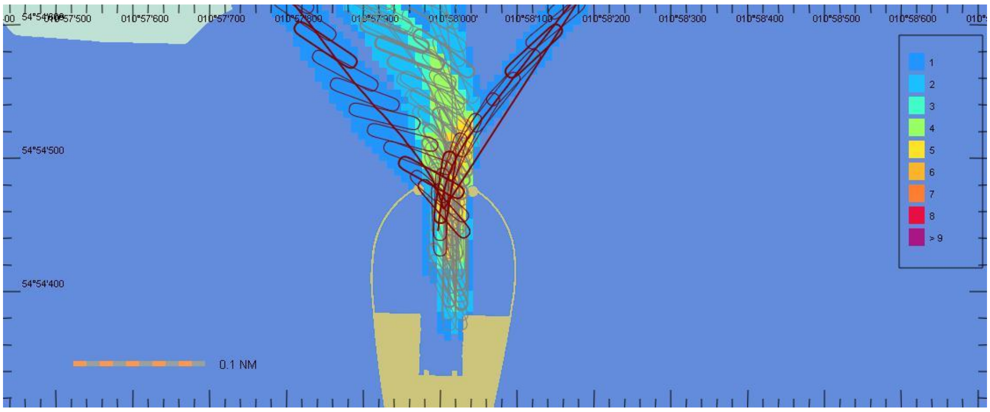


Figure B-29 Swept area simulations 11, 12, 13, 24 and 25