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NAVIGATION SIMULATIONS

Technical report on the definition of navigation simulations

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1. CONTENT

The final goal of the comprehensive set of undergoing activities is to quantify the impact along the Malamocco – Marghera Channel and surrounding areas induced by vessel transits in the Channel, to identify possible solutions aimed at minimizing the erosion processes that are now affecting the tidal flats surrounding the Channel, thus achieving sustainable navigation conditions.
To match this ambitious goal, following Public Tender procedures, the Contract was awarded by Port of Venice to a Consortium led by DHI S.r.l. and formed by DHI A/S, Force Technology, HS Marine S.r.l., Cetena S.p.A. and Around Water.

The present document preliminarily illustrates the set of tools and approaches used to implement the navigation simulations: Under-keel Clearance Assessment Capacity using NCOS ONLINE, Fast-time simulations, Real time simulations. With reference to the "*Capitolato Tecnico*" the present document includes:

7. *Relazione tecnica per la definizione della tipologia di simulazioni di navigazione in riferimento agli scenari clima-canale-nave.*

2. TECHNICAL REPORT ON THE DEFINITION OF NAVIGATION SIMULATIONS

As a preparatory stage for identifying solid and sustainable solutions, the navigational operability of the *existing* Malamocco-Marghera Channel (MMC), was investigated. The key objective of the study was to assess the transit feasibility in the existing MMC for selected design vessels and under pre-determined meteomarine conditions. Ultimately, the assessment aimed to increase the knowledge on the meteomarine conditions limiting the channel operability and to identify the channel sections endangering the navigational safety as an input for channel expansion design changes.

The joint DHI-FORCE study was undertaken as coordinated approach comprising of four main steps:

1. DHI modelled one (1) full year of representative meteomarine forcing conditions for the entire Venice lagoon and MMC including water levels, winds, currents, and waves.
2. DHI quantified the operability of the MMC related to vessel under-keel clearance for selected designed vessels under the one-year of meteomarine conditions cf. step no. 1. The operability was calculated by using DHI's physics-based Nonlinear Channel Optimization Simulator NCOS ONLINE software.
3. FORCE performed the fast-time navigation simulations powered by their SimFlex engine to calculate transit feasibility accounting for maneuverability conditions and grounding events. These simulations were performed for several selected relevant meteomarine conditions, i.e., combinations of water levels, winds, currents and waves, extracted from the database at step no. 1. The outcome of the analyses at step no. 2 provided input for selecting relevant meteomarine scenarios.
4. FORCE carried out "full-bridge mission" simulations to further investigate the transit feasibility along the MMC accounting for maneuverability conditions and grounding. While the vessel maneuvering was mimicked with a numerical engine in the "fast-time" simulations, a real pilot maneuvered a virtual vessel in the "real time" missions, through a ship-bridge simulator at FORCE's premises in Kgs. Lyngby, Denmark. Therefore, the "full missions" also allowed to account the human behavior and response during the navigation along the channel, under critical environmental conditions especially. The full missions were conducted for several meteomarine scenarios selected according to the limits (eg. spring/ebb, wind, etc) illustrated in different documents (Ordinanza) provided by Port of Venice**:** Ordinanza n. 175/09,

Ordinanza n. 096 2021 and Ordinanza n.099 2021. These limits were therefore challenged during the full-bridge missions. The selected meteomarine scenarios were guided by the results of the “fast-time” simulations at step no. 3.

The present chapter provides an extended executive summary of the types of navigation simulations that have been carried out, along with the main findings. The in-depth details of the methodology, models, assumptions and results from NCOS ONLINE simulations, fast-time simulations and full-bridge simulations are illustrated in dedicated reports.

2.1. Extended executive summary of the types of implemented navigation simulations

DHI and FORCE Technology has jointly undertaken a navigational operability assessment study for the existing Malamocco - Marghera Channel (MMC) considering a number of vessel types and load conditions as agreed with Port of Venice. The objectives of the study were to increase the knowledge on the meteomarine conditions limiting the channel operability and to identify the channel sections endangering navigational safety. The outcome of the study has provided essential input for the final phase of the project, where a channel design optimization will be carried out to mitigate the present MMC limitations.

As a first step, a comprehensive meteomarine study was conducted by DHI to produce detailed temporally and spatially varying validated data on water levels, currents, waves, and winds along the channel and surrounding areas. A full and representative year (2020) covering seasonal variations, was modelled. This meteomarine database provided the environmental forcings to be used in the subsequent steps of the joint approach. Three state-of-the-art numerical tools were applied sequentially to analyze the navigational conditions along MMC. Initially, the DHI’s NCOS ONLINE physics-science based tool allowed efficient screening of an entire year of meteomarine conditions to identify the environmental conditions limiting the channel operability efficiently. The outcome of the screening served the selection of the meteomarine scenarios to be further investigated with FORCE’s fast-time simulation tool using a numerical navigator. Finally, the findings from the fast-time simulations supported the setup of the full-mission bridge simulations undertaken at FORCE premises in Kgs. Lyngby, Denmark.

The following subsections summarize the input, the setup, and the findings of the three steps, i.e., NCOS ONLINE screening study, fast-time and full-bridge mission simulations. Overall conclusions and recommendations were derived from the real-time simulations, which accounted the realistic operational conditions for the *existing* MMC to a greater extent compared to the NCOS ONLINE screening simulations and the fast-time modelling, especially with respect to the existence of the mud interface on the channel bed. Therefore, the NCOS ONLINE and fast-time results were used mainly to guide the setup of the real-time full bridge mission as explained above. The capabilities of the NCOS ONLINE tool will be instrumental in the mentioned second phase of the project, where they will be used to verify the increased operability of the MMC deriving from the proposed design optimization.

2.1.1. Under-keel Clearance Capacity Assessment using NCOS-ONLINE

The under-keel clearance study was conducted applying DHI's Nonlinear Channel Optimization NCOS ONLINE UKC software that simulated both inbound and outbound transits of all selected vessels along the MMC. Simulations were performed for three vessels, a bulk carrier with draft of 11.0 m, a container vessel with draft of 11.0 m and cruise ship with draft 7.85 m. A maximum and minimum loading condition were assumed. Ten (10) scenarios were modelled in total. In each scenario, approximately 17,500 transits throughout the one-year meteomarine conditions were simulated, as a new transit was initiated every half hour. The same vessel speed profile was applied for the three vessels. Speed was 10 knots between Malamocco and the bend in San Leonardo, then the speed was reduced to 6.5 knots and kept constant until arrival in Marghera following the agreement between Port of Venice. Vessels transited along the centerline of the MMC with the prescribed speed profile.

The feasibility of each transit was determined by calculating the Under Keel Clearance (UKC) and the Maneuverability Margin (MM) parameters during the simulated navigation, as advised by eg. PIANC guidelines (PIANC, 2014). Where the UKC parameter is related to the grounding risk; the MM parameter indicates the potential existence of critical manoeuvrability conditions. Both metrics represent a vertical distance between the vessel keel and the channel bed and are calculated as the combined effect of waves (only for UKC), squat and dynamic heel. In agreement with Port of Venice, the operability of a single transit was assessed as reported in Table 1.

Table 1 Operability transit criteria applied in the study

Parameter	UKC (m)	MM (m)
Transit operable	**> 0.50 m**	**> 0.60 m**
Transit inoperable	**< 0.50 m**	**< 0.60 m**

In particular, the UKC threshold implied that a grounding was defined as the event in which the keel was at a distance less than 0.50 m from the channel bed, and *not necessarily* when the keel *touched* the bottom.

The main findings of the under-keel clearance study were:

- For inbound transits of the bulk carrier and the container vessel, the highest operability (50 %) was achieved when voyages departed between 1.5 and 1 hour before high tide at Punta della Salute. For outbound transits, the highest operability (35 %) level was found when leaving Marghera no earlier than 30 mins before the high tide at Punta della Salute. Inbound and outbound transits starting at low tide in Punta della Salute were inoperable.
- No specific section of the MMC restrained the operability. Most of the transit failures took place consistently along the bend at San Leonardo and along the North-South alignment, where shallower depths are located.
- The operability had strongest dependency on the water level. In this regard, initiating a transit with a water level above approximately +0.50 mMSL (+0.82 mZMPS) at Punta della Salute ensured the safe UKC margin of 0.50 m. This occurs 8% of the time.
- Wave-induced vessel motions were significant only near Malamocco, where however the operability is generally not a concern as it is due to the large depths. Vessel heel caused by wind did not have a meaningful impact on the transit feasibility. Nevertheless, wind-induced drift, not modelled in the present under-keel clearance study, can push vessels towards the shallower sides of the channel where grounding is likely to happen.

2.1.2. Fast-time simulation study

The fast time simulations used the same numerical engine as the full bridge simulations (section 2.3) but uses a numerical navigator to control the vessels. The numerical navigator was configured with human behaviour so that repetitive simulations with the same settings will give slightly different outcome. For the three different vessel types 20 different scenarios were conducted 5 times.

The results of the fast-time simulations confirm that to be able to navigate the MMC with the selected bulk carrier and container vessel, it is necessary to undertake the transit at the water levels as stated in the actual Ordinanza.

2.1.3. Full bridge mission simulations

The scenarios used in the full mission simulations were agreed between Port of Venice and FORCE, taking wind limits and speed limits specified in the Ordinanza into account, as well as lessons learned from the NCOS ONLINE and fast-time studies.

Table 2 provides an overview of the vessels tested in the full-mission bridge simulator including tug support. Figure 1 shows an image from the simulator in action.

Table 2 Vessels tested in the full-mission bridge simulator. The color indicates different vessel types. Please note the Svitzer Maitland tug (3852) was operated as a vector tug.

Ship No.	Name	Ship Type	Description	Load Con.	LOA m	Lpp m	Bmld m	Tf m	Ta m	Displac em	Prop.	Rudd.	Bow thrst.	Stern thrst.
3644	"Gold Sapphire"	Cruise Ship	294 m	S	294.0	261.0	32.2	8.3	8.3	50453	2F	2	3	3
3481	Roberta	Bulker	51.000 DWT	L	200.0	191.0	32.2	11.0	11.0	55690	1F	1	1	0
3601	"Atlas"	Container Ship	2.680 TEU	L	215.6	206.2	32.2	11.0	11.0	48571	1F	1	1	0
3556	Costa Luminosa	Cruise Ship	294m	S	294.0	265.4	32.25	8.1	8.1	47646	0	0	3	2AZ(fp)
3297	Tor Magnolia	RoRo	199.8m	L	199.8	190.3	26.5	7.7	7.7	21248	1C	1F	2	1
3583	"Melusina"	RoRo	215 m	L	215.0	205.0	26.5	7.7	7.7	25341	1C	1	2	2
3764	Multratug 4	Tug VSP	36m, 72 t BP	S	36.0	34.0	12.5	5.7	5.7	855	2VS	0	0	0
3852	Svitzer Maitland	Tug ASD	30m, 70 t BP	S	30.0	25.6	11.0	4.6	4.8		0	0	1	2AZ(cp)

Figure 1 Inbound transit full-mission bridge simulation.

The simulations were carried at FORCE in Kgs. Lyngby, Denmark using a full-mission bridge (bridge A) and a full-mission tug bridge (bridge H) for the main assisting tug.

The vessels were maneuvered by the participating captains from Italian Coast Guard, FORCE captains and pilots from Port of Venice. The VSP 72t BP tug at bridge H was maneuvered by the tug master from Port of Venice. A captain/instructor from FORCE controlled the other vector tugs and conducted the simulations. The layout of the MMC and the Port of Venice is showed in Figure 2.

Figure 2 The MMC setup used in the full-mission bridge simulator.

The following conclusions are based on the conducted simulation runs in the tested environmental conditions, as well as the run evaluations carried out by participating captains, pilots, tug master and the FORCE instructors:

- Too low under keel clearance (less than 0.5 m) observed for both bulk carrier and container vessel during the full-mission simulations.

- Too narrow channel for all vessels especially during high winds (above 20 knots for cruise ships and 25 knots for bulk and container vessels) due to induced drift angle at low ship speed (below 6 knots).

- The simulations showed that the existing limits specified in the ordinance are confirmed with respect to both wind limits and navigation speed for the bulk carrier and the container ship used in the simulation.

- Both conventional and Azipod propelled cruise ships up to 300 m LOA were able to perform safe passage in wind speeds of 20 knots which is higher than specified in the Ordinanza of 15 knots for that size of ships used in the simulations.

The following recommendations are based on discussions and brainstorming carried out between all parties involved:

- Further investigations are suggested on the most appropriate “reference wind station” to be considered for acceptance of vessel transit, given that the main wind-induced issues for navigation was found in the narrowest part of the MMC.

- Simulations confirmed the actual safety limitations of the container vessels and the bulk carrier used in the simulation, as stated in the Ordinanza, hence it is recommended to keep the safety limitations for the existing channel as is.

- A possible increase to 20 knots of the wind speed limitations for the cruise vessel up to 300 m LOA could be taken into account. Azipod propelled ships showed an even larger safety margin.