OPERATIONAL AND STRUCTURAL SOLUTIONS FOR A SUSTAINABLE NAVIGATION IN THE MALAMOCCO – MARGHERA CHANNEL (VENICE LAGOON)

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A comprehensive and interdisciplinary investigation has successfully pinpointed sustainable strategies for increasing the capacity of the Malamocco-Marghera Channel, the main navigational route in the Venice Lagoon. These measures address the erosion challenges affecting the tidal flats surrounding the channel, at the same time ensuring safe and sustainable navigation conditions. The study activities have been carried out within the "Channeling the Green Deal for Venice", a CEF European funded project that tackles the limited nautical accessibility of the port of Venice, fully respecting the environment and the UNESCO protected site of the Venice Lagoon. After conducting a rigorous selection process through Public Tender procedures, the Port of Venice entrusted the study to a consortium led by DHI S.r.l. This consortium included DHI A/S, Force Technology, HS Marine S.r.l., Cetena S.p.a., and Around Water. To achieve the ambitious goal, a complex and structured combination of navigation and hydrodynamic/sediment transport models have been planned and implemented. For the first time hydrodynamics, real time navigation and morphological models mutually interact to identify the best solutions.

METHODOLOGY

The development of an integrated hydrodynamic and wave model capable of simulating the spatial-temporal distribution of the main meteomarine variables at lagoon scale is a prerequisite for the entire study's development. Following a complex and articulated phase of data acquisition and interpretation, a 2D model was developed covering the entire Venice lagoon (Figure 1). The goal was to simulate, for an entire representative year, the spatial-temporal distribution of water levels, currents, and waves.

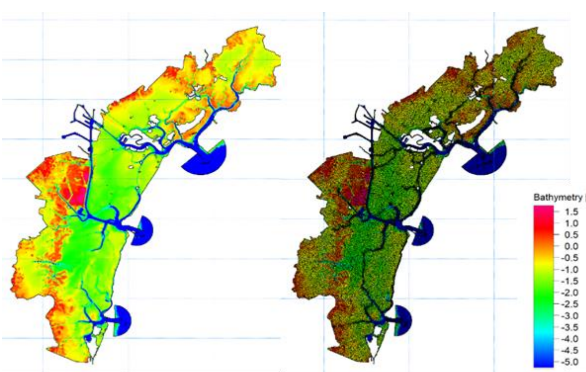

Figure 1 : Bathymetry of the 2D model of the Venice Lagoon (on the left) and computational mesh adopted in the numerical model (on the right)

The hydrodynamic model was developed using MIKE 21 HD (Hydrodynamics) by DHI. Boundary conditions of sea level at the three lagoon inlets were set based on the measurement from the Lido, Malamocco, and Chioggia stations. Meanwhile, wind conditions, varying both spatially and temporally, were constructed using available measurements. The wave model was implemented using MIKE 21 SW (Spectral Waves) by DHI, a flexible mesh third-generation spectral model. The distribution of water levels in the lagoon, varying in both space and time and essential for an accurate representation of wave generation, propagation, and dissipation, was directly derived from the hydrodynamic model's results.

The calibration of the hydrodynamic model was conducted by comparing the results of a test period (corresponding to a complete 14-day tidal cycle) with observed water level data from a series of tide gauge stations. Due to the very limited availability of wave measurements in the lagoon, reference was made to literature data for several Scirocco and Bora wave conditions (Carniello et al, 2005).

The navigation part of the study involved the integrated usage of three different tools, providing a unique set of information to support the decisions on the possible solution. The first tool is the Nonlinear Channel Optimisation Simulator (NCOS ONLINE), here used to assess the MMC's capacity regarding vessel under keel clearance (UKC) in quantification of the spatial and temporal variations in channel operability for the most important deep-drafted design vessels, considering vessel specific response to local meteomarine conditions, and vessel transit procedures. The analysis of NCOS ONLINE results enabled the identification of the relevant meteomarine and transit conditions to further test in the fast-time vessel simulator environment (2nd tool). The software Simflex was used to study the navigation conditions in the Channel under different weather conditions repeatedly. The main goal of the fast-time simulations in the Channel is to better address the definition of critical sections and meteomarine conditions through systematic analysis of different manoeuvres, also accounting for tug support.

Finally, a mathematical and 3D visual model of the MMC (Figure 2) was developed to form the basis for the full bridge mission simulations (3rd navigation tool).

Figure 2: Example the 3D visual database

The real-time study was performed in one of the FORCE Technology full-mission simulators and involved the presence of Captains and technicians from FORCE as well as personnel from the Port Authority, Venice Coast Guard, Venice pilots and tug operators. The weeks of simulations aimed at finally identifying the main challenges in the navigation of the existing Channel under different meteomarine conditions. The current operational limits indicated in the rules for navigation in the Venice Lagoon were discussed and thoroughly tested using a set of representative vessels.

The effect of navigation on the hydrodynamics and morphology of the MMC and surrounding areas primarily deals with two types of waves induced by passing vessels: primary waves (draw down) and secondary waves (Kelvin wake). Primary waves are bound displacement waves induced by the acceleration of the flow under and around the vessel hull. The secondary wave system consists of diverging and transverse waves in a restricted wedge-shaped region around the vessel.
In the MMC, primary waves showed greater importance than secondary waves. Primary waves were simulated using a 3D hydrodynamic model (MIKE 3 HD FM) covering the MMC and surrounding areas. The passing vessel is simulated accurately as a moving pressure field boundary condition, where the pressure field is proportional to the draft of the vessel. The numerical model for simulating the draw-down, that has previously been successfully validated against physical model tests, was calibrated against wave data measured by CNR (August 2019 to February 2020) and against new wave data collected by HS Marine in a dedicated campaign.

To determine the bed shear stresses induced by the displacement wave and to quantify the sediment resuspended and moved in the central lagoon, the hydrodynamic model was coupled with a sediment transport model, MIKE 3 MT by DHI. In the transport model, implemented for different particle size fractions, critical bed shear stress values for sediment suspension were assumed to be in the range between 0.5 and 1.8 Pa, based on available literature (Scarpa et al, 2019, Saretta et al, 2010, Zaggia et al, 2017).

The simulations of the effects of ship passage on hydrodynamics and sediment transport highlighted that the navigation speed in the MMC is a primary factor in generating displacement waves that impact the lagoon morphology. A reduction in speed from 10 to 8 knots makes a difference in the conditions of erosion (bottom shear stress values higher than 0.5-0.7 Pa) and non-erosion of the shallow areas adjacent to the Channel, and it should be pursued as the ideal <u>operational</u> solution.

The proposed <u>structural</u> solutions include both the optimization of the channel geometry, to increase navigation safety, and the implementation of new morphological structures in shallow areas around the channel, with the purpose of wave displacement dissipation, Figure 3 shows a detail of the planned morphological structures alongside with local widenings of the Channel.

The combination of navigation simulations and hydro-morphodynamic models has verified the enhancement of port performance in terms of operations and navigation safety, and on the other hand, effectively reduced the effects of ship passage in the channel. This has resulted in a reduction of over 50% in the overall volume of erosion over an entire representative year of naval traffic.

Figure 3: Example of morphological structures to the right of the Channel (light green indicates the emerged part - salt marshes - dark green corresponds to semi-submerged part)

CONCLUSIONS AND PERSPECTIVES

The study involved the synergic use of the most advanced technological tools available today for navigation and hydro-morphodynamic simulations. It demonstrated that it is possible to ensure an increase in port operational efficiency and navigation safety while improving the environmental impacts of naval traffic along the Malamocco-Marghera channel. The proposed design has encompassed:

- Localized adjustments of the channel geometry, with restoration of bottom levels as per the current Port Master Plan and specific local widening to enhance navigation safety.
- Construction of morphological structures in shallow areas that are fully integrated into the lagoon environment. These structures aim to restore morphological variability to a portion of the central lagoon and mitigate the residual effects of naval passage in the lagoon.
- Reduction of transit speed in the Channel, aimed at minimizing the generation of disturbances induced by ship passage, primarily the displacement wave.

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