

EROSION FROM DISPLACEMENT WAVES ALONG THE MALAMOCCO MARGHERA CHANNEL

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Loss of sediment from the Lagoon of Venice has been a well-known problem for many years. The erosion has been pronounced in the central part of the lagoon, where the navigational channel leading from the Malamocco Marghera Mouth to the industrial harbour of Marghera on the mainland west of Venice is also located, see Figure 1.



Figure 1 Overview of the MMC, the three main cross-sectional parts and the modelled speed profile.

Previous studies have shown high concentrations of suspended sediment in the water column close to and inside the channel during and after vessel passages in the channel. The 'Channeling the Green Deal for Venice' project has sought to find means to mitigate this problem while balancing the continued functionality of the harbour. This paper describes a numerical model used in the study to simulate vessel generated hydrodynamics and erosion from displacement waves. Another important topic of the project has been the navigational safety.

THE CHANNEL

The Malamocco Marghera Channel (MMC) is about 15.5 km long from the Malamocco Marghera Mouth to the entrance to the industrial harbour of Marghera. The channel is initially oriented from east to west (Part I) going from the lagoon mouth towards the marshlands west of

Venice. From here, the channel takes an almost 90-degree curved trajectory (Part II, known as the San Leonardo bend) into the south to north oriented part of the channel (Part III) leading to the industrial harbour. The geometry varies along the channel trajectory:

Part I is characterised by cross sectional widths in the range 180 to 150 m and large water depths in the range 25-15 m-MSL, deepest near the lagoon mouth. Part I is located relatively far from the coast. Therefore, the navigational channel is largely unrestricted in this area. Through Part II the cross-sectional width of the channel decreases from around 150 m to 60 m (measured at the bottom), the maximum water depth goes from around 15 to 12 m-MSL and the channel becomes aligned by the artificially established marshlands on the western side (Cassa di Colmata A, B, D and E). Throughout Part III the channel maintains a cross-sectional width of about 60 m (measured at the bottom) and a maximum water depth of about 12 m-MSL. Towards west the channel is aligned by the artificial marshlands. The eastern side of the channel is exposed to the Venice lagoon until around Cassa di Colmata B. From here a series of morphological structures and low rubble mound structures align the channel on the eastern side until the industrial harbour.

MARITIME TRAFFIC

A wide range of vessel types (e.g., container vessels, tanker vessels, bulk carriers and RoRo's) navigate the channel. Some of the vessels navigating the MMC are quite large (relative to the channel geometry) with widths often in the range 20-40 m and drafts from about 7.5 to around 11 m. Originally, a speed limit of 10 knots was applied until the point of Fusina. From there the maximum speed was reduced towards the harbour entrance. The MMC facilitates about 2,200 vessel transits to (and from) the industrial harbour per year. Additionally, the MMC has come to support the transits of large cruise vessels, which previously navigated through the Lido Mouth into Canale della Giudecca to the Venice cruise terminal.

THE CHALLENGE

Strong draw down events (also known as displacement waves, Bernoulli wakes or primary waves) are observed along the channel when large vessels navigate through the channel. The intensity of the displacement waves is determined by 1) the size of the transiting vessels, 2) the restricted geometry of the MMC during Part III, and 3) the navigational speed. This type of vessel generated wave is related to the displacement stencil of the vessel and the acceleration of the flow in the water volume along the sides of the vessel during a passage. The displacement wave follows the vessel through the channel. The more restricted the channel geometry, the larger the local draw down and flow acceleration becomes. Very strong current

speeds can be generated by the drawdown waves. The currents are directed towards the vessel, which means that the sediment mobilized during such events gets pulled towards the channel.

Vessel generated displacement waves have been identified as one of the main drivers of the erosion along the MMC. The modelling of this problem represents a numerical challenge given the size of the channel, the need for high resolution to resolve the vessel geometry reasonably, the variety in the fleet of vessels navigating the MMC coupled with the complexities of modelling suspended sediment transport in general.

METHODOLOGY

DHI's MIKE3 FM model was used to model the hydrodynamics of the displacement waves. A moving pressure field was applied, to represent the moving vessel in terms of shape and displacement volume. The moving pressure field gets translated to surface elevation (η) in the model. For illustration eq. (1) and (2) present the well-known Bernoulli equation in one dimension. Here p is the pressure in Pa, v is the flow velocity in m/s, ρ is the water density in kg/m³, g is the gravitational acceleration in m/s² and p_0 is the atmospheric pressure in Pa.

$$v^2/(2g) + p/(\rho g) = c \quad (1)$$

$$p = -\rho g \eta + p_0 \quad (2)$$

Initially, the hydrodynamic model including the representation of the moving vessel was calibrated using local measurements of surface elevation for selected events. The measurements were carried out during the fall of 2019 and made available to the team by CNR. The model was further validated against a set of measurements (current speed and surface elevation) provided by HS Marine during May 2022.

Erosion was simulated by dynamically coupling a model for cohesive sediment transport (MIKE MT) to the hydrodynamic model. The model was based on the pre-existing knowledge available for the Venice lagoon in terms of magnitudes of the critical bed shear stress for erosion ($\tau_{cr,E}$) and sediment types. The literature data, especially (Saretta et al, 2010), (Scarpa et al., 2019) and (Zaggia et al., 2017) was discussed and processed in collaboration with Prof. Giorgio Fontolan within the framework of the Channelling project. The sediment transport model was then calibrated against measurements of suspended sediment concentration during a vessel passage from (Scarpa et al, 2019).

Finally, the vessel fleet navigating the MMC was simplified into 10 representative vessels based on data supplied to the team by Port of Venice: A large and small container vessel, a large and small tanker vessel, a large and small bulk carrier, a general cargo vessel, a RoRo-vessel and finally a small and large cruise vessel.

Single in- and out-bound passages for all selected vessels were modelled for existing channel geometry, applying the 10-knot navigation speed limit. The total annual erosion was then calculated as the weighted sum of the contributions of each vessel.

A mitigation option was developed based on the present model results and the navigational modelling. The effect of the mitigation measure on the erosion was then evaluated by applying the calibrated models considering

an updated channel layout and reduced navigation speed limit of 8 knots in Part III of the channel.

FINDINGS

Modelled results from a developed Venice lagoon model indicate that natural waves in the centre of the lagoon are small (significant wave heights are below 0.25 m almost 92% of the time during a year). In comparison, most of the modelled vessels navigating at 10 knots generate draw down levels around -0.4 to -0.6 m-MSL to almost -1.0 m-MSL 200 m from the channel, see Figure 2. With an assumed threshold for erosion of 0.7 Pa the model indicates that vessel generated displacement waves can cause bed shear stresses above this threshold up to around 1,200 m from the channel with the existing configuration (i.e., vessel speed of 10 knots).

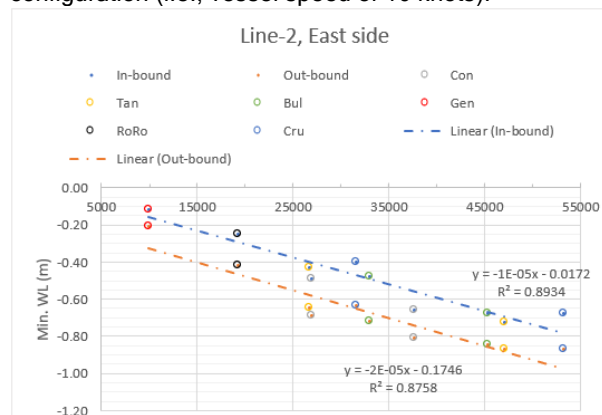


Figure 2 Modelled draw down 200 m from the channel versus displacement stencil volume (m³) using existing channel configuration and 10 knots.

Applying the new speed limit of 8 knots (20% reduction in speed) the model indicates that the eroded volume east of the channel caused by a single passage (in + out) reduces by up to 90% for small vessels (displacement stencils below around 30,000 m³) and around 45% for large vessels (displacement stencils above around 45,000 m³). Accounting for the occurrence frequency of the vessels, about 50% less eroded volume east of the channel is estimated. Also, the new layout limits the erosion width.

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