Wave-current interaction in the Porto di Lido entrance of the Venice Lagoon

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***Abstract* — The wave propagation and flow modules of the TELEMAC system have been applied to the "Porto di Lido" entrance of the Venice Lagoon. Wave-current interactions were analysed by direct coupling of the phase-averaged model TOMAWAC and of the two-dimensional depth-averaged flow TELEMAC 2D model. ARTEMIS software was separately applied to estimate the effect of refraction.**

The model includes the "Porto di Lido" entrance, one of the three channels connecting the Lagoon and the Adriatic Sea. The aim of the analysis is to evaluate the wave climate and the harbour tranquillity of a planned landing cruise, recently proposed in order to prevent the cruise ships from entering the Lagoon and mooring near San Marco. Several tests were performed and the results permit a comparison between the present condition and a future scenario including the planned terminal (landing cruise).

I. INTRODUCTION

In the past years several projects have been proposed in order to prevent large cruise ships from entering the Venice Lagoon (Venice, Italy) and, therefore, from causing environmental damage and increasing the environmental risks. One of the most promising projects (Venis Cruise 2.0) involves the construction of a terminal at the "Porto di Lido" entrance (Fig. 1). This structure would allow large ships to dock outside the Lagoon and the tourists should be fetched to the main islands by electric boats (at a reduced environmental impact). The pier (about one kilometer long and 34 meters wide) would be supported by circular pillars with a diameter of 7 meters and would be placed parallel to the North breakwater delimiting the entrance. Fig. 2 shows a rendering of the planned Venis Cruse 2.0 terminal.

The present study examines the influences of tide-induced water currents and waves at the Porto di Lido entrance in two different cases: (i) in the actual configuration (without the structure described above); (ii) in the presence of the planned pier according to the Venis Cruse 2.0 project.

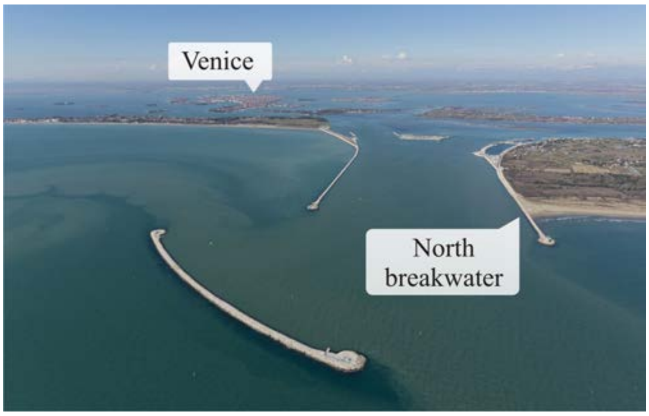

Figure 1. "Porto di Lido" entrance.

Figure 2. Rendering of the landing cruise.

Several runs were performed considering different combinations of mean wave direction and significant wave height (computed on the base of a risk analysis). Simulations were performed taking into account the effects of the different operating conditions of the MOSE gates (the Experimental Electromechanical Module intended to protect the city of Venice and the Venetian Lagoon from flooding).

The paper first describes the input data (computational domain and boundary conditions) used to launch the simulations. Then the results of all runs are compared, with particular attention to the effects of the structures described in the Venis Cruise 2.0 project (comparison between cases (i) and (ii)).

II. MODEL SETUP

A. Site characteristics and wave climate

The coastal area near the Porto Lido (Fig. 3) has been widely investigated in the past years. The studies were carried out to design the MOSE, a well-known system of mobile barriers built up to protect the Venice lagoon from the phenomenon of "high water".

Figure 3. Area of interest: the yellow line represents the planned pier.

For this reason, a detailed knowledge of the wave climate and several field measurements are available. Fig. 3 shows the area of interest and the planned layout of the landing cruise. The direction of onshore winds are in the range of 67° N and 192° N, with a fetch length up to 500 kilometres (see Fig. 4). The observation of effective fetch provides a clear and concise indication of the direction of significant waves. The stronger winds come from N-NE (Bora winds), but the limited extension of the fetch in that direction does not allow the waves to grow. Scirocco winds are not so intense, nonetheless they are characterized by a much more extended fetch length (in theory, extended along the Adriatic Sea, in practice no more than 500 km). The wave climate was determined with a statistical analysis of the data collected by wave recorder buoys and by several instruments installed on the offshore platform "CNR 3" (Lat 45°18'48''N, Long 12°30'54''E), close to the area of interest. The available data were collected from October 1987 to November 2012.

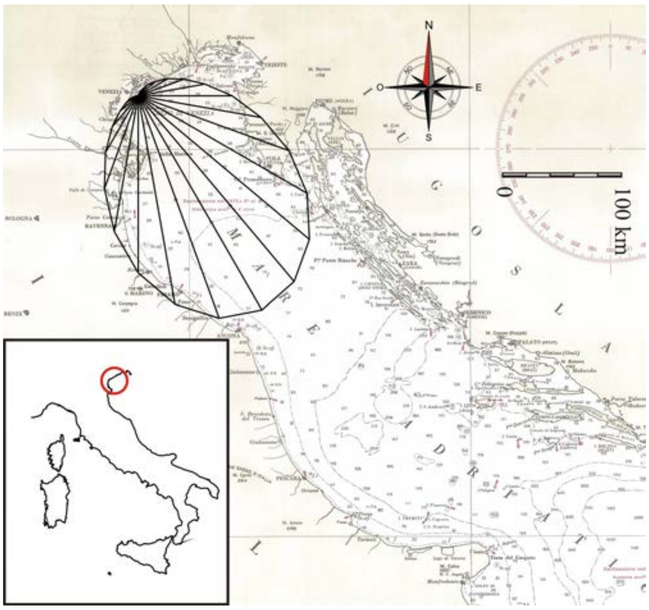

Figure 4. Effective fetch.

Fig. 5 shows the frequency of significant wave height by direction. The design wave height was calculated considering (1) the service life of the cruise terminal (L = 50 years [1]) and (2) the maximum allowable chance of exceeding the design wave (E = 0.05 [1]).

The return period of the critical event can be calculated as

$$Tr = L/-ln(1-E) \tag{1}$$

and for the assumed admissible damage, it is nearly equal to one thousand years.

The wave probability distribution function (according to Fisher-Tippet II [2]) is represented in Fig. 6 for waves from S-SE. The significant wave height corresponding to the critical event is Hs = 8.57 m. Similar analyses were carried out for waves from NE (Bora) and E-SE (Bora-Scirocco), estimating a significant wave height equal to Hs = 4.86 and Hs = 6.67, respectively.

The spectral analysis of the waves indicated a peak period of the spectrum according to the following equation [3]:

$$Tp = k\sqrt{Hs} \tag{2}$$

with k = 4.0, 4.25, 4.5 for waves from Bora, Bora-Scirocco and Scirocco. A Mitsuyasu directional distribution was assumed [4].

The sea level is locally subjected to relevant variations due to the astronomical tide and to the storm surge. The estimated highest maximum level is about 180 cm over the mean sea level (with a return period of 300 years) while the lowest minimum level is about -120 cm below the mean sea level.

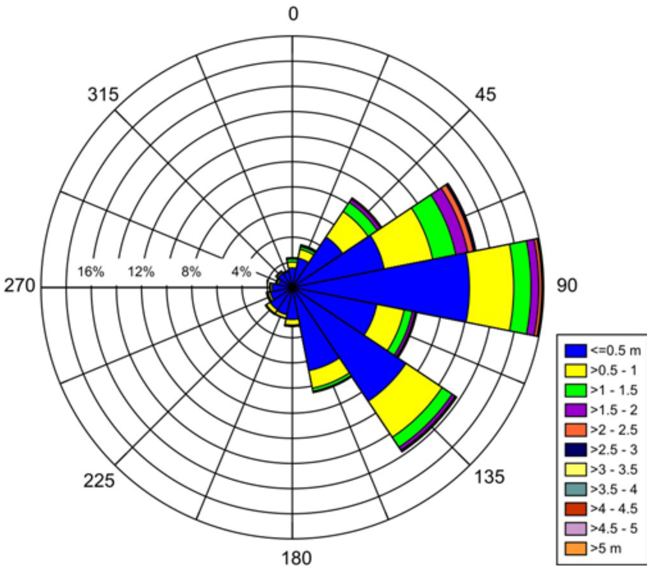

Figure 5. Frequency of significant wave height

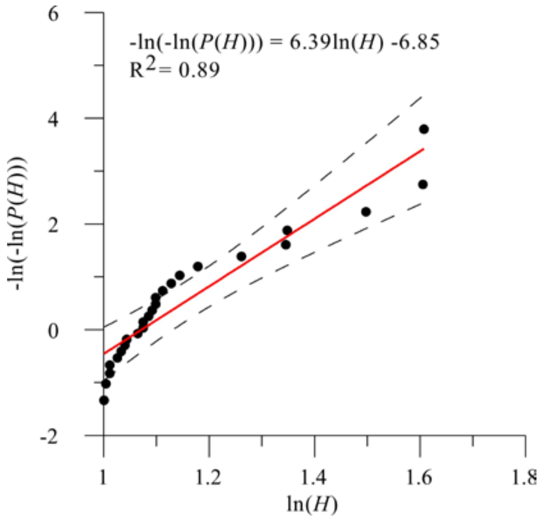

Figure 6. Wave probability distribution function (Scirocco sector, S-SE).

The typical ebb and flood current discharge through the "Porto di Lido" entrance are equal to 7150 m^3s^{-1} and 8000 m^3s^{-1}, respectively.

These values were calculated on the bases of several field measurements collected in the last years.

B. Domain contours and computational mesh

Once the domain contours were properly defined, the open source software BlueKenue was used to generate four different unstructured triangular grids. The first case (i) refers to the actual configuration (without the structure described above). The second case (ii) refers to the presence of the terminal to be built according to the Venis Cruse 2.0 project.

Two different MOSE operating conditions were analysed for each case:

- case (i.1): actual configuration, MOSE barriers off;
- case (i.2): actual configuration, MOSE barriers on;
- case (ii.1): pillars of the cruise terminal located at the design position, MOSE barriers off;
- case (ii.2): pillars of the cruise terminal located at the design position, MOSE barriers on.

Fig. 7 (1) shows the domain contour in cases (i.1) and (ii.1), while Fig. 7 (2) shows the domain limitation imposed by MOSE mobile barriers, cases (i.2) and (ii.2). Both figures provide information about the reflection coefficient, R, imposed in ARTEMIS simulations.

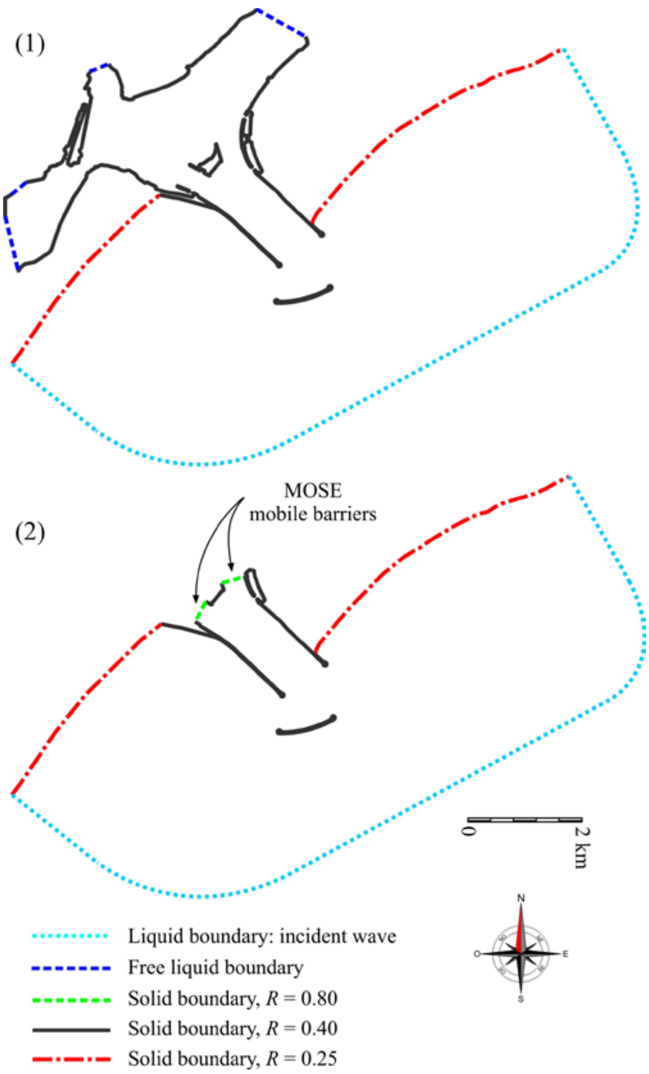

Figure 7. Domain contours. (1) MOSE barriers off and (2) domain limitation imposed by MOSE mobile barriers.

The cruise terminal pier rests on more than a hundred pillars, which are arranged in about 30 rows (each row consists of 3 or 4 pillars). Other pillars (6 units) support the access ramp at the North end of the landing cruise. Pillars represent the main interaction between the structure and the fluid domain. For this reason each pillar is represented by an island in the computational domain. Fig. 8 shows the area occupied by pillars. The grid, shown in Fig. 9, consists of more than 135 000 nodes with a minimal distance of 12 m into the "Porto di Lido" entrance. The grid size gradually increases to 50 m outside the channel. In the modified configuration (case ii) a more detailed mesh was created, with a minimal size of 2 m close to the pillars (see Fig. 10).

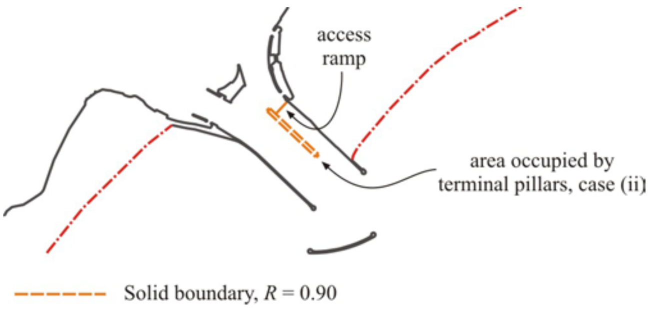

Figure 8. Domain modified according to the Venis Cruse 2.0 project.

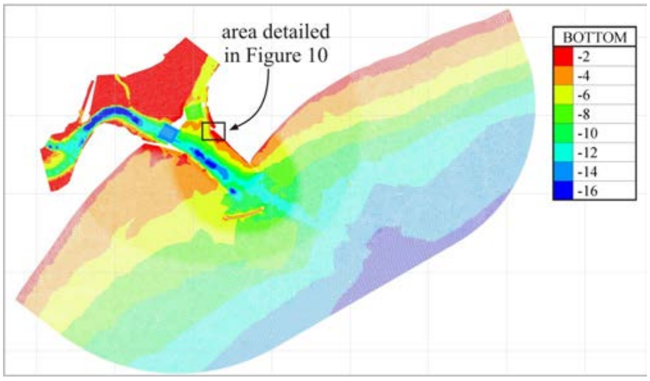

Figure 9. Bathymetry and computational grid (case i.1).

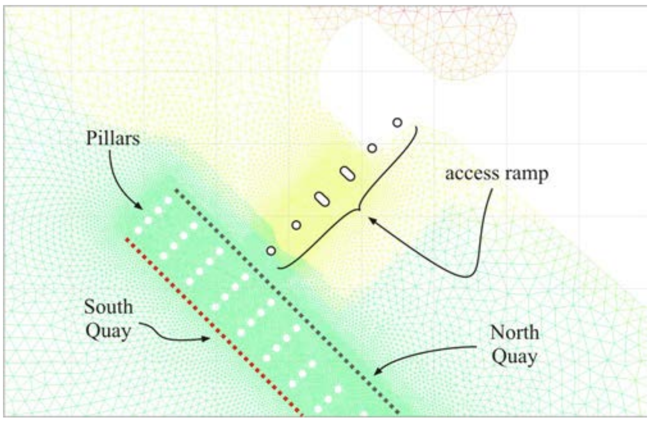

Figure 10. Detailed view of the bathymetry and computational near the North head of the pier (cases ii.1 and ii.2).

If MOSE barriers are lifted on, no flood or ebb current occurs. Therefore, the analysis of wave-current interaction (coupled TELEMAC 2D – TOMAWAC model) was limited to the condition of MOSE barriers lifted down. The mesh described above (cases i.1 and ii.1) was used for both ARTEMIS and TELEMAC 2D – TOMAWAC simulations.

III. RESULTS

A. ARTEMIS simulations

The first set of runs was performed without taking into account the effects of flood/ebb currents. Fig. 11 shows the results of the ARTEMIS wave modelling for case (i.1) where the incident wave travels from Scirocco (Hs = 8.57 m). A sea level equal to + 2.0 m was assumed in order to consider the toughest conditions, since it was checked that larger water depth induced higher waves near the planned pier. It is partly a consequence of the reduced wave breaking due to reduced shoaling, partly of the reduced bottom friction effect.

The pillars of the landing cruise (and the local excavation of the seabed required to guarantee a safe mooring and movement of the ships) do not increase the transformed wave height near the South Quay (see Fig. 12, case i.1). The energy propagation pattern changes according to the new local bed geometry. Near the North Quay a small reduction of the wave height is observed.

The worst condition occurs when MOSE mobile gates are lifted on and the wave energy do not propagate into the Venice Lagoon but is reflected back into the channel (see Fig. 13). The barriers reflect a relevant fraction of the energy of the incident waves which remains inside the "Porto di Lido" entrance channel, with an increment of the significant wave height up to 1.6 m (near the pier). There is no substantial difference between scenarios (i.2) and (ii.2).

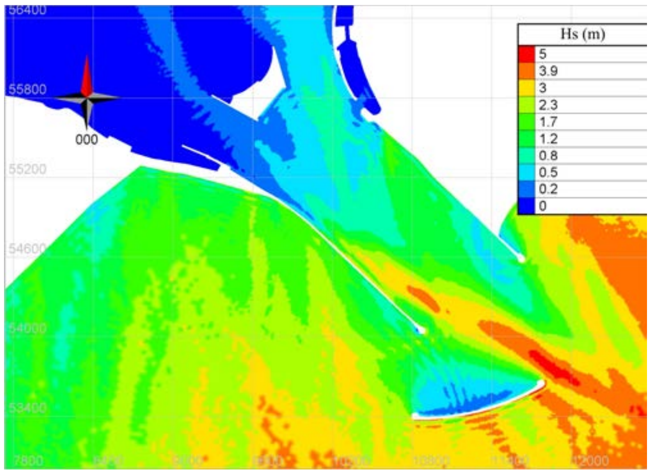

Figure 11. ARTEMIS simulations, critical wave (case i.1).

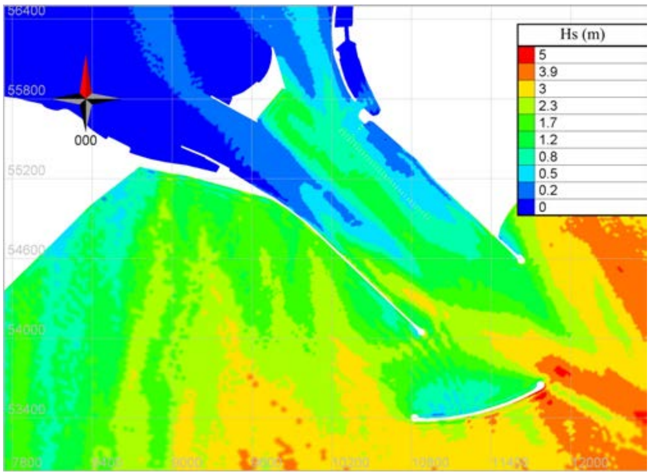

Figure 12. ARTEMIS simulations, critical wave (case ii.1).

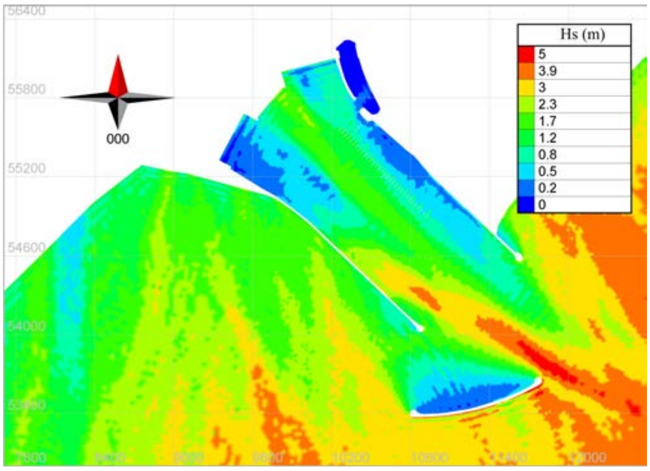

Figure 13. ARTEMIS simulations, critical wave (case i.2)

B. *TELEMAC 2D – TOMAWAC simulations*

Results from previous simulations were used to calibrate the input parameters of the wave–current model.

Data from TOMAWAC simulations are usually used as boundary conditions for ARTERMIS. In this case, we used experimental wave data from "CNR 3" platform close to the cost to calibrate the model. In addition, some simultaneous measurements of wave height inside the channel and offshore were also available. Hence, it was possible to compare field observations and ARTEMIS results, finding a good agreement. TOMAWAC results were not so accurate, with a systematic overestimate of the wave height. Energy losses due to wave refraction (neglected in TOMAWAC) are not negligible and that partially explains the behaviour of the phase-averaged model applied to the small domain under analysis.

We calibrated TOMAWAC parameters using ARTEMIS results, in order to obtain a more realistic and consistent wave propagation pattern. Finally, the resulting TOMAWAC model was directly coupled with a TELEMAC 2D model characterized by a constant level at the outflow section and by one of the following stationary discharge boundary conditions: flow inshore, toward the Venice Lagoon (flood current) or flow offshore (ebb current). Tide currents are modelled neglecting their time variation and considering only the peak values. In this way the effects of the interaction between waves and high velocity currents acting for a long time inside the entrance channel are verified.

Fig. 14 and 15 show the results of the TELEMAC 2D – TOMAWAC coupled modelling (case i.1, with flood and ebb current, respectively).

Wave height is increased by ebb currents (propagating in opposite directions). This phenomenon can be addressed to the Doppler shift (effect of a steady current on intrinsic relative wave frequency) [5]: waves of the same apparent absolute period have a longer intrinsic period in a favourable following current and a shorter intrinsic period in an opposing current. As a consequence, there is a steepening of waves propagating with opposite currents.

In the case of flood tide, the high velocity flow (up to 2.0 m/s, entering the channel) increases the wave height close to the head of the South breakwater. These waves propagate toward the pier. Both flood and ebb currents increase wave height up to 1.7 m (near the pier).

Fig. 16 shows the flow dynamic close to the pillars. In that region of the domain the high resolution of the mesh allows the appreciation of an interesting phenomenon that was not expected at the beginning of the present investigation, even though it is quite common in rivers. Flood and ebb currents encountering the piers pillars generate vortices that result in a periodic flow. This flow can induce local erosion and excavation, hence some further studies on physical model should be carried out to prevent erosion and possible failure of the structure.

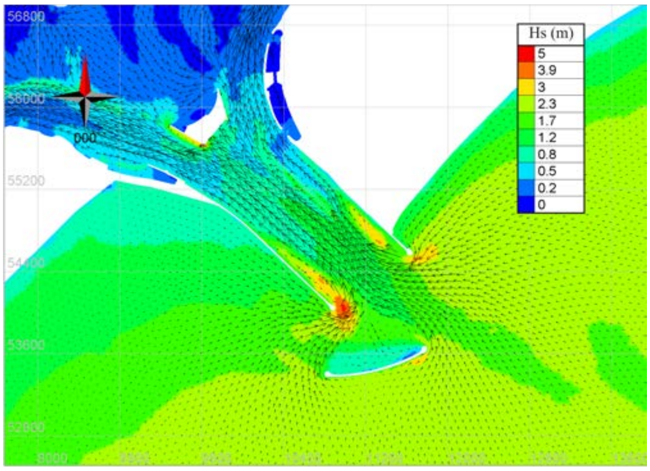

Figure 14. TELEMAC 2D – TOMAWAC simulations, critical wave and velocity field (case ii.1, maximum flood current).

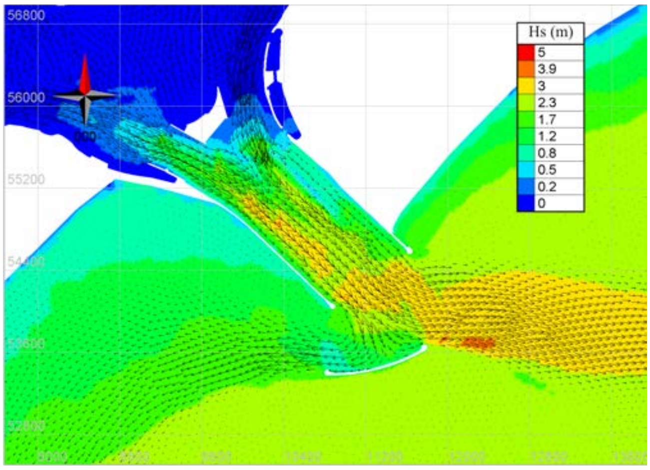

Figure 15. TELEMAC 2D – TOMAWAC simulations, critical wave and velocity field (case ii.1, maximum ebb current).

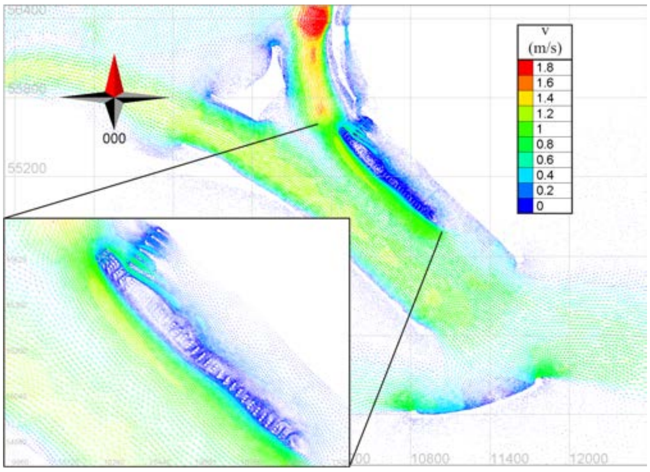

Figure 16. Velocity field (case ii.1, maximum ebb current).

IV. CONCLUSION

A numerical model based on hydrodynamic and wave propagation modules has been implemented at the "Porto di Lido" entrance of the Venice Lagoon. The aim of the work is to evaluate the harbour tranquillity for a planned landing cruise. The effect of tide currents on wave height was also investigated. The main outcomes of the present study are the following:

- the worst condition occurs with MOSE barriers lifted on, with the maximum water depth in the channel and with highest waves from Scirocco. The critical wave height near the pier is equal to 1.6 m;
- wave height is increased (up to 1.7 m, at project site) by the interaction between incoming waves and tide currents (occurring only with MOSE barriers lifted off); however, there is a very limited probability of occurrence of highest wave offshore and MOSE barriers lifted off, with high water depth.
- the pillars do not affect the wave field. However, flood and ebb currents interacting with the pillars generate vortices that should be further analysed in a physical model, in order to prevent local erosion and a possible failure of the structure.

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