CHAPTER 144

WATER FLOW MODELLING OF THE VENICE LAGOON

Enrico Marchi [(1)]
Attilio Adami [(2)]
Alfredo Caielli [(3)]
Giovanni Cecconi [(4)]

Abstract

The paper describes the relevant set of analogical, mathematical and phisical models used to simulate the hydrodynamics phenomena of the Venice lagoon. The various models are devided in two classes, depending on the scale: the great scale models, to examine the problems interesting the entire lagoon, and the little scale models for the problems localized near the inlets, where the barrages will be built to control the lagoon water level.

1 - Foreword

In 1984 the Italian Government commissioned the "Consorzio Venezia Nuova" to undertake what had been called the "Venice Project"; this project comprised a number of works necessary for the safeguarding of the city of Venice and its lagoon. Amongst these , by far the most expensive and technically difficult task was the project for the deployment of flapgates across the three lagoon entrances for the control of high tides within the lagoon.

It was evident straight from the start of works that such a large and complex project would have to be supported by a series of model tests in order to investigate the various project hypotheses.

It was also evident that one model only would not have been enough, and that due to the many different problems studied, the project would have to avail itself of investigative means that were in keeping with the different aspects to research.

For the purpose of the rcsearch, the project-related phenomena were classified in two categories: the large scale phenomena, which concern the general behaviour of the

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(1) Full professor, Institute of Hydraulics, Genoa University, via Montallegro 1, Genova

(2) Full professor, Institute of Hydraulics, Padua University, Via Loredan 20, Padova

(3) Chief Engineer Safeguard Office of Venice, Magistrato alle Acque, Palazzo X Savi, Rialto, Venezia

(4) Director of Studies Office of Consorzio Venezia Nuova, Palazzo Morosini, Campo S. Stefano, Venezia

lagoon, and the small scale phenomena, which concern the phenomena in the immediate vicinity of the flapgates.

When the New Veniee Consortium became operational in 1987 the following models of the Venice lagoon already existed, so they were also adopted for the new activities: the general physical model of the lagoon, the specific physical model of the Lido entrance and the unidimensional mathematical model of the entire lagoon itself.

Alongside these models a new set of models were prepared, a description of which follows hereafter.

2-1 Large Scale Models

2,A - General Model of the Lagoon

The model (refer to Fig. 1) reproduces the entire lagoon to a planimetric scale of 1:250 and an altimetric scale of 1:20. The area occupied by the model is approximately 12,000 sq.m. Its distortion ratio of 12.5, which is typical for maritime models — in this case with a morphology consisting of canals and shoals — creates problems with regard to the roughness of the walls, which generally appear too smooth. The model is equipped with a tide generator for each of the three entrances; the three generators operate automatically and are controlled by a computer.

Due to the size of the model and the encumbrance of test handling, typical of physical models, the general model was not widely used in the engineering work eoncerning the lagoon entrance flapgates; thus it was often replaced by the mathematical models discussed hereafter. Nonetheless, it is the best means of investigating the phenomena that take place in the innermost parts of the lagoon where continuous contouring is a fundamental characteristic. Refer to [1] for a more detailed description of the possible uses of the model.

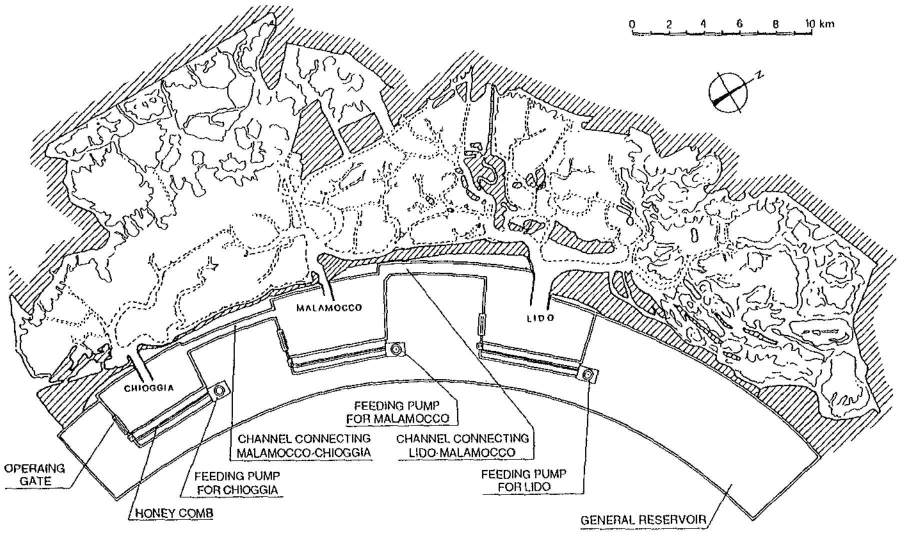

Fig. 1 -General plants of the model of the entire lagoon of Venice.

2,B - Mathematical Models

From a historical point of view the first mathematical model of the lagoon that was ever made is the one that mapped the lagoon with its network of interconnected canals alongside which are the shallow areas whose main function is that of providing storage capacity. This lay-out features the great advantage of simplicity and a reduced number of unknown quantities (unlike other lay-outs); but it requires an in-depth knowledge of the actual phenomena to be able to trace an illustrative network of canals and therefore work out the shallow water basin on both sides of each canal. Today this 1D model is still employed in a recent version (i.e. the fourth generation) whose network is shown in Fig. 2.

More recently, a 2D model has been developed using the finite element technique whose mesh is shown in Fig. 3, and another 2D finite differcnce model whose mesh is shown in Fig. 4, which also shows a stretch of sea opposite the entrances. This model blocks out the lagoon with a mesh having a 300 m pitch, and has the advantage of being able to zoom in on areas of limited surface area by reducing the spatial grid to 50 m.

Table 1 compares the characteristics of the three adopted models.

At present, in the engineering work, all three models are used depending on their different characteristics and on the phenomenon that is to be investigated. In fact, the finite difference model has proved to bc the best in reprcsenting lagoon hydrodynamics in the areas closer to the entrances by depicting both the adjoining stretch of sea and the somewhat flat bathymetry of the area (with very wide canals and deeper shoals). The finite element models have instead proved to be very versatile in reproducing phenomena in the intermediate area of the lagoon where canals and shoals are clearly

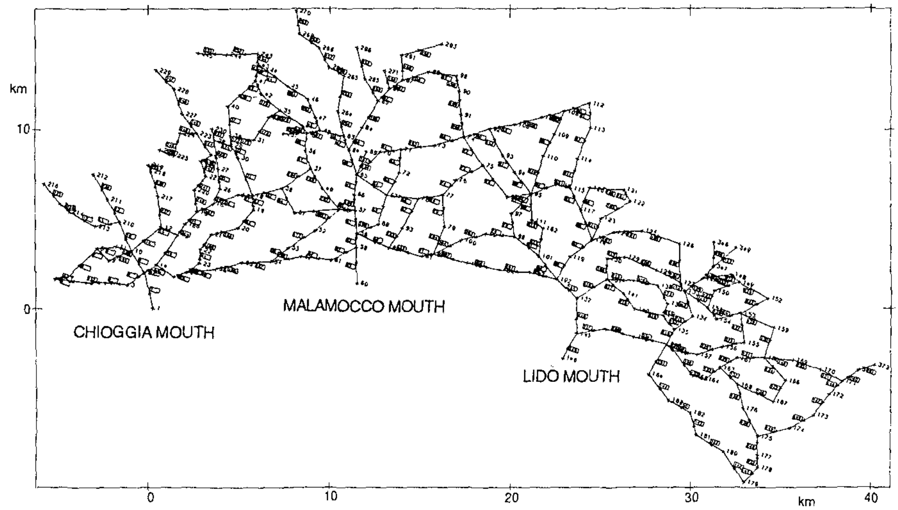

Fig. 2 -The channel net of thc 1 D, mathematical model.

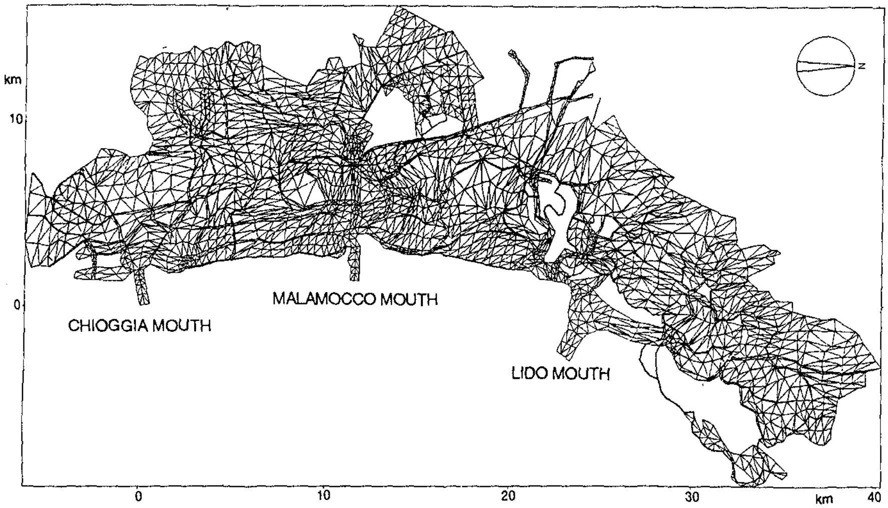

Fig. 3 - The mesh of the 2 D, finite elements mathematical model.

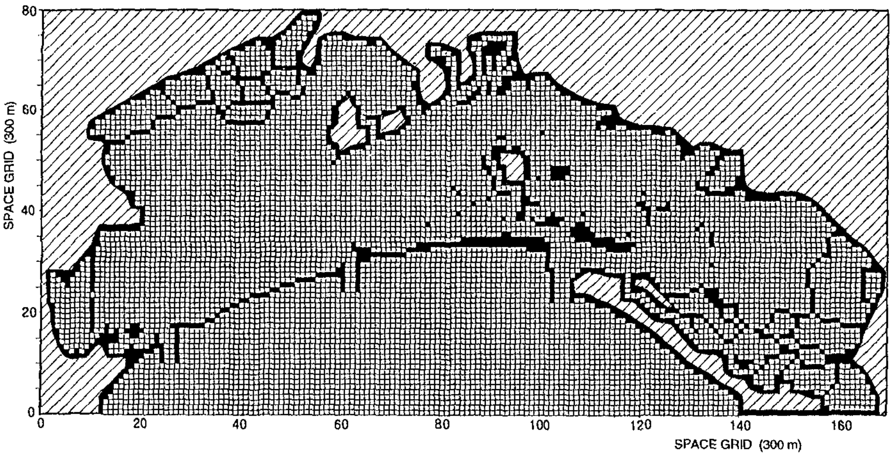

Fig. 4 - The mesh of the 2 D, finite differences mathematical model.

Table 1

	1 dimension	2 dimension Finite elements	2 dimensions Finite difference
Type of mesh and number of elements	323 multiconnected branches	2580 vertices and 4528 triangular elements	Square grid with 13,851 vertices
Dimension of elements	1000 - 2000 m	Distance between two vertices 100 - 1000 m	Squares 300 x 300 m
Average number of elements for km^2 of lagoon	0.9	7	11
Roughness coefficient	Chezy C=50$m^{1/2}$/s	Strickler k=30,25,20 $m^{1/3}$/s in channel and shallows	Strickler k=28 $m^{1/3}$/s
Time step	600 s	300 s	90 s
Resolution method	Implicit with interations	Two level time scheme, semi-implicit	Algoritm of alternate direction, implicit
Time to simulate 24 h of tide with a VAX 8600	6 minutes	60 minutes	75 minutes

distinguishable. Finally, the unidimensional model is still considered the best for the reproduction of phenomena in the innermost area of the lagoon where the tidal flow takes place nearly exclusively along the narrow submerged canals — a phenomenon that is hardly reproducible in the other lay-outs. A factor in favour of the unidimensional model is the calculation time which is nearly one order of magnitude less than that required for the other two models.

More detailed information about these models and the algorithms used can be found in [4].

3 - Small Scale Models

This name has been attributed to those models detailing the port entrances; they have allowed the study of localised phenomena that take place in the vicinity of the new barrage structures. The models that were used are described below.

3,A - Aerodynamic Models

These types of models are not widely used in current techniques; but in this case they were found to be a very effective means of research. Obviously, in aerodynamic models the water flow is replaced by an air flow and the flow must take place in a confined field. For this reason the free surface of the water is replaced by a solid plate which acts as a covering lid for the model. The result is a double approximation of a top contour of the flow with a horizontal plain and a zero speed. At any rate, in this case the differences in level between the sea and the inside of an entrance are maximum 20/30 cm over a depth that may vary from 8 to 15 metres; this means a percentage level variation of less than 10%; consequently, the above mentioned approximations appear acceptable, especially if one researches data not in the absolute sense but merely as a parametric value, i.e. to highlight what happens in the presence or absence of a certain modification to the flow contours. A critical appraisal about these types of models can be found in [2].

The scales used in the models have been 1:3000 in planimetry and 1:1000 in altimetry; the models reproduced (refer to Fig. 5) the inletl, the initial tract of the lagoon canals that stem from the entrance, and a sufficient stretch of open sea. A further simplification was introduced in these models; this consisted in the fact that, unlike the real case, the flow was permanent. Given the extent of complexity to correctly reproduce the periodical variations of current, a decision was taken to represent in the model a certain configuration of the flow, usually the one at peak flow rate, and to maintain it steady throughout the time needed to take the measurements. The model boundary conditions, i.e. the flow rate at the entrance and in the adjacent canals, were provided by the mathematical models.

It is understood that by reproducing a stationary flow the model does not reproduce the forces linked to temporal accelerations, but this is acceptable if one bears in mind that under maximum speed conditions these forces are practically null.

The information elicited from these models concerned the course of the water levels by drawing up an analogy between Euler's number of the model and Froude's number of the real flow, velocity distribution, paying special regard to the areas of current separations and to wakes. The great advantage of these models is the rapid and economical reproduction and study of the inlet flapgates layout, immediately indicating their major defects.

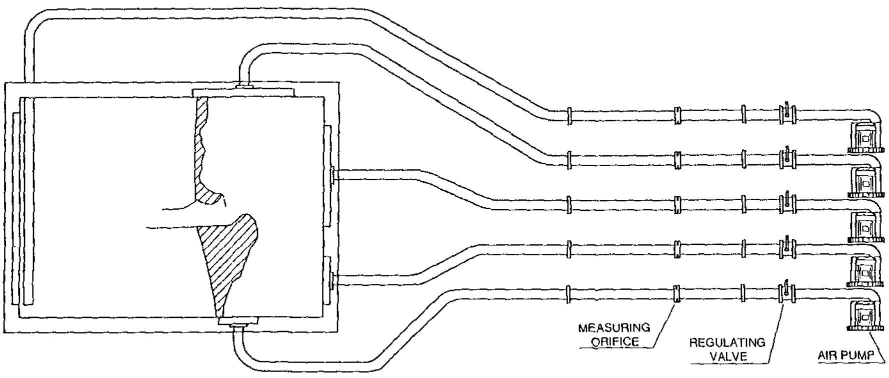

Fig. 5 - The general scheme of the aerodynamical model of the Malamocco mouth.

3,B - The Mathematical Models of the Mouths

These derive from the finite difference bidimensional model of the lagoon, already mentioned previously, where it was possible to perform close-ups reducing the mesh size to only 50 m. For the "mouths" (refer to Fig. 6) a rotation of the mesh was performed which was different for each entrance, so that one direction of the two axes would coincide with that of the breakwaters that project into each entrance — this was done to reproduce the contours of tidal flow in the best possible way.

Of course the boundary conditions were provided by the general mathematical model of the lagoon; thus flood and ebb tides were correctly represented.

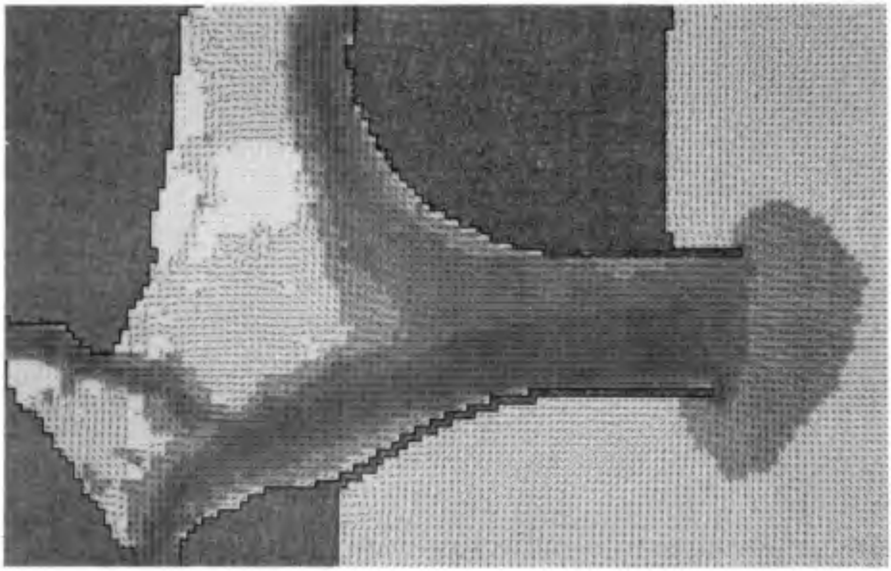

Fig. 6 - A tipical flow field of the 2 D mathematical model of the Lido mouth with a 50 m space grid.

3,C - Detailed Physical Models

As already stated, the first detailed model of Lido mouth had been constructed far back in 1972 for a number of studies that were then being conducted on the hydrodynamics of that entrance. The model was made to a scale of 1:60, undistorted. This model, like the aerodynamic ones previously mentioned, is not equipped with a tide generator, so it was used for permanent tide flow by reproducing a certain tide flow condition and keeping it steady throughout the whole test.

Thanks to the experience gained with that model, the New Venice Consortium built similar models on the same scale for the other two lagoon mouths, Chioggia and Malamocco. The three models have a fixed bottom, but the facility to reproduce a movable bottom in limited areas is featured, and this is where the flapgates will be deployed. These models can accommodate a wave generator as wide as 20 m which enables hydrodynamic studies to be combined together with those about the penetration of wave motion from the sea into the entrances. Fig. 7 shows a planimetry of the Chioggia mouth model, in which one may notice the large area of sea reproduced; this allows the simulation of heavy seas heading from the principal sectors of the prevailing winds. The other two models are absolutely similar.

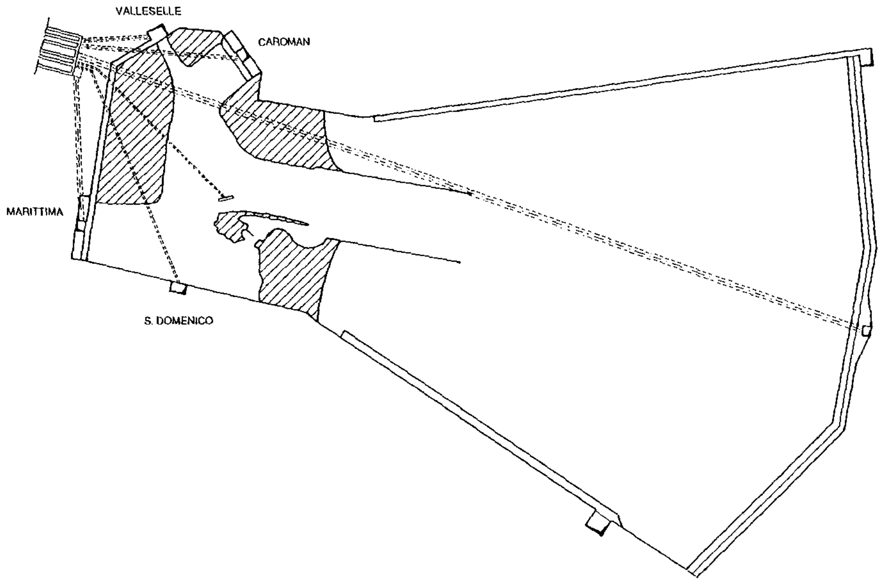

Fig. 7 - The map of the particular model of Chioggia mouth in scale 1:60.

The three models have been constructed at the Experimental Centre of Voltabarozzo in Padua, adjoining the shed that houses the physical model of the entire lagoon. The shed also houses the aerodynamic models, so that all the physical models in question have been concentrated in the same location for practical purposes. Fig. 8 shows an aerial photograph of the centre at Voltabarozzo which illustrates the various locations of the models.

Fig. 8 - Aerial view of the Voltabarozzo Center with the models of the three mouthes.

4 - Use of the Models

In the research work about the inlet flapgates, Project REA (environmental recovery) [3] the following procedure was adopted:-

• Literally starting off at the drawing board, the engineers designed all the planimetric configurations of the flapgates that were deemed feasible: eventually six possible lay-outs were produced for Lido mouth, seven for Chioggia mouth and as many as twelve different lay-outs for Malamocco mouth.

• All of these feasible solutions were reproduced and studied on the aerodynamic models, out of which were rejected those that caused an excessive current contraction, which meant speeds unacceptable for navigation and large areas of separation and vorticity.

• The solutions that passed the first test were studied on the mathematical models of the entrances in order to have more detailed information about the distribution of speeds, with special emphasis laid upon its transversal components which are the most hazardous for navigation.

• The information elicited from these models also allowed the correct reproduction of these lay-outs on the general mathematical models so that the large scale effects following their construction could be assessed.

• Finally, the solution that was judged to be the best for each mouth is currently undergoing study on the detailed physical models to allow a more in-depth study and to proceed with optimisation of the configuration of the flapgates.

5 - Conclusions

To proceed with the design of the "mouth" flapgates for the control of the high tides in the Venetian lagoon, the New Venice Consortium has constructed a set of physical, analogic and mathematical models for the reproduction of lagoon hydrodynamics, discriminating between models for large scale phenomena and models for small scale phenomena.

For the study of large scale phenomena three mathematical models of the entire lagoon, having different characteristics, were used; for the small scale phenomena, i.e. for those localised in the lagoon entrances, an extra small scale aerodynamic model, a mathematical model and an undistorted physical model were used.

These models are used in sequence with different retroactions, in the sense that the mathematical models of the lagoon create the boundary conditions of the aerodynamic models and undistorted physical models; these produce information that allows to improve the performance of detailed mathematical models of the inlets and of the general mathematical models of thc lagoon. To sum up, the end result has been a complex hybrid system of models that together enact maximum verisimilitude of incoming results.

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