HENRY
Hydraulic Engineering Repository

Ein Service der Bundesanstalt für Wasserbau

Conference Paper, Published Version

Garzon, Andrea

Study for the hydraulic framework of the lower course of Piave river (Italy)

Zur Verfügung gestellt in Kooperation mit/Provided in Cooperation with:
TELEMAC-MASCARET Core Group

Verfügbar unter/Available at: https://hdl.handle.net/20.500.11970/104288

Vorgeschlagene Zitierweise/Suggested citation:
Garzon, Andrea (2012): Study for the hydraulic framework of the lower course of Piave river (Italy). In: Bourban, Sébastien; Durand, Noémie; Hervouet, Jean-Michel (Hg.): Proceedings of the XIXth TELEMAC-MASCARET User
Conference 2012, 18 to 19 October 2012, St Hugh's College,
Oxford. Oxfordshire: HR Wallingford. S. 81-88.

Standardnutzungsbedingungen/Terms of Use:

Die Dokumente in HENRY stehen unter der Creative Commons Lizenz CC BY 4.0, sofern keine abweichenden Nutzungsbedingungen getroffen wurden. Damit ist sowohl die kommerzielle Nutzung als auch das Teilen, die Weiterbearbeitung und Speicherung erlaubt. Das Verwenden und das Bearbeiten stehen unter der Bedingung der Namensnennung. Im Einzelfall kann eine restriktivere Lizenz gelten; dann gelten abweichend von den obigen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Documents in HENRY are made available under the Creative Commons License CC BY 4.0, if no other license is applicable. Under CC BY 4.0 commercial use and sharing, remixing, transforming, and building upon the material of the work is permitted. In some cases a different, more restrictive license may apply; if applicable the terms of the restrictive license will be binding.

Study for the hydraulic framework of the lower course of Piave river (Italy)

Andrea GARZON
Hydraulic Engineering Research Department
CREA TECHNOLOGY Srl
Corso Milano, 9, 37138 – Verona (Italy)
aGarzon@creaurl.it

***Abstract*— The hydraulic study was designed to evaluate the hydrodynamic characteristics of Piave river (Venetian Region, Italy), studying deeply the hydraulic safety thematic of the lower course of the river, in order to define the existing conditions and eventually propose a new framework for the estuary configuration. To perform the study was used the particularly advanced two-dimensional finite element mathematical model TELEMAC-2D coupled with MEFH, developed by CREA, currently used by Consorzio Venezia Nuova for the regulation of mobile gates of MOSE. The lower course of Piave river has been accurately modeled in a adequate information system GIS inside Microstation CAD. At first the model has been tested to reproduce the analytic solution found in the case of a prismatic one dimensional channel, representing schematically the actual lower course of Piave river. Then the model has been applied, among other things, to simulate the effects of an important flooding of Piave river, which occurred during the period from 25th to 29th November 2002. Experimental measurements of the maximum levels and the same historic articles of the time fully confirm the results of this model, describing in a timely and precise curve the maximum levels obtained from the model results. Due to these results, the Venetian Region has requested a revision of the existing embankment altimetry for the safety of the territory. The results provided by the model, in fact, did not have agreement with those inferred from previous studies, which analyzed the same flooding event. In our opinion one of the most important problems to solve in order to obtain meaningful results from this kind of applications is to previously determine the flow pattern by the modeller, characterised by the equipotential and stream lines, then schematising the same by using the finite element mesh.**

I. INTRODUCTION

The Administration of Jesolo Municipality (VE) has entrusted the company Crea Srl a specialist professional task to realise a hydraulic study for the configuration of the estuary of Piave river in Jesolo Municipality.

To perform the study was used a 2D finite element mathematical model particularly advanced, able to solve the equations governing the water movement in 2D hydrodynamic systems using the most appropriate numerical methods in relation to the complexity of the actual hydrodynamic conditions.

In particular, the company CREA thanks to the experience gained through the development of its own 2D hydrodynamic finite element mathematical model MEFH, currently used by Consorzio Venezia Nuova's Information Service relating to the implementation and maintenance of CRUP system and by Consorzio Venezia Nuova for the assessment of hydrodynamic and dispersive effects produced by MOSE mobile barriers, has taken over and adapted to the purposes of the study the 2D finite element mathematical model TELEMAC-2D, in turn developed by a group of experts led by Jean Michel Hervouet of the French company Sogreah [16] [17] [18] [19], integrating and supplementing it with their own model [10] [11] [12] [13].

The developed software, which we called TelmH2D, is a mathematical model particularly advanced and devoted to study specifically the hydrodynamics of rivers, gathering all the bathymetric and hydraulic information of the finite elements of the mesh in a interactive development environment Microstation, in which the real physical system of Piave river, from the town of Zenson to the town of Cortellazzo, located at the river estuary, has been faithfully modeled with the necessary care to represent each particular discontinuity of the real physical system.

In the preliminary phase the model was tested in the case of a prismatic horizontal channel equivalent to the real Piave river, comparing the results provided by the model with those relating to a known analytical solution.

Subsequently, the attention has been devoted to investigate the critical flood wave propagation of the period since 25th to 29th November 2002, critically rebuilt by examining some of the studies previously realised.

II. THE MATHEMATICAL MODEL

TELEMAC-2D is an ideal modelling framework for the river environment due to its finite element grid which allows graded and refined mesh resolution. The model is based on the shallow water Saint-Venant equations of momentum and continuity, derived from the Navier-Stokes equations by taking the vertical average. A hydrostatic assumption is valid in this application where bed slopes are small and, hence, vertical accelerations caused by the pressure are balanced by gravity. The shallow water equations are solved either in a fully coupled mode or with the help of a wave equation, depending on the option chosen. Several advection schemes

are available depending on the type of flow. One of the most interesting and key features of TELEMAC-2D, characterising it from all the other finite element mathematical models, is the consideration of the characteristic method in order to solve the most difficult part of the Saint Venant equations, i.e. the non-linear advection terms. Other options include the streamline-upwind Petrov-Galerkin scheme (SUPG), in the conservative and non-conservative forms, and residual distributive schemes such as the N-scheme and PSI-scheme. TELEMAC-2D solves the turbulence model with four different methods, i.e. the classical $k-\varepsilon$ model, Elder, Smagorinski and constant isotropic diffusion. The matrix-storage in TELEMAC is edge-based and several linear solvers are available in the BIEF library, including conjugate gradient, conjugate residual, CGSTAB and GMRES solvers. TELEMAC-2D is fully parallelised using MPI.

CREA company has integrated this formidable software TELEMAC-2D with another finite element mathematical model, MEFH, developed by the same company to study the Venice lagoon hydrodynamic problems. Among the other, in MEFH is used a different method to assign the boundary condition to closed boundaries. MEFH routines, written in F90 like the main code TELEMAC-2D, have been added and linked, assembling the new model, called by the company TelmH2D.

This approach has given the possibility to use the interactive environment developed for the Venice lagoon inside Bentley Microstation CAD to create the input data GIS and the output for the model results. The preprocessor PreM2d to the data and the postprocessor PstM2d for the model results, also developed by Crea Company, were used to manage the interactivity with the user.

III. THE LOWER COURSE OF PIAVE RIVER

The lower course of Piave river, between Zenson del Piave (TV) and Cortellazzo (VE), has different characteristics along the river course.

The most meandering part is comprised between the towns of Zenson and San Donà along a reach equal to about 14 [Km], where the width of the watercourse is reduced to less than 100 [m] (Fig. 1). At the same time, the overall width of the hydraulic section varies between 250 and 1000 [m], due to large alluvial expansions following the main course of the river. Downstream San Donà till to Eraclea, for a reach equal to about 10 [Km], the Piave river follows a straight path and its cross section has a width practically constant, around 100 ÷ 130 [m] (Fig. 2). The river is enclosed between embankments rising about 4 to 5 [m] over the surrounding land while the river bed is, on average, about 10 [m] deep respect to the embankment plan, occupying the greater part of the liquid section. From the bridge of Eraclea to the estuary at Cortellazzo, for a distance approximately equal to 9 [Km], the river course again assumes a meandering path, characterised by enlargements of the section in the last meanders (Fig. 3).

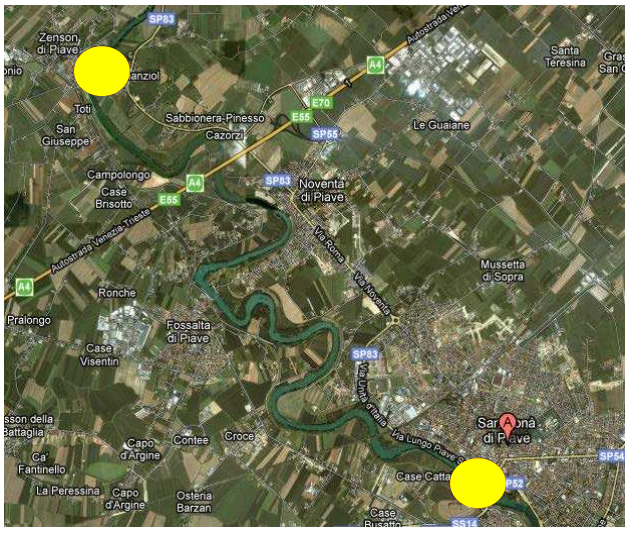

Figure 1. Piave river between Zenson and San Donà. It may be noted both the meandering path, both the large areas of floodplain between the embankments of the watercourse.

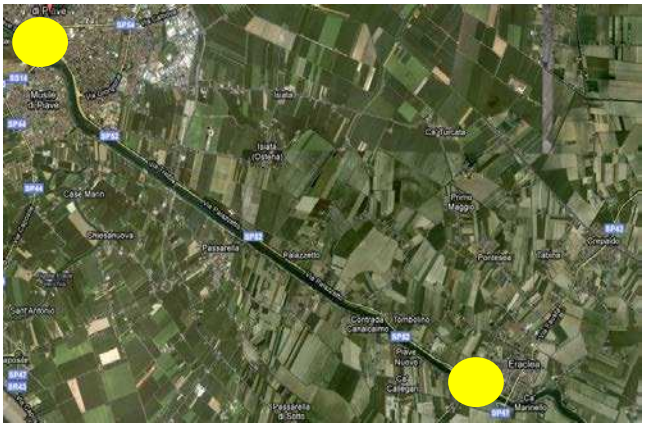

Figure 2. Piave river between San Donà and Eraclea. The river is straight without alluvial zones.

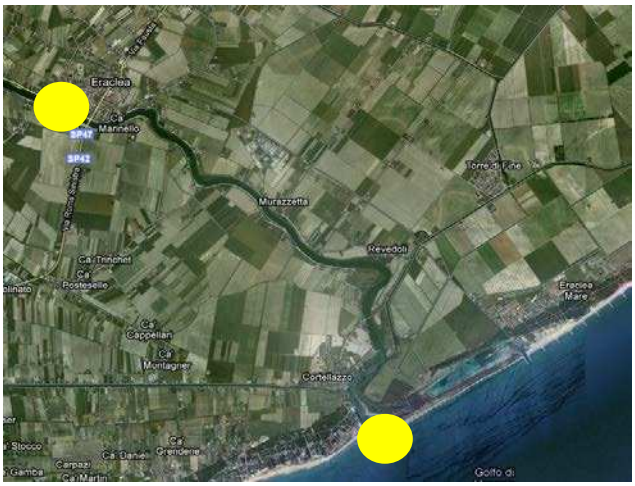

Figure 3. Piave river between Eraclea and the mouth of Cortellazzo.

Shortly before the mouth, at Cortellazzo (VE), Piave river is connected to the Venetian coastline waterway through two navigation locks currently disused and opened. The waters of Piave river can then penetrate freely in the watercourses of the channels Revedoli, on the left bank, and Cavetta, on the right one.

IV. CASE STUDY I: EQUIVALENT PIAVE RIVER

In order to assess the accuracy of the mathematical model, TelmH2D has been applied to the case of a schematic channel able to represent Piave watercourse.

To achieve this goal, the first step has been to evaluate either the volume with respect to the sea level, either the liquid surface and the length of Piave watercourse from Zenson and the mouth. The watercourse of Piave river has a total volume under the sea level approximately equal to 14104800 [m3], a liquid surface totalling 3235700 [m2] and a length of about 33600 [m], corresponding to an average width equal to 97.30 [m] and a mean depth equal to 4.539 [m]. To represent the watercourse has been assumed, then, a rectilinear schematic channel of length equal to 33000 [m], width 100 [m] and horizontal bottom. Since the liquid surface is, in this case, equal to 3300000 [m2], the equivalent depth has been evaluated equal to 4.274 [m].

The schematic channel has been, therefore, represented by a finite element mesh consisting of four flow tubes, each of width equal to 25 [m]. The length of the elements, in the direction of flow, has been assumed to be equal to 100 [m]. The Strickler roughness of the channel has been assumed to be 35 [$m^{1/3}/s$].

The initial part of the channel is represented in Fig. 4. The schematic outline of the channel needed 2640 finite elements corresponding to 1655 nodes.

The hydrograph imposed at the upstream section of the watercourse is represented in Fig. 5. The hydrograph reproduces, in its rising phase, the catastrophic flood event of 3-5 November 1966. After reaching the maximum value of 3740 [m^3/s], the flow was kept constant to determine conditions of permanent motion in the channel.

The level at the downstream section of the channel has been kept constant at a height of 1.00 [m] over the sea level.

In the schematic channel, then, some control points have been placed at a mutual distance of 5500 [m]. An upstream section PIAVE INP has been identified, together with five intermediate sections PIAVE 01, PIAVE 02, PIAVE 03, PIAVE 04, PIAVE 05 and, finally, the downstream section PIAVE OUT. A cross section, PIAVE MAIN, which runs throughout the axis of the channel, has also been introduced to derive the water level profiles in different moments of the simulation.

In Fig. 6, where the velocities at all control points are shown, one can observe the extremely high velocity (almost 7 [m/s]) that appears at the mouth of the channel, section PIAVE OUT.

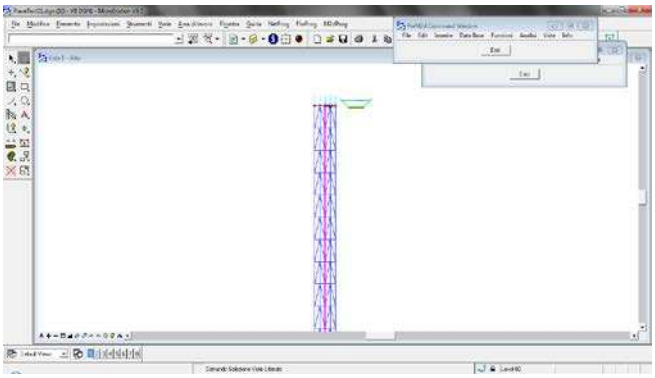

Figure 4. The lower course of Piave river has been schematised by an equivalent prismatic channel having length 33000 [m], width 100 [m] and depth 4.274 [m]. The channel mesh has been represented by four flow tubes of finite elements, each of width equal to 25 [m] and length 100 [m].

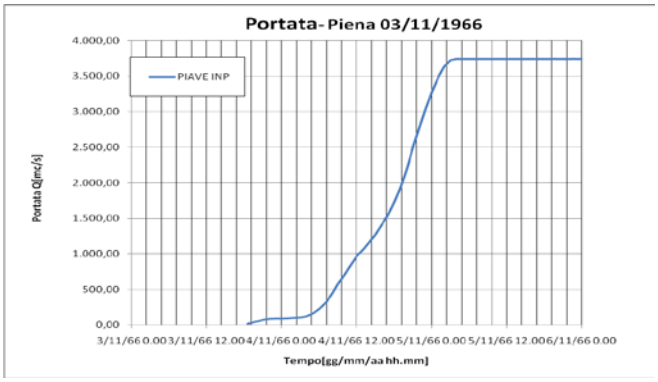

Figure 5. Hydrograph at the upstream section of the schematic channel, reproducing in its rising phase the flood event of 3-5 November 1966. After reaching the maximum capacity of 3740 [m^3/s], the flow has been kept constant to determine conditions of permanent motion in the channel.

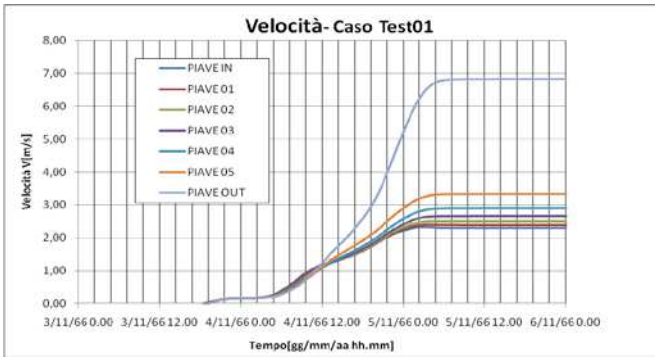

Figure 6. Velocities calculated by the model corresponding to the control sections arranged along the channel at a distance of 5500 [m]. One can observe the extremely high velocity (almost 7 [m/s]) appearing in the section at the mouth of the channel PIAVE OUT.

The shown test case of the schematic channel, with average characteristics similar to the lower course of Piave river from Zenson to the mouth, assumes a very special importance not only because it provides information relating to an extreme event for the river but, above all, because it is

possible, in the permanent motion conditions achieved during the terminal phase of the simulation, to compare the solution provided by the model with that one obtained analytically by solving, directly, the Saint Venant equations.

To calculate the analytical solution on considers, then, the specific energy E associated to a generic section of the channel, relating to the sum of kinetic and potential energies:

$$E = Z_f + h + \frac{v^2}{2g} \tag{1}$$

where Z_f is the bottom altitude [m], h the water depth [m], v the water velocity [m/s] and g the gravitational constant [m/s^2].

The momentum conservation equation allows writing, then, the following relation:

$$\frac{\partial E}{\partial x} = -J \tag{2}$$

being J the continuous energy loss according to Chézy formula:

$$J = \frac{v^2}{C^2 R_h} \tag{3}$$

in which C is the Chézy coefficient [m$^{1/2}$/s] and R_h the hydraulic radius [m].

In the case of a large rectangular section, in which the hydraulic radius R_h is almost equal to the water depth h, and considering the Strickler formula $C = k_s R_h^{1/6}$ on obtains:

$$J = \frac{Q^2}{B^2 k_s^2 h^{10/3}} \tag{4}$$

where Q is the flow [m^3/s], B the channel width [m] and k_s is the Strickler friction coefficient [m$^{1/3}$/s].

Since in the prismatic channel with horizontal bottom Z_f is constant, therefore its derivative along the x-axis of the channel is null. Then we have:

$$\frac{\partial E}{\partial x} = \frac{\partial h}{\partial x} + \frac{Q^2}{2gB^2}\frac{\partial}{\partial x}\left(\frac{1}{h^2}\right) = \frac{\partial h}{\partial x} - \frac{Q^2}{gB^2}\frac{1}{h^3}\frac{\partial h}{\partial x} = \left(1 - \frac{Q^2}{gB^2 h^3}\right)\frac{\partial h}{\partial x} \tag{5}$$

Substituting (5) and (4) in (2) one obtains:

$$\left(1 - \frac{Q^2}{gB^2 h^3}\right)\frac{\partial h}{\partial x} = -\frac{Q^2}{B^2 k_s^2 h^{10/3}} \tag{6}$$

directly integrable, by separating the variables, from $P_0(0, h_0)$, being $h_0 = 4.274 + 1.000 = 5.274$ [m], to $P(x, h)$:

$$\int_{h_0}^{h}\left(\frac{Q^2}{gB^2 h^3} - 1\right)\frac{B^2 k_s^2 h^{10/3}}{Q^2}dh = \int_0^x dx \tag{7}$$

Executing the integration of (7), after few simple analytical steps here omitted, on obtains the following expression, which provides the theoretical solution of the problem:

$$3k_s^2\left[\frac{1}{4g}\left(h^{4/3} - h_0^{4/3}\right) - \frac{1}{13}\frac{B^2}{Q^2}\left(h^{13/3} - h_0^{13/3}\right)\right] = x \tag{8}$$

In Fig. 7 is shown the comparison between the theoretical solution, expressed by (8), and the results provided by the model TelmH2D, relating to the depth h of the profile PIAVE MAIN. From this comparison between the theoretical solution and that provided by the model, one may observe the accuracy of the results obtainable by the application of TelmH2D to 2D hydrodynamic systems.

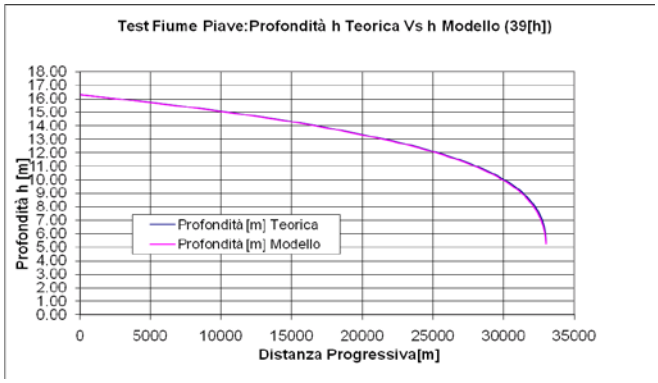

Figure 7. Comparison of the theoretical solution (8) and the results provided by the model TelmH2D relative to the water depth profile for a schematic channel equivalent to the Piave watercourse between Zenson and the mouth. For the design of the prismatic channel the liquid surface, the volume andthe total length of Piave between Zenson and the mouth have been conserved. The comparison shows the precision obtainable using the model in case of 2D hydrodynamic systems.

V. CASE STUDY II: LOWER COURSE OF PIAVE RIVER

A. Schematisation of topo-bathymetric plan

Relating to the topo-bathymetric data affected by the study, the High Adriatic Sea Authority (VE) has made available its DEM database, with its orthophotos, taken over in 2004.

The grid was then imported not only verifying the exact location of the spatial data, but assigning, at each point, a default colour connected to a specific locally graduated scale. Local reference for the colour allocation, where individual cells of the grid corresponding to a single ASCII file have referred, was related to the local average altitude computed in advance for the same ASCII file. Applying this methodology

it was possible not only to rebuild the entire topo-bathymetric plan, but also take advantage of specific colour references to determine barriers and embankments along the river, then essential information which was found at the time of designing the finite element mesh.

The detail of the reconstruction of the topo-bathymetric plan of Piave river basin from Zenson to San Donà is shown in Fig. 8.

B. Finite element schematisation

The most important problem to obtain meaningful results from the applications of mathematical models is to determine the mean size, and thus the number of finite elements, to be used in the schematisation of hydrodynamic system.

In particular, two conflicting requirements collide: the first is to increase, as far as possible, the size of finite elements and decrease the number of the nodes with which the solution is calculated, to not excessively burden the required computational effort; the second is to increase the number of finite elements and of the calculation points, to simulate with more detail and precision the situation of the watercourse, taking into account also that, at least from a theoretical point of view, there is no lower limit to the size of finite elements.

In the quest to simultaneously meet both the needs the Piave river, between the sections of Zenson del Piave and the mouth of Cortellazzo, aside from Cavetta and Revedoli channels, was schematised by about 3600 triangular finite elements, corresponding to a scatter of over 2200 nodes (Fig. 9).

In particular, the whole fluvial course was schematised by four flow tubes, corresponding to the mainstream, as well as other two partially submergible flow tubes, corresponding to the banks of the Piave river.

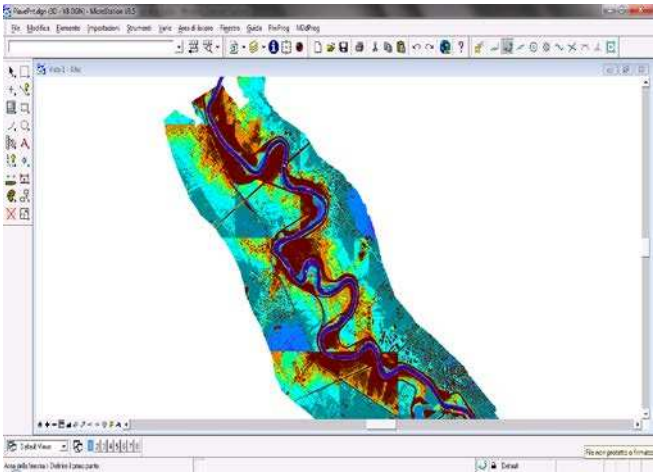

Figure 8. Detail of the reconstruction of the topo-bathymetric plan of Piave river basin from Zenson to San Donà derived from the ASCII files in ESRI GRID format. It can be seen both the meandering path of Piave river and the large alluvial areas comprised between the river embankments.

Particular attention has been paid to the schematisation of all alluvial areas existing along the river, either in the initial part of the river, between the towns of Zenson and San Donà and, especially, in the final part at Cortellazzo (Fig. 10), an area of particular interest to this study. In these areas has been sought, with careful examination, the alleged texture of the flow field that is established in critical condition of flow, dividing the same flow field in flow tubes through the preliminary identification of any current and equipotential lines.

C. Hydrological flood event of 2002

The event of 2002 did not result in a real flood, despite having constituted much more than just an emergency. In fact, in the period 25/11/2002-29/11/2002 the water level of

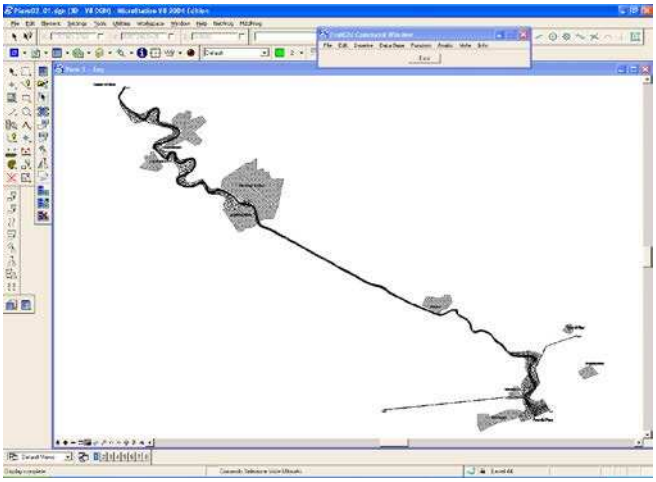

Figure 9. Schematisation of Piave river. The Piave river, between the sections of Zenson del Piave and the mouth of Cortellazzo, aside from Cavetta and Revedoli channels, was schematised by about 3600 triangular finite elements, corresponding to a scatter of over 2200 nodes

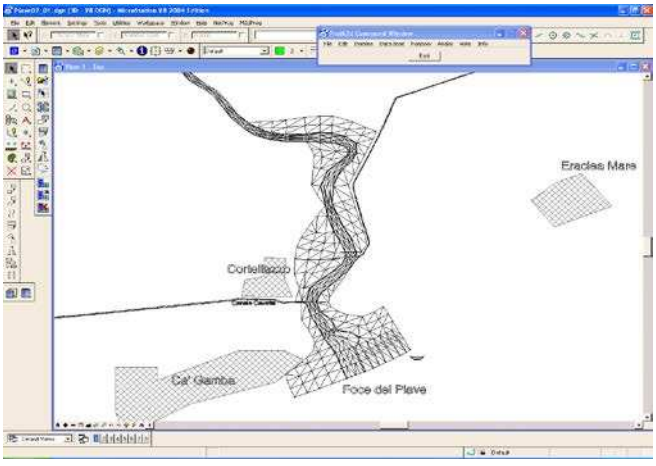

Figure 10. Schematisation of Piave river in the area of Cortellazzo. A particular attention has been devoted to the alluvial area schematisation, individuating the alleged texture of the flow field established in critical condition of flow and dividing the same field in flow tubes through the preliminary identification of any current and equipotential lines.

Piave river has raised to almost lick the summit portion of the banks of the river, causing great alarm for the whole population.

The flood of the period in question was preceded, inter alia, by another significant flood event, with the peak day 20/11/2002, which helped to soak and further weaken the banks of the river.

Since in relation to this flood event the hydrographical section of Busche (BL) has remained in complete efficiency, the flow of the watercourse has been adequately monitored and measured, constituting a reliable boundary condition for the mathematical model. A graph relative to the flow at Zenson del Piave, the upstream section of the model, is shown in Fig. 11.

In relation to the same event, the concomitant level tide in the Adriatic Sea has been applied as boundary condition at the mouth of Cortellazzo.

Strickler friction coefficients k_s have been assumed 35 [$m^{1/3}$/s] for the main channel finite elements, 25 [$m^{1/3}$/s] for bank elements and 20 [$m^{1/3}$/s] for alluvial elements.

To execute the simulation by means of TelmH2D, particular options regarding the algorithms allowed by the model have been applied. The most relevant are:

- the system of equations were coupled;
- the water depth h was solved using the SUPG in the conservative form, without unwinding operations;
- the velocities u and v were solved using the characteristics method with the modified SUPG method;
- the turbulence model was the Elder one;
- the flooding and dry process for alluvial areas was the level gradient method;
- the used solver was the generalised residual method.

The model has been run in Microstation CAD environment, using the pre-processor and the post-processor developed by CREA.

In Fig. 12, as an example, it is shown the velocity field and the contour lines for elevation in a particular instant, 58 [h] since the beginning of the simulation, at the mouth of Cortellazzo.

The application interest is not distributed evenly across the whole flood event simulated but is concentrated in the period between the days 25/11/2002 and 29/11/2002, in which Piave river has actually risked to overflow and to flood the surrounding land.

To assess the flood propagation effects along the course of Piave river between Zenson and the mouth on considers, with a single image, all levels connected together in a unitary overall profile in the different instants of flood phenomenon.

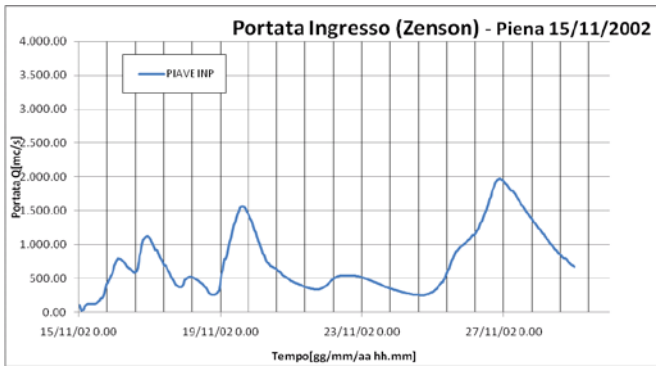

Figure 11. Graph relative to the flow at Zenson del Piave, the upstream section of the model, in the period 15/11/2002-29/11/2002.

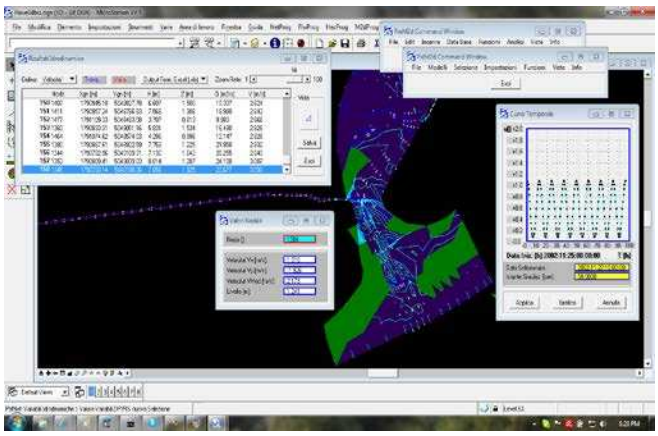

Figure 12. Microstation CAD environment to show model's results. As an example, it is shown the velocity field and the contour lines for elevation in a particular instant 58 [h] of the simulation at the mouth of Cortellazzo.

In Fig. 13 these profiles are detected with an interval of 4 [h] since the beginning of the simulation November 24th, 2002 at 24 [h].

It may be noted that, according to the realised hydrodynamic finite element model, the maximum level of the flood wave is approximately equal to 10.68 [m] at Zenson after 48 [h] from the beginning of the simulation.

The most interesting phenomenon appears near the mouth, where the water level shows a sudden decrease in proximity of the mouth itself, at the point where Piave river connects, on the right bank, the Cavetta channel. This result could be foreseen by observing the graph of Fig. 7 relative to the profile of the depth in the case of a schematic channel.

In Fig. 14 it is shown the plot of the maximum level envelope provided by the model during the flood event of 25-29 November 2002 along the Piave River between Zenson and Cortellazzo.

By analysing the profile of the maximum level envelope shown in Fig. 14, resulting from the application of the 2D finite element hydrodynamic model, it appears near the mouth, where it detaches, on the orographic right, the Cavetta channel, a sharp decrease of the level. The results obtained

Figure 13. Profiles of the levels along Piave River between Zenson and Cortellazzo, detected, with an interval of 4 [h], since the beginning of the simulation November 24th, 2002 at 24 [h]. It may be noted that, according to the realised hydrodynamic finite element model, the maximum level of the flood is equal to 10.68 [m] at Zenson 48 [h] from the beginning of the simulation. It can be seen that the levels decrease sharply only near the mouth, even downstream of Cavetta channel placed at only 1300 [m] from the sea mouth of Piave river.

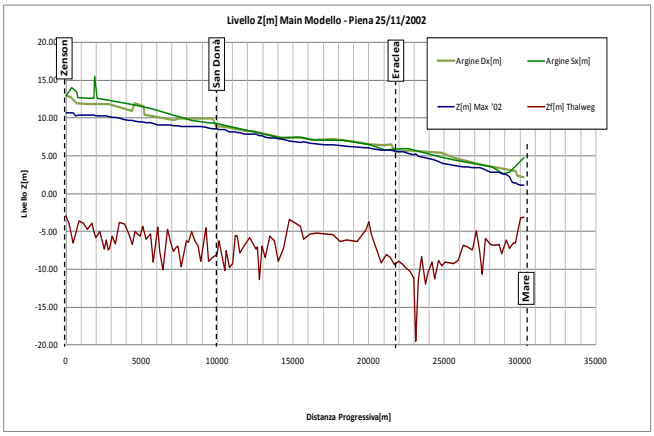

Figure 14. Plot of the maximum levels' envelope during the flood event of 25-29 November 2002 along the Piave River between Zenson and Cortellazzo, provided by the finite element hydrodynamic model. The results obtained by means of the model TelmH2D show a rapid decrease in the free surface at the point where it detaches, on the right bank, the Cavetta channel. The narrowing of the section in that point of the river supports an increase in the hydrometric levels throughout the course of the river, until to Zenson. The profile obtained from the application of this model shows both the attainment of the top of the bank at Eraclea, both the need to raise the embankment in this tract of embankment with sandbags to protect the town, both the situation of great alarm and emergency throughout the whole Sandonatese and, in general, for all the lower course of Piave river, including Jesolo, as confirmed by the chronicles of the time.

by the application of TelmH2D model confirm that the narrowing of the section at that point of the watercourse supports an increase in the hydrometric level throughout the course of the river, until to Zenson.

As there were no precise measurements on water levels reached along the river embankments, we report, as factual evidence, two articles appeared in the Gazzettino of Venice the 28/11/2002, one of which written by G. Bedin. At least the macroscopic effects on the territory, the attainment of the top embankment at Eraclea, the intervention of the Civil

Data: giovedì 28.11.2002
IL GAZZETTINO
Estratto da Pagina: 4
Il Piave è straripato ad Eraclea, tra Fossalta e Noventa è un lago di fango

Figure 15. 'Il Piave è straripato a Eraclea' ('The Piave river burst its banks at Eraclea'). Article published on Gazzettino of Venice, 28.11.2002 p. 4 which shows the flooding of the Piave River at Eraclea without causing serious damage.

Data: giovedì 28.11.2002
IL GAZZETTINO Venezia
Estratto da Pagina: 6
Allarme nella notte, il Piave esonda a Eraclea
Il parco fluviale si trasforma in un lago di fango, chiusi i sottopassi, tre famiglie evacuate a Fossalta e Noventa

Figure 16. ''Il Piave esonda a Eraclea' ('The Piave river overflows at Eraclea'). Article published on Gazzettino of Venice, 28.11.2002 p. 6 by Gianfranco Bedin. The article describes the profile of the maximum levels provided by the model TelmH2D of Fig. 14 as better it couldn't. The profile obtained from the application of this model, in fact, shows both the attainment of the top of the bank at Eraclea, both the need to raise the embankment in this tract of embankment with sand bags, both the situation of great alarm and emergency for all the Sandonatese and, in general, for all the lower course of Piave.

Protection and the sensations caused by that event on the population appear clarified.

VI. CONCLUSIONS

The model TelmH2D has been used to study the hydraulic framework of the lower course of Piave river (Italy). This model consists by coupling two 2D finite element models, the first TELEMAC-2D, extremely powerful, versatile to solve hydrodynamic and dispersive problems in the case of rivers, the other MEFH developed by CREA in the case of the Venice lagoon.

This coupling has given the possibility to use the interactive environment developed by CREA for the Venice lagoon inside Bentley Microstation CAD to create the input data GIS and the output for the model results. The pre-processor PreM2d to the data and the postprocessor PstM2d for the model results, also developed by Crea Company, were used to manage the interactivity with the user.

At first the model TelmH2D has been tested in the case of a prismatic channel having characteristics equivalent to the real lower watercourse of Piave river. After having found an analytical solution for this simple case in permanent motion conditions, the model results have been compared obtaining a perfect approximation of the same solution.

Subsequently the model has been applied to simulate the hydrological flood event of the period 25/11/2002-29/11/2002. During this event the water levels of Piave river have raised to almost lick the summit portion of the banks of the river, causing great alarm for the whole population.

This study has achieved an important result. Before this study it was believed that Piave river could transport a discharge near to or more than 3000 [m^3/s]. These, in fact, were the conclusions obtained by the previous researches realised to analyze the hydraulic behaviour of Piave river.

On the other side we have to remember, also, that this river was responsible, in November 1966, of a very catastrophic flooding event for its entire basin, with great damages and many deaths.

On the contrary, this study demonstrates, unequivocally, that the maximum value of the flow that can be transported by the lower course of Piave river is 2000 [m^3/s], diminishing a lot the return time for the river flooding and, at the same time, increasing the need for action to prevent further catastrophic events.

As a result of our experience we believe that, in order to obtain good results from the application of mathematical models, two components are necessary, both extremely important.

The first one is naturally constituted by the need to use a mathematical model of an undoubted quality as TELEMAC-2D, which, for example, is able to solve the nonlinear terms of the hydrodynamic two-dimensional shallow water equations with the most appropriate method of the characteristic curves.

The second, fairly important in our experience, is tied to the design of the finite element mesh, which must be able to follow the cross linked flow constituted by the orthogonal curves of the current and equipotential lines, a priori identified by the skilful designer engineer.

ACKNOWLEDGEMENT

This work was founded through the Jesolo Municipality (VE), to which manager Dr. Gianni Favaretto go in particular our thanks. We are pleased to thank also Dr. Francesco Maicu for his support. Secondly, we thank the High Adriatic Sea Authority (VE) which has made available its DEM database, with its orthophotos, taken over in 2004, and has given its kind readiness in the different phases of the work.

REFERENCES

[1] Autorità di Bacino dei fiumi Isonzo, Tagliamento, Livenza, Piave, Brenta-Bacchiglione, “Bacino del Fiume Piave – Piano Stralcio per la Sicurezza Idraulica del Medio e Basso Corso”, Comitato Tecnico, 2000.

[2] Autorità di Bacino dei fiumi Isonzo, Tagliamento, Livenza, Piave, Brenta-Bacchiglione, “Bacino del Fiume Piave – Progetto del Piano Stralcio per la Sicurezza Idraulica del Medio e Basso Corso”, Comitato Tecnico, 2000.

[3] Bates P.D., Stewart M.D., Siggers G.B., Smith C.N., Hervouet J.M. e Selin R.H.J., ”Internal and external validation of a two-dimensional finite element code for river flood simulations“, Proceedings of the Institutions of Civil Engineers, Water, Maritime and Energy, vol. 130, pg. 127-241,1998.

[4] Bates P.D., Anderson M.G., Hervouet J.M., ”Computation of a flood event using a two-dimensional finite element model and its comparison to field data“, Modelling of Flood Propagation Over Initially Dry Areas, American Society of Civil Engineers, New York, pg. 238-248, 1994.

[5] Brooks A.N., Hugues T.J.R., ”Streamline Upwind Petrov Galerkin Formulations for Convection Dominated Flows with Particular Emphasis on the Navier-Stokes Equations“, Computer Methods in Applied Mechanics and Engineering. pg. 199-259, 32, 1982.

[6] D’Alpaos L., Defina A., “Modellazione matematica del comportamento idrodinamico di una zona di barene solcate da una serie di canali minori”. Istituto Veneto di SS.LL.AA., volume XII, Venezia 1995.

[7] D’Alpaos, Ipros S.r.l., “Studio finalizzato al riconoscimento delle aree di pertinenza idraulica e di sicurezza idraulica lungo il Piave a valle di Nervesa della Battaglia, mediante modello matematico bidimensionale”, Autorità di Bacino dei fiumi Isonzo, Tagliamento, Livenza, Piave, Brenta-Bacchiglione, 1997.

[8] Defina A., D’Alpaos L., Matticchio B., “A new set of equation for very shallow water and partially dry areas suitable to 2D numerical models”. Proceedings of Modelling of Flood Propagation Over Initially Dry Areas, ASCE Eds., Milano 1994.

[9] D’Alpaos, Dipartimento IMAGE Università di Padova, “Modello matematico bidimensionale per lo studio della propagazione delle piene nel fiume Piave tra Macchietto e la foce”, Autorità di Bacino dei fiumi Isonzo, Tagliamento, Livenza, Piave, Brenta-Bacchiglione, 2008.

[10] Garzon A., ”Taratura e calibrazione del modello idrodinamico 2-D agli elementi finiti“, Consorzio Venezia Nuova, Crea s.r.l., Gennaio 1995.

[11] Garzon A., Cecconi G., ”A Two Dimensional Semi-Implicit Finite Element Model for Tidal Propagation in the Venice Lagoon”, Proceedings of the Ninth International Conference on ”FINITE ELEMENTS in FLUIDS, New Trends and Applications”, Venezia, 15-21 Ottobre 1995.

[12] Garzon A., “Deformazione dell’onda di marea astronomica nella laguna di Venezia con l’utilizzo del modello matematico bidimensionale agli elementi finiti”, Consorzio Venezia Nuova, Crea srl , 1997.

[13] Garzon A., Tommasi E., “Fornitura di supporto tecnico alle attività di aggiornamento della schematizzazione del modello agli elementi finiti con le ultime rilevazioni batimetriche del 2000”, Consorzio Venezia Nuova, Crea srl, Aprile 2004.

[14] Ghetti A., Berti L., Scardellato E., “Studio per la sistemazione del Piave a difesa dalle piene”, Provincia di Treviso, 1970.

[15] Goutal N. , “Résolution des équations de Saint Venant en Régime transcritique par une methode d’élément finis. Application aux bancs decouvrants”, Thèse de doctoract de l’Université Paris VI.

[16] Hervouet J.M., ”Vectorisation et simplification des algorithmes en elements finis“, E.D.F. Bulletin del la Direction des Etudes et Recherches. Serie C, Mathematiques, Informatique, pg. 1-37, 1991.

[17] Hervouet J.M., ”Characteristiques and mass-conservation. New developments in Telemac-2D“, Rapport E.D.F. HE-43, 1992.

[18] Hervouet J.M.,”Telemac-2D. Version 3.0: Principle Note“, Sogreah, 2000.

[19] Hervouet J.M.,”Telemac-2D. Version 5.0: Validation Document“, Sogreah, 2000.

[20] Ministero dei Lavori Pubblici - Magistrato Alle Acque - Nucleo Operativo di Treviso - “Progetto di interventi straordinari di regimazione idraulica in alcuni tratti d’alveo riguardanti il fiume Piave”, Treviso, 1994.

[21] Rastogi A.K., Rodi W., ”Predictions of Heat and Mass Transfer in Open Channels“, Journal of the Hydraulics Division, ASCE, n. HY3, pg. 397-420, 1978.

[22] Tonini D., “Le piene nel Veneto, Friuli-Venezia Giulia nel novembre 1966”, Accademia Naz. dei Lincei - Quad. N.112: Atti del conv.: “Le scienze della natura di fronte agli eventi idrogeologici”, Roma, 1967.

[23] Ufficio Idrografico del Magistrato alle Acque di Venezia, “Piano di bacino del Piave - Fase conoscitiva 1° lotto - 3.1 Idrologia e climatologia - Relazione”, CBP Consorzio Bacino Piave, 1986.

[24] Zollet Ingegneria S.p.A., Studio Sicem S.r.l., “Indagine sulle portate massime convogliabili dall’asta principale del fiume Piave ai fini della difesa idraulica e valutazione dell’efficacia di interventi di moderazione delle piene - Prima fase”, Autorità di Bacino dei fiumi Isonzo, Tagliamento, Livenza, Piave, Brenta-Bacchiglione, 1993.