

A NUMERICAL MODEL OF THE WAVE THAT OVERTOPPED THE VAJONT DAM IN 1963

Silvia BOSA¹ & Marco PETTI²

(1) Department of Chimica, Fisica e Ambiente, University of Udine, Italy, email: silvia.bosa@uniud.it

(2) Department of Chimica, Fisica e Ambiente, University of Udine, Italy, email: marco.petti@uniud.it

ABSTRACT

The Vajont landslide took place in northern Italy on October 9th 1963 and caused a huge impulse wave to travel in the artificial reservoir and overtop the dam, flooding and devastating a considerable area along the Piave riverbed. In this event, about 1900 people died, 1700 of them in the Piave Valley alone.

The water depth of the wave in some points exceeded 50 m. Although the phenomenon is clearly tridimensional, the application of a pure 3D hydraulic numerical model to this wide and natural territory is very difficult. Recently, the authors have presented a numerical model of the impulse wave that wasted the Vajont basin as a consequence of the landslide (Bosa and Petti, 2011). In this paper, a 2DH numerical model is applied to study the effects of the overtopping wave in the Piave Valley, in order to verify if the simplifications assumed by a 2DH model still make it possible to describe the evolution of the wave in the proper manner.

1 INTRODUCTION

On October 9th 1963 at 22:39 a huge landslide of about 270 million m³ slid from Mount Toc into the Vajont artificial reservoir, in north-eastern Italy (Schnitter, 1964, Slingerland and Voight, 1980, Datei, 2003, Genevois and Ghirotti, 2005). The amount of water in the basin at that moment was about 115 million m³. The resulting displacement of water caused the generation of an impulse wave that spread throughout the basin. Its impressive runup on the north slope of the lake, in front of Mount Toc, reached and damaged buildings located in Casso about 235 m over the original height of the lake surface (Fig.1a). The resulting rundown wave crashed into the landslide front and partially crossed over the slide bulk, reaching the depressions behind the slide (Fig.1b). On the east side of the basin, a portion of the water which was pushed forward by the landslide, formed a wave with smaller amplitude that travelled to the east, reaching the eastern most end of the reservoir in the mountains.

During the whole event several impulsive waves crested the dam or moved onto the surrounding slopes which became a way for the water to move out into the narrow canyon that connects the dam to the Piave Valley (Bosa and Petti, 2011). First, a direct wave reached the dam and the right hand slope of the canyon, generating a first

overflowing wave; then a rundown wave moved over the same areas. During the rundown, part of the water impacted against the landslide and it was redirected towards the dam and the left hand slope of the canyon, giving rise to another outgoing wave (Fig.1b-c). Later on, a portion of the water that jumped over and crossed the slide bulk flowed out over the left hand slope of the canyon (Fig.1d). To sum up, there were different impulsive waves that moved out of the Vajont basin and combined together in the canyon which then reached the Piave river at Longarone and flooded and partially destroyed the Piave Valley. The villages located along the riverbed were completely devastated and turned into a flat plain of mud, with about 1700 casualties. The wave travelled upstream for about 5 km and in the downstream cross-sections of Ponte nelle Alpi and Belluno (located respectively at about 11 and 19 km from Longarone) the estimated maximum flow was 20% – 50% higher than the one observed during the famous 1966 flood wave (Reberschak, 2003, Bondesan et al., 2004).

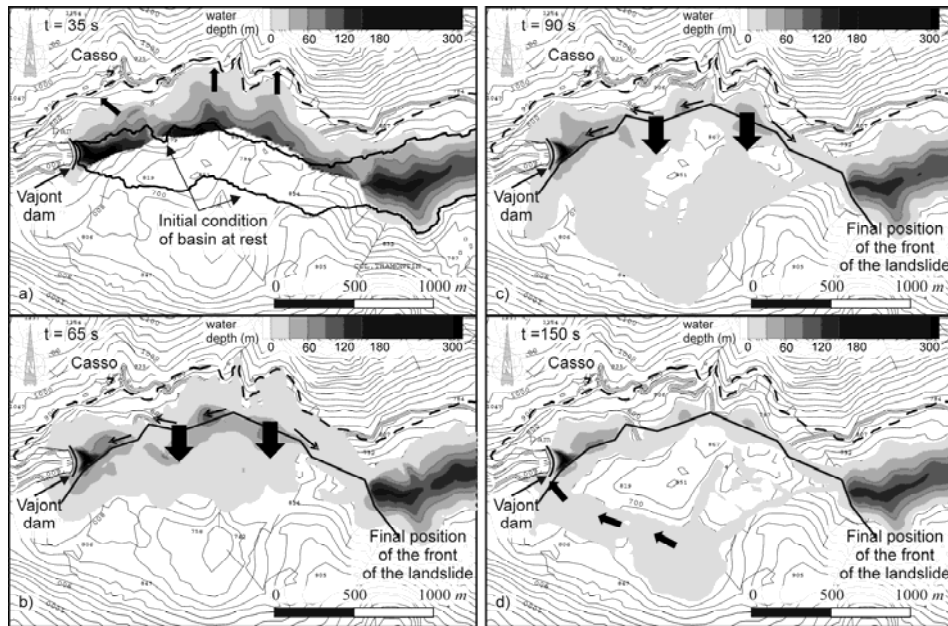


Figure 1. Simulation with landslide duration 45s: water depth at sequential time steps; the dashed line represents the observed runup limit, the continuous line is the initial basin (a) or the final position of the front of the landslide (b – d).

Documentation available in literature consists mainly of historical pictures of the Piave Valley in the days just after the event. This allows one to estimate the maximum runup of the wave in the villages located along the riverbed, based on the depicted damages. The evaluation of the time of propagation of the flow is much more debated. This is mainly based on witness statements, so that the time estimated to cover the path from the dam to Longarone ranges from 60 s to 4 min, for instance (Reberschak, 2003).

Also, the reconstruction of the hydrograph that overtopped the dam is not easy. In literature only an approximate evaluation of the water volume which poured over the dam was carried out, on the base of estimations of the water volume in the Vajont basin

before and after the event.

Numerical models can be used in engineering practice as an aid to study hydraulic critical situations in country planning in order to prevent environmental disasters. Nevertheless, before a numerical model can be considered useful in applied research with the community benefiting from its applications, it must overcome at least two steps of verification. First, it must be applied to benchmark tests with an analytical solution or to small scale laboratory tests. After that, the model can be verified on a large scale on site (see for example Nwe and Tokuzo, 2010). The first step alone does not ensure that the model works in a proper way in wide and complex natural domains. Moreover, one would often like to apply the models to real events which do not exactly match hypotheses made during the development of the model itself. Hence, the applicability of the model to unusual situations must be tested with particular care.

The Vajont event was clearly a tridimensional phenomenon, but with the present computer technologies, 3D models are still not applicable to natural and wide topographies. In this paper a 2DH numerical hydraulic model of the propagation in the Piave valley of the wave that flowed over the Vajont dam is presented with the aim of evaluating if a 2DH numerical model is able to describe this event in its main aspects, in spite of all the simplifications implied in the model.

The paper is organized in the following manner. The numerical model is briefly recalled in the following section. In section 3 the numerical simulations of the wave generated by the Vajont landslide inside the reservoir (Bosa and Petti, 2011) are briefly described and the hydrographs of the waves that flowed towards the Piave river are analysed. In section 4, the numerical simulation of the wave that overtopped the dam and flooded the Piave valley is described and the results are discussed and compared with direct evidence.

2 NUMERICAL MODEL

In the present modelling, bidimensional shallow water equations are used:

$$\begin{cases} \frac{\partial h}{\partial t} + \frac{\partial Uh}{\partial x} + \frac{\partial Vh}{\partial y} = 0 \\ \frac{\partial Uh}{\partial t} + \frac{\partial}{\partial x} \left(U^2 h + \frac{gh^2}{2} \right) + \frac{\partial UVh}{\partial y} = -gh \left(\frac{\partial z_b}{\partial x} + S_{fx} \right) \\ \frac{\partial Vh}{\partial t} + \frac{\partial UVh}{\partial x} + \frac{\partial}{\partial y} \left(V^2 h + \frac{gh^2}{2} \right) = -gh \left(\frac{\partial z_b}{\partial y} + S_{fy} \right) \end{cases} \quad (1)$$

being (t, x, y) temporal and horizontal spatial coordinates, h water depth compared to the bottom, U and V mean velocity over the depth in x - and y - directions, g gravity acceleration and z_b bottom height. S_{fx} and S_{fy} are friction slope in x - and y - directions and are evaluated through the Manning equation:

$$S_{fx} = n^2 \frac{U \sqrt{U^2 + V^2}}{h^{4/3}}, \quad S_{fy} = n^2 \frac{V \sqrt{U^2 + V^2}}{h^{4/3}}, \quad (2)$$

n being Manning roughness coefficient.

The numerical scheme used to solve system (1) has already been described in Bosa and Petti (2011) and consists of a second order accurate temporal discretization and a second order accurate finite volume scheme spatial discretization over quadrangular irregular elements. Particular care is taken in the solution of the local Riemann problem, where the HLL approximate Riemann solver is coupled with minmod limiters.

Boundary conditions used in the present numerical scheme are classical transmissive or outflow boundary conditions, reflective or wall boundary conditions and inflow boundary conditions.

3 NUMERICAL SIMULATION OF THE WAVE GENERATED BY THE VAJONT LANDSLIDE IN THE RESERVOIR

The phenomenon that gave rise to the impressive wave that inundated the Piave Valley on October 9th 1963 was a huge landslide that fell into the Vajont artificial reservoir. A portion of the water present in the basin overtopped the dam and reached the Piave Valley through a narrow canyon. Thus, the landslide, the wave inside the artificial reservoir and the flooding downstream of the dam are definitively bounded, so they should be studied together. Nevertheless, the area interested by the event is too wide to be analysed in detail by a single model. Therefore, first the Vajont basin was studied (Bosa and Petti, 2011) and then the Piave Valley.

The Vajont Valley was represented through a mesh made up of about 133000 quadrangular irregular elements. The cell surface ranged between 0.7 and 500 m², where the smaller ones were used to describe the upstream face of the dam. The bottom height was first assigned according to current numerical cartography and then corrected using maps of the valley as it was before October 9th 1963 (Rossi and Semenza, 1965). Areas characterized by homogeneous Manning roughness coefficients were estimated by means of numerical cartography and historical pictures, where available. Initial conditions were those of a basin at rest, as it was before the landslide occurred. The Vajont landslide was an extraordinary large, partially submerged rockslide with a thickness of about 200 m, that pushed forward the water as if it were a piston. Thus, in the model, the landslide was depicted as a moving impermeable vertical wall located at the landslide front; therefore, the headway of the slide is represented as a wall that pushed the water towards the slope in front of it, just below the village of Casso. The bottom height of the cells intercepted by the landslide was updated after the passage of the front with the post landslide elevation deduced by the post event maps (Rossi and Semenza, 1965). Moreover, after the landslide stopped, the moving landslide boundary condition was removed to allow the rundown wave to cover the areas previously filled by the landslide (Bosa and Petti, 2011). The time-length of the landslide, from start to finish, is a highly discussed theme in Vajont literature (Müller, 1964, Selli and Trevisan, 1964, Ciabatti, 1964, Caloi, 1966, Datei, 2003). In order to try and estimate this time-length some tests were conducted with different sliding durations and the numerical results were compared in terms of the maximum runup limit with a map of the observed runup limit on the slope in front of Mount Toc, between the dam and the village of Erto (Rossi and Semenza, 1965). For each simulation, the root mean square of the runup error was evaluated and the result shows a minimum height error for sliding duration ranging between 40 and 55s, with no significant variation inside this interval.

Moreover, the same tests were conducted doubling and halving the set of Manning roughness coefficients, obtaining no significant difference in the results with regard to the runup when the sliding duration was ranging between 40 and 55s. This shows that the influence of the flow resistance set is not very significant in this kind of phenomena, which is mainly dominated by the momentum.

In Fig.1 the results of the simulation with landslide duration 45s are depicted as a contour of water depth together with observed runup limit by *Rossi and Semenza* (1965) and final position of the front of the landslide. The direction of the main waves involved in the event is also indicated.

In particular, Fig.1a shows the situation during the movement of the front; here the water displaced by the landslide boundary condition forms a single direct wave that moves to the slope opposite to Mount Toc (direction north), where it almost reaches the observed runup limit. During this phase part of the water was pushed over the dam and left the basin.

In Fig.1b the behaviour of the main rundown wave that impacts against the landslide front is presented. Part of the water moves along the landslide front, directed either towards the east part of the basin or towards the dam (thin arrows), while the rest crossed over the slide bulk (thick arrows) and it either inundated the depression behind the slide itself, or it reached the left hand wall of the canyon and it definitively left the basin (Figs.1c-d).

Particular care was taken in the analysis of the water that left the Vajont valley to then reach the Piave valley through a narrow canyon. This flow was evaluated over several sections (Fig.2): 3 dam sections (DN, DC and DS) that take into account the water overtopping the dam, 7 sections located on the right hand slope of the canyon (R1 to R7) and 5 sections located on its left hand slope (L1 to L5). The sections were designed to be as perpendicular as possible to the maximum slope direction and their contribution to the water reaching the Piave Valley is then summed up to give the flow crossing the entire slope (R and L) or the dam (D). The contribution of water volume greatly decreases as soon as it moves away from the dam, so that on the right hand side the water volume through R4, R5, R6 and R7 was 11738 m^3 , i.e. only 0.33% of the amount of water through whole right hand side slope. On the other side, sections L4 and L5 were completely dry.

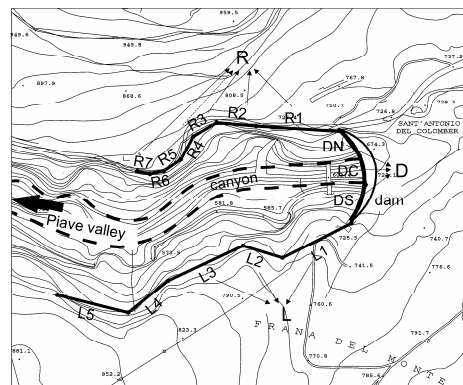


Figure 2. Sections used to evaluate the flow leaving the Vajont valley and directed to the Piave River.

The flow hydrographs over the right slope (R), the dam (D) and the left slope (L) are depicted in Figs.3 and 4, together with the main contributions of the single sections. Fig.3a shows that the right hand slope has a hydrograph characterized by two narrow peaks, where the former is much higher than the latter (188×10^3 vs 47×10^3 m³/s). Moreover, the two peaks are separate, the former being due to the first direct runup wave and the latter due to the rundown wave. The contribution of section R1 is predominant and the input of R2 and R3 only concerns the first peak. At 100 s the flow over both sections is almost zero, underlining the impulsive nature of this hydrograph.

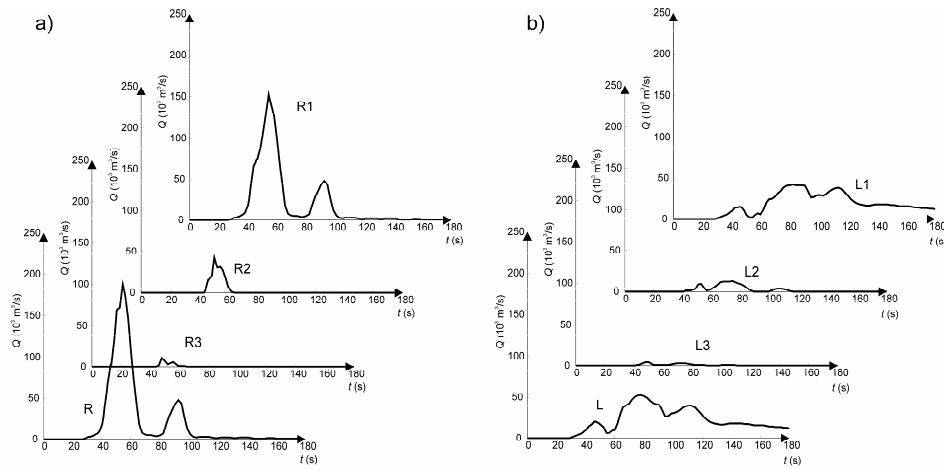


Figure 3. a) Flow hydrograph over right hand side slope (R) with its main contributions: R1, R2 and R3 together supply 99.68% of its whole water volume. b) Flow hydrograph over left hand side slope (L) with its contributions: L1, L2 and L3.

On the left hand slope (Fig.3b) the major contribution is due to section L1, while sections L2 and L3 give only a small input to each of the three peaks. In this sense, the situation is similar to that of the right hand slope, i.e. the further a section is from the dam the smaller its contribution is to the resulting hydrograph. Nevertheless, here the peak reached by the flow is very low, compared to those of the right hand slope or of the dam (53×10^3 vs 188×10^3 m³/s), but it lasts longer, being at 180 s still 13×10^3 m³/s. This is the reason for which the total water volume that flowed over left hand slope is higher than over right hand slope (5.11×10^6 vs 3.61×10^6 m³).

The flow over the dam is shown in all its contributions in Fig.4. The input of the three sections is very similar for both the peaks flows (82×10^3 vs 75×10^3 vs 79×10^3 m³/s) and the hydrograph form; moreover, the total water volume which flowed through sections DN, DC and DS is also similar (3.47, 2.86 and 4.49 million m³).

Integration of the hydrographs gives the total water volume that flowed out of the basin, estimated at 19.54 million m³, which is the sum of the contribution of right-, dam- and left- sections (3.61, 10.82 and 5.11 million m³).

All these hydrographs and the time series of the mean water depth over each section are applied as boundary conditions to the study of the Piave Valley as will be discussed later on.

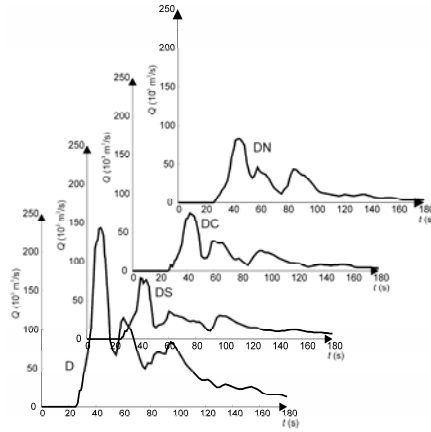


Figure 4. Flow hydrograph over the dam (D) with its contributions: DN, DC and DS.

4 EVOLUTION OF THE WAVE IN THE PIAVE VALLEY

The area which is the object of this study begins at the crest of the Vajont dam, follows the canyon and reaches the Piave Valley near the town of Longarone; from this point it extends to the north up to Ospitale di Cadore and to the south just after Belluno in the west and to the Santa Croce Lake in the east making up a surface of about 32 km² (Fig.5a).

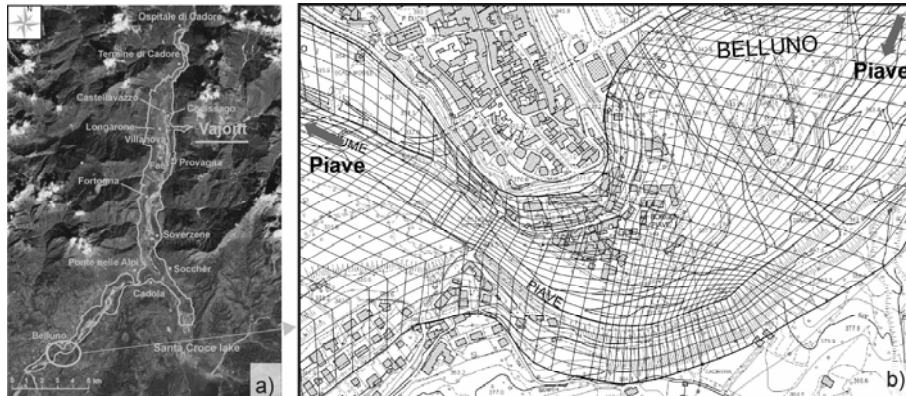


Figure 5. a) Area covered by the study and mesh boundary. b) Zoom of a portion of the mesh near Belluno.

The mesh was developed by using the Italian numerical cartography at the scale 1:10000 and has almost 54000 quadrangular irregular elements (Fig.5b), with cell surfaces ranging between 5 and 3100 m², where the larger ones are located along the Piave riverbed in areas that are not involved by the flow and the smaller ones on the downstream face of the dam.

The bottom height was assigned by means of numerical cartography at the scale

1:5000; nevertheless, the canyon and the steep slopes where the water came into the domain were made more regular to assure the inflow boundary conditions work in a proper manner.

The Manning coefficient was assigned to homogeneous roughness classes deduced from cartography, aerial photographs and some historical pictures. The classes into which the territory was subdivided and the assigned Manning coefficients are shown in Fig.6 and Tab.1. In this paper, the flow resistance due to buildings is considered as if they were high density vegetation.

Table 1. Range of Manning roughness coefficient representative of various bottom materials.

Manning coefficient	gravel	high density vegetation	medium density vegetation	low density vegetation	rock
$n \text{ (s/m}^{1/3}\text{)}$	0.024	0.045	0.030	0.025	0.020

The boundary conditions applied to the model were inflow boundary condition at Ospitale di Cadore in the north, outflow boundary conditions at the two southern ends of the domain near Belluno and the Santa Croce lake and wall boundary conditions along all other boundaries. The only exceptions are represented by the sections surrounding the eastern extremity of the canyon that forms the conjunction between the Piave Valley and the Vajont Valley domains (R1 to R7, DN, DC and DS and L1 to L5 as shown in Fig.2). Here, hydrographs and water depth were imposed as they were deduced from the simulation performed in the Vajont basin. Moreover, the inflow at Ospitale di Cadore was negligible compared to the water entering the mesh through the canyon and for this reason the inflow at the northern end of the mesh was set to zero.

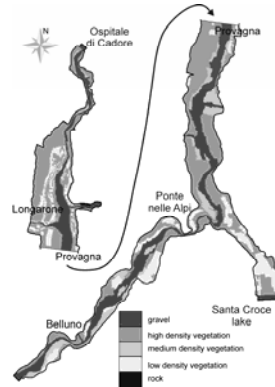


Figure 6. Surface roughness homogeneous areas. As rock areas are limited in the canyon between the dam and Longarone, they are not very visible on the map.

The initial conditions were those of a dry bed, i.e. any pre-existing tiny flow in the Piave river was neglected.

4.1 Numerical results compared with literature data

Hereafter the numerical results of the simulation in the Piave Valley are presented, starting from the canyon and Longarone and then proceeding first towards the north and then to the south. All mentioned villages are displayed in Fig.5a. The simulation begins

when the landslide in the Vajont basin set in motion. So until the wave reached the dam and the canyon slopes, the hydrographs were zero as shown in Figs.3 and 4. The overtopping of the dam took place at about 24 s from the beginning of the simulation, i.e. the wave entered the canyon at this time.

The front of the wave reached the mouth of the canyon at about 55 s (Fig.7a); thus the mean velocity of the wave in the canyon is estimated to be about 45 m/s, about 1400 m being the length of the canyon, from the dam to the mouth. In literature there is not a firm evaluation of the time needed to cover this path, with values ranging from 60 s to 4 minutes (Reberschak, 2003). The maximum water depth of the simulation (63÷67 m) was registered at the mouth of the canyon first at 1'20'' and then again at 1'50'' with flow velocities ranging between 40 and 50 m/s. Moving to the west to the river bed of Piave river, the water depth decreased to 20÷30 m but there were higher velocities (up to 65 m/s at 1'). These values agree with direct evidence that talks of a water depth of about 70 m at the end of the canyon (Reberschak, 2003).

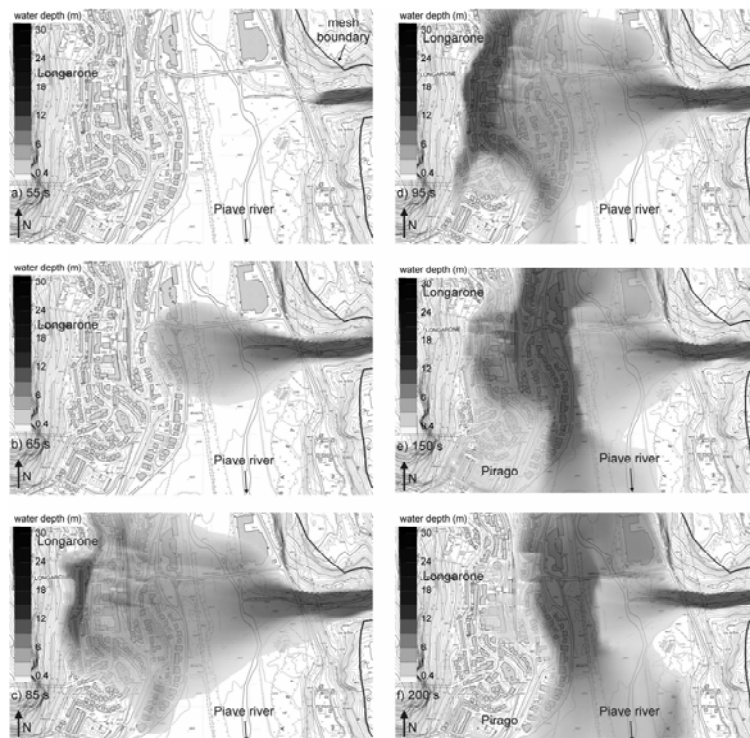


Figure 7. Wave evolution at the mouth of the canyon in front of Longarone.

At about 1'10'' the wave collided with the lowest hamlet of Longarone, located in front of the mouth of the canyon (Fig.7b). Here, maximum water velocity in the town of Longarone was reached twice, first at about 1'25'' and then at 2'05'' with velocity of about 40÷45 m/s and water depth of 5÷10 m. The centre of Longarone was flooded at about 1'10''; at about 1'25'' the maximum runup was reached at height 550 m in the western most side of the town (Fig.7c). Direct evidence talks of a runup height of about

80 – 100 m compared to the Piave riverbed, as can be deduced from Fig.8, where Longarone is depicted before and after the event and where the lowest part of the Murazzi terraces are recognizable as the maximum runup limit.

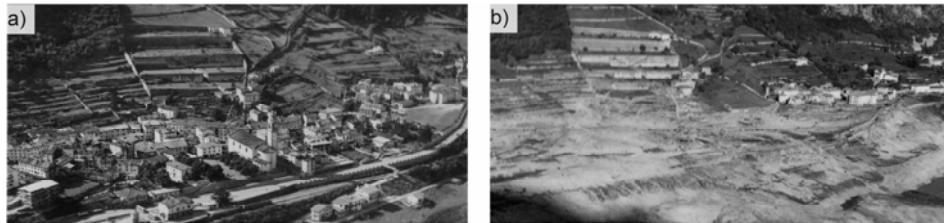


Figure 8. Longarone before (a) and after (b) the wave. In the upper part of the pictures the Murazzi terraces are visible as the maximum runup limit (Comune di Erto e Casso, 2002).

The consequent rundown wave between 1'25'' and 1'50'' brought a water depth of about 30÷40 m into the town with velocities of 4÷8 m/s. This water depth remained in the town for quite a long period as visible in Figs.7d and 7e because the rundown wave collided with the direct wave coming from the canyon causing repeated runup waves of lower intensity. The wave only definitively left the town of Longarone and flowed back in the Piave bed after about 3'20'' (Fig.7f).

A share of the rundown wave moved towards the south, completely covering the village of Pirago (Fig.7e-f and Fig.9).



Figure 9. Pirago's bell tower: the only building left standing in the village after the transit of the wave (Zanfron, 2006).

A portion of the wave coming from the dam went up the Piave river towards the north, causing major damage to the village of Codissago, located on the left riverbank, with the total destruction of some buildings and minor damage to the villages on the right riverbanks in a higher position over the river bed. The northern most point touched by the wave is not well defined in literature: some witnesses reported that the wave did not reached the village of Termine di Cadore (located about 5 km upstream from Longarone) and that it stopped at about 600 m from it (Longarone, 2008); nevertheless, reports from the local Fire Department talk of finding corpses all along the Piave river from Longarone to Termine di Cadore. In the numerical simulation, the northern most section reached by the wave was located about 510 m north of Termine di Cadore along

the river (Fig.10).

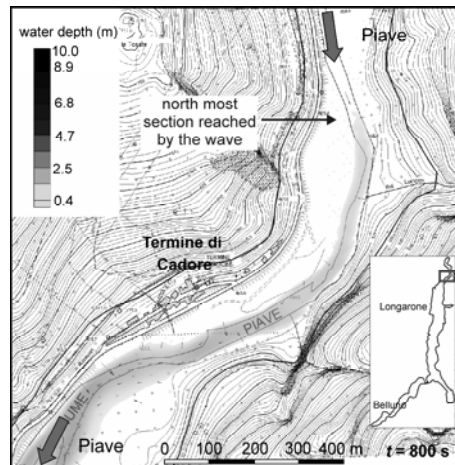


Figure 10. Northern most section reached by the wave during the simulation.

Moving from Longarone towards the south, the simulated wave spread all over river bed and holms, reaching the main “Alemagna” road on the right riverbank, but was contained by the steep slope on the opposite side of the river (Fig.11a). All the villages on the left riverbank are located higher than river bed and so they were not quite touched by the wave (Dogna, Provagna, Soverzene, Soccher, etc.) and this is in agreement with literature (Longarone, 2008).

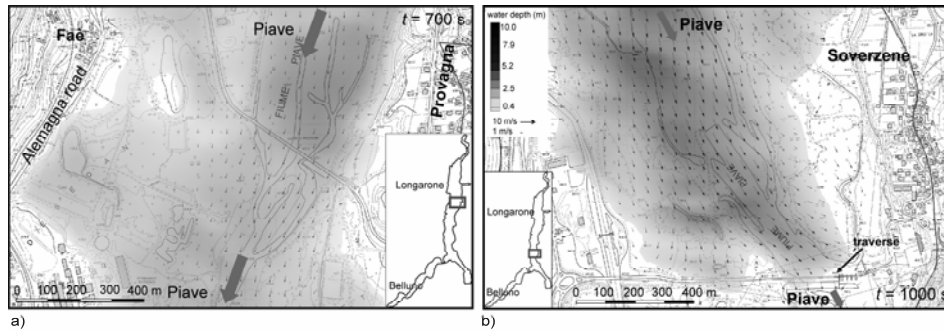


Figure 11. a) The wave travelling along the Piave river near Provagna and Faè. On the left riverbank the water is contained by a steep slope and on the right riverbank it reaches the Alemagna road. b) The wave travelling along the Piave river near Soverzene.

Just downstream of Soverzene there is a hydroelectric power station and a traverse. The simulated wave reached this area about 17' after the beginning of the slide motion, i.e. it covered the path from the canyon mouth to Soverzene (about 7.5 km) with a mean velocity of 8 m/s (Fig.11b). In literature, it is reported that this distance was covered in 21 mins, at the mean velocity of 6 m/s (Reberschak, 2003).

Moving to the south, the Piave river approaches Ponte nelle Alpi, with a very meandering stream; here the wave arrived after 34' from the beginning of the

simulation; maximum values for water depth and flow (14.5 m and 3130 m³/s respectively) were observed between about 1h05' – 1h25' (Fig.12a). Further downstream is Belluno which was reached by the wave after 1h15' and where the maximum values for water depth and flow (10 m and 3180 m³/s respectively) were observed between about 1h50' – 2h05' (Fig.12b). Water depth and flow indicated in literature are 12 m and 4000 – 5000 m³/s both in Ponte nelle Alpi and Belluno (Reberschak, 2003).

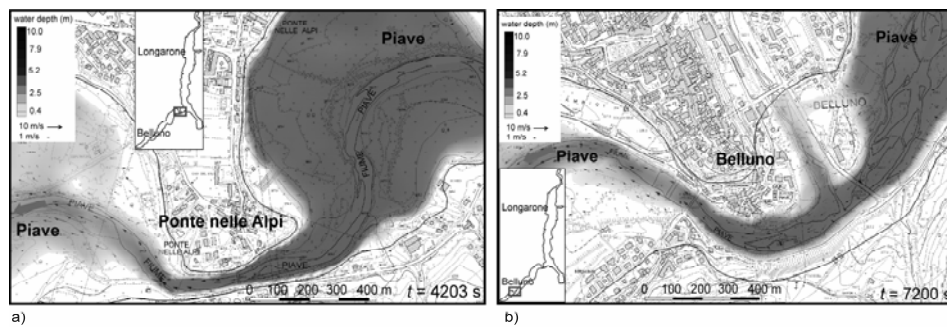


Figure 12. The wave travelling along the Piave river near Ponte nelle Alpi (a) and Belluno (b).

5 CONCLUSIONS

A 2DH finite volume numerical model was applied in order to study the wave that overtopped the Vajont dam and spread out in the Piave valley as one effect of the huge landslide of about 270 million m³, that fell into the Vajont artificial reservoir on October 9th 1963.

In a previous paper (Bosa and Petti, 2011), the authors described the consequences of the slide in the Vajont basin, recognizing the formation of different waves. The direct wave moved to the slope opposite to Mount Toc, where it showed an impressive runup of about 270 m. The following rundown spread all over the slope: to the east part of the basin, against the slide and to the west, flowing out of the basin over the dam and surrounding slopes of the narrow canyon that connects the dam to the Piave Valley.

In this paper, the evolution of the wave generated by the landslide inside the artificial reservoir is briefly recalled. The hydrographs of the flows that left the Vajont basin are analysed in detail in all their contributions, as they represent the inflow boundary condition for the study of the evolution of the wave that inundated and partially destroyed the Piave Valley. Moreover, a numerical finite volume model of the valley from Ospitale di Cadore to Belluno and the Santa Croce lake was developed to study the effect of the wave over a significant area. The results have been analysed in depth and compared to data available in literature. These consist mainly of historical pictures before and after the event, where damages due to the wave are clearly visible and that allow an initial estimate of the runup limit of the wave over the slopes and in the villages surrounding the riverbed. Moreover, a number of witness statements are available, mainly concerning the runup limit and propagation times of the wave.

The comparison of numerical results with direct evidence shows that the wave is described in a proper manner, where both the wave speed and runup limit are almost in

accordance with the observed effects of the real event.

In this way, this kind of model seems to be suitable for the study of the evolution of an impulsive wave like the one generated by a huge landslide, as in the Vajont case. This is an important result, because, even if the phenomenon to be studied is 3D, it encourages the use of 2DH models which can be more easily applied to large natural domains compared to 3D models.

REFERENCES

- Bondesan A, Caniato G, Vallerani F, Zanetti M. 2004. *Il Piave*, CIERRE, Sommacampagna (VR), (in italian).
- Bosa S, Petti M. 2011. Shallow water numerical model of the wave generated by the Vajont landslide. *Environmental Modelling & Software*, 26 (2011) 406–418, DOI: 10.1016/j.envsoft.2010.10.001.
- Caloi P. 1966. *L'evento del Vajont nei suoi aspetti geodinamici*. Ist. Naz. Geofisica, Roma (in italian).
- Ciabatti M. 1964. La dinamica della frana del Vajont. *Giornale di Geologia* 32: 139-159 (in italian).
- Comune di Erto e Casso, Parco Naturale Dolomiti Friulane. 2002. *Materiali della mostra permanente del centro visite di Erto* (in italian).
- Datei C. 2003. *Vajont. La storia idraulica*. Cortina, Padova (in italian).
- Genevois R, Ghirotti M. 2005. The 1963 Vajont Landslide. *Giornale di Geologia Applicata* 1: 41-52.
- Longarone. 2008. *Testimonianze dirette di persone che hanno vissuto in prima persona l'evento del ottobre 1963* (in italian).
- Müller L. 1964. The rock slide in the Vajont valley. *Felsmechanik und Ingenieur Geologie* 2: 197-199.
- Nwe, T., Tokuzo, H. (2010). Sediment transport due to flooding from levee breach: a numerical application of the 2004 Niigata flood. *International Journal of River Basin Management*, 8(1), 3-14. doi:10.1080/15715121003714993.
- Reberschak M. 2003. *Il grande Vajont*, CIERRE, Verona (in italian).
- Rossi D, Semenza E. 1965. *Carte geologiche del versante settentrionale del M.Toc e zone limitrofe, prima e dopo il fenomeno di scivolamento del 9 ottobre 1963*, Scala 1:5000. Ist. Geologia Università di Ferrara. 2 Maps.
- Schnitter G. 1964. Die Katastrophe von Vajont in Oberitalien. *Wasser- und Energiewirtschaft* 56 (2/3): 61-69 (in german).
- Selli R, Trevisan L. 1964. Caratteri ed interpretazione della frana del Vajont. *Giornale di Geologia* 32 (in italian).
- Slingerland R, Voight B. 1979. Occurrences, properties and predictive models of landslide-generated impulse wave. *Rockslides and avalanches* 2: 317-397, Voight B. ed. Elsevier, Amsterdam.
- Zanfron B. 2006. *Vajont 9 ottobre 1963 – cronaca di una catastrofe*, Tipolitografia Print House, Cortina d'Ampezzo (BL) (in italian).