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NUMERICAL ANALYSIS OF A BREACH IN A LATERAL FLOOD DEFENSE EMBANKMENT

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Abstract: The paper presents a discrete 1D / 2D numerical model with the formation of a breach in the defense embankment on the left bank, Bârzava river at Resita area, at the appearance of an extraordinary flood wave and configuration given by a synthetic hydrograph. The uncertainty parameters at the failure gap formation are obtained from a probabilistic sampling application of the predefined statistical distributions with the external control program McBreach by Kleinschmidt [8] and the automatic running with HEC-RAS version 5.07 [7] hundreds of times, using the Monte Carlo method. The numerical simulation aims to form the gap in the defense embankment on the left bank on the river Bârzava, estimating the floodable area and establishing the parameters of transient hydraulics in the vicinity of an area associated with new structural investments in the near future.

Keywords: dam breach modelling, high waters, flood protection, numerical model

1. GENERAL CONSIDERATIONS

The Bârzava River springs in the Semenic Mountains, Caraș-Severin County, a mountainous group of the Banat Mountains, located on the territory of Caraș Severin County. The Bârzava River has a reception basin of 1190 km2, a length of 166 km of which 127 km in Romania. The Bârzava River also flows through Timiş County, Vojvodina Province in Serbia and then flows into the Timiş River, on the territory of Serbia. The Ţerova brook is an important tributary on the right and has a confluence in the municipality of Reșița. When modeling the geometry of the Bârzava riverbed, a section of approx. 6042 m on the administrative territory of Reșița Municipality, location bordered to the North by the Road Bridge on DJ 582, and to the South by the Calea Timişoarei-Reșița Road Bridge (see Figure 1-left)

Figure 1. Plan view of River Bârzava (left) and plan view detail (right) in Reșița locality

The documentation [1] describes a database concretized by a site plan (topographic survey in Stereo 70), 121 transversal profiles (framed by the flood defense embankments and which highlight the morphology of the riverbed and floodplains; the modeled surface includes approx. 14541 distinct points in geographical coordinates and terrain elevations). In order to make new investments in a possible area that may be floodable (see Fig.1-right), it is necessary to perform a discrete numerical simulation in case of transit of an extraordinary flood wave that will reach the maximum flow value with the probability exceeding Q0.2%. HEC-RAS vers. 5.07 [7] is a hydrodynamic software that can also simulate the failure of a defense embankment with one-dimensional (1D) and / or two-dimensional (2D) equations. McBreach © version 5.07 [8] is an external control software application that facilitates the probabilistic modeling of a structure failure by sampling the parameters of the predefined statistical distribution failure and the automatic running with HEC-RAS vers. 5.07 thousand times, using the well-known Monte Carlo method. The probabilistic analysis of the failure of a structure will thus contribute to the quantification of the uncertainties associated with flood mapping and the associated potential risk, attributed to the

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probabilities of exceeding the peak flows flowing through the structure and the resulting flood maps. For the hydraulic calculations and verifications necessary to determine the variation of the water level, the flow velocity regime and the transit mode of the water flows on the Bârzava river, in the associated area of Reșița municipality, the following elements are known: maximum flows with different exceedances, the probabilities of exceeding 1% and 0.2%, Q1%, = 140 m3 / s and Q0.2% = 204 m3 / s; the appearance of the flood hydrograph; roughness coefficients in the channel riverbed and floodplains; hydrodynamic slope of the water flow in the section downstream of the analysis section (i = 4.017 ‰).

McBreach © version 5.07 can randomly test predefined statistical distributions for all parameters of failure of linear structures (dams), side structures and associated 2D connections. In addition to the yield parameters, the user may include the flow hydrography of the numerical model in the probabilistic analysis by random sampling of the flow hydrograph and duration multipliers. A Monte Carlo simulation with McBreach © version 5.07 produces peak flows with different probabilities of exceeding, respectively, determines all the parameters of the sampled failure that can then be used to produce flood maps with different probabilities of exceeding. Therefore, McBreach © version 5.07 allows decision-making based on risk and uncertainty and compliments the safety wishes of structures and leads to informed decisions about risks and uncertainties in decision-making.

Execution in HEC-RAS vers. 5.07 in a Monte Carlo uncertainty exercise, it requires many hundreds or even thousands of achievements to achieve statistical convergence of the mean and standard deviation, which is why a truncated version of the discrete numerical model is made. Upon completion of McBreach © version 5.07, the user reproduces the sets of predefined failure parameters for peak flow, places them in the discretized integer numeric model, and then maps the flood extensions to them. This is usually done automatically in the eight sets of failure parameters (eg, probability of exceeding 0.2% and by default: 1%, 5%, 10%, 50%, 90%, 95%, 99%).

For the graphical realization of a terrain in 3D representation, the satellite graphics given by Earth Explorer are usually used. A very useful method for graphically processing discrete topographic data known from topographic surveys is presented in documentation [10], [11] and [12]. The method uses a 2D graphical interpolation topographic program, from which a 3D shape surface (shx extension) can then be generated. This surface is then loaded into ArcMAP 9.3 [4], divided by discrete triangular elementary surfaces and resulting in a final 3D spatial shape type TIN (Triangulated Irregular Network). In order for this spatial form to be recognized by the RAS Mapper module (graphical processing or post-processing in the HEC – RAS 5.07 program [7]), it is necessary to convert it into a file with an accessible grid-loading form (DTM) (Digital Terrain Model). From the current configuration of the natural terrain, originating the spatial points (x, y coordinates and terrain elevation) resulting from the standard topographic survey - Stereo 70 [1] and the graphic processing of the 3D geometric surface (traversing the different types of procedures in discrete numerical modeling can be seen in detail in the numerical modeling [10], [11] and [12], respectively, in the technical documentation [5] and [6]), the final 3D spatial configuration of the flow, visible in the graphical representation in (Figure 2)

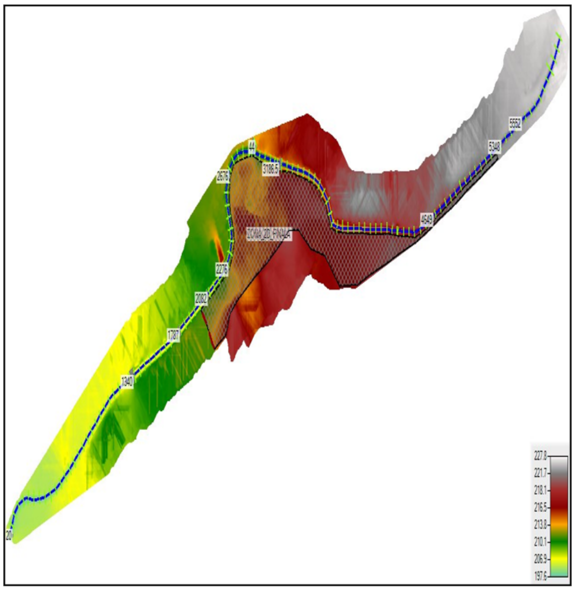


Figure 2. Combined discrete numerical model: 1D (River Bârzava and Țerova tributary), respectively, 2D (2D discretization and fictive lateral structures on the left bank – notation: “5296” and “2898”)

2.NUMERICAL SIMULATION

2.1 GENERAL CONSIDERATION

The documentation [2] includes a discrete 1D numerical model (contains 12 structures: road crossing and / or supporting bridges or pedestrian structures). To monitor water discharges over the canopy of the defensive dam on the left bank of the river Bârzava, two fictitious side structures were introduced, spillway type - spillway with wide threshold and drainage coefficients md = 0.248 (the program introduces: cd = md * sqrt {2 g}). The configuration of the canopy route at the two fictitious structures was determined by the points resulting from the topographic elevation itself (left bank topographic longitudinal profile). When monitoring the volumes of water transiting over the fictitious lateral structures on the left bank and which accumulate over time (it was considered the most unfavorable situation for the maximum flow of approx. Q0.2%), it was necessary to achieve a discrete numerical model coupled 1D / 2D (with the real surface of the natural land and possibly floodable, associated with the fictitious lateral structures), as a limited area in 2D and marked with “ZONA_2D_FINALA”, in the HEC-RAS version 5.07 model visible in the graphic representation from (Figure 2).

The truncated version (see also paper [13]) in the 1D / 2D numerical model, required only during the McBreach simulation © version 5.07 (used as an external control application), facilitates the probabilistic modeling of dam failure by sampling yield parameters of predefined statistical distributions used in automatic running with HEC-RAS vers. 5.07 hundred times using the Monte Carlo Method. Launch McBreach mode © version 5.07 [8] and automatic coupling to HEC-RAS vers. 5.07, is observed in (Figure 3).

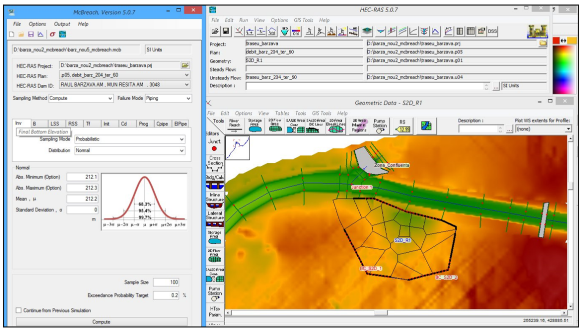


Figure 3. Discrete numerical model in the truncated version of the 1D and the associated 2D surface in McBreach © version 5.07

The tool of probabilistic modeling of the failure of the defense embankment by sampling the parameters of failure of predefined statistical distributions (see the explicit menu in the description of each parameter) and associated in the automatic running with HEC-RAS vers. 5.07 hundred times, using the Monte Carlo method, can be observed in the presentations in (Figure 3), (Figure 4) and (Figure 5 left).

In addition to the yield parameters, the user can include the flow hydrography of the model in the probabilistic analysis by random sampling of the flow hydrograph and duration multipliers as seen in the graphical presentation in (Figure 5 right)

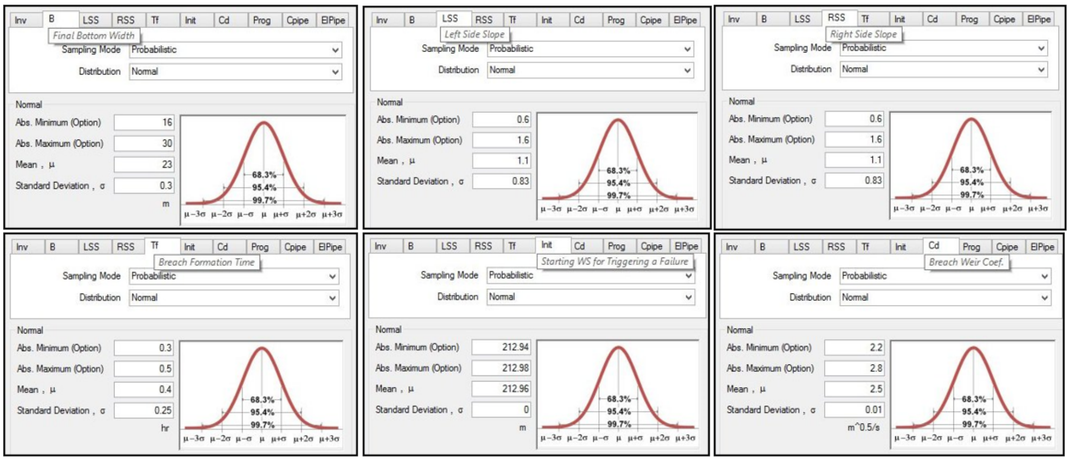


Figure 4. Sampling elements of predefined statistical distribution failure parameters

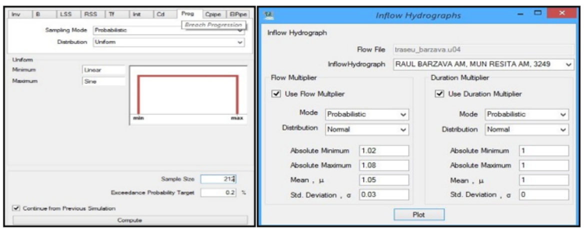
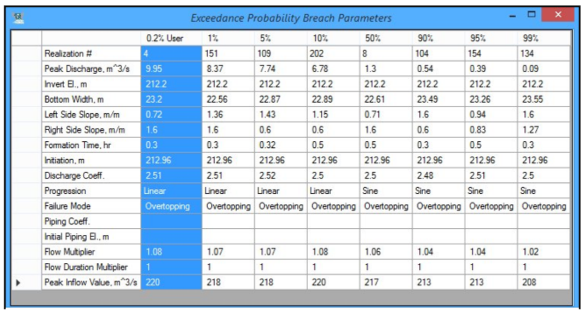


Figure 5. Gap progression, random sampling of input hydrograph and time scale factors

Following the actual execution (Compute) resulted the elements from the sampling of the parameters for yielding the predefined statistical distribution, final values visible in the presentation in (Figure 6).

The parameters with a probability of exceeding 0.2% are defined, which define the yield gap of the defense dam on the left bank of the Bârzava River and are entered in the options in McBreach © version 5.07 with the "deterministic" facility, then the final execution is simulated. said in the deterministic truncated numerical variant.

Following the graphic post-processing operation of the results with the associated program HEC-RAS vers. 5.07, results the variation of the levels in the discrete longitudinal profile, in the situation of transit of the maximum flow with the probability of exceeding. $Q_{0.2\%}$= 204.15 m^3/s (Figure 5).



Exceedance Probability Breach Parameters

	0.2% User	1%	5%	10%	50%	90%	95%	99%
Realization #	4	151	109	202	8	104	154	134
Peak Discharge, m^3/s	9.95	8.37	7.74	6.78	1.3	0.54	0.39	0.09
Invert El., m	212.2	212.2	212.2	212.2	212.2	212.2	212.2	212.2
Bottom Width, m	23.2	22.56	22.87	22.89	22.61	23.49	23.26	23.55
Left Side Slope, m/m	0.72	1.36	1.43	1.15	0.71	1.6	0.94	1.6
Right Side Slope, m/m	1.6	1.6	0.6	0.6	1.6	0.6	0.83	1.27
Formation Time, hr	0.3	0.3	0.32	0.5	0.5	0.3	0.5	0.3
Initiation, m	212.96	212.96	212.96	212.96	212.96	212.96	212.96	212.96
Discharge Coeff.	2.51	2.51	2.52	2.5	2.5	2.48	2.51	2.5
Progression	Linear	Linear	Linear	Linear	Sine	Sine	Sine	Sine
Failure Mode	Overtopping	Overtopping	Overtopping	Overtopping	Overtopping	Overtopping	Overtopping	Overtopping
Piping Coeff.								
Initial Piping El., m								
Flow Multiplier	1.08	1.07	1.07	1.08	1.06	1.04	1.04	1.02
Flow Duration Multiplier	1	1	1	1	1	1	1	1
Peak Inflow Value, m^3/s	220	218	218	220	217	213	213	208

Figure 6. Dam breach parameters using the statistical analysis for different exceeding probabilities

The assessment of the natural terrain was based on the topographic surveys updated at the level of 2017 (it contains 14541 distinct points where the x, y and z elevation coordinates are known) and materialized on a situation plan, or in longitudinal sections through troughs and defense embankment, from the floodplains, respectively, cross sections through the river channel and floodplains (and through water) produced and made available by a specialized topographic firm [1].

2.2 NUMERICAL MODEL BUILT

The distribution of the roughness coefficients in the cross section on the 1D route is variable, within the limits specified for the Bârzava riverbed and the Țerova tributary: the major riverbed n = 0.065 and n =

0.064, and in the minor riverbed: n = 0.035. The actual values of the coefficients in the cross section are visible at the top of the cross sections when presenting the results.

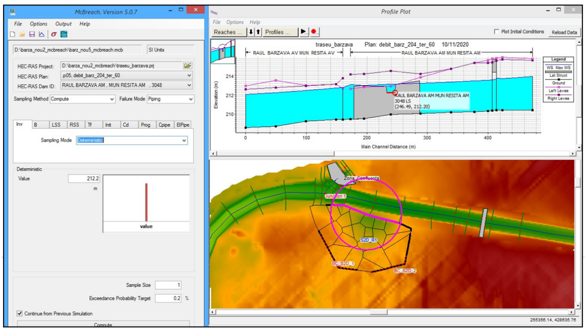


Figure 7. Deterministic selection method and longitudinal variation of water levels on the truncated numerical model

In order to achieve the 2D discretization of the land near the left bank of the river Bârzava (urban land), a simple polygonal surface is defined marked "ZONA_2D_FINALA", which will be connected to the two fictitious lateral structures (in the metric notation: "5296 "And" 2898 "), then divide into discrete polygonal elements (a polygon can have a maximum of 8 sides) by simply choosing two distances in the orthogonal directions Ox, respectively, Oy, in order to divide it.

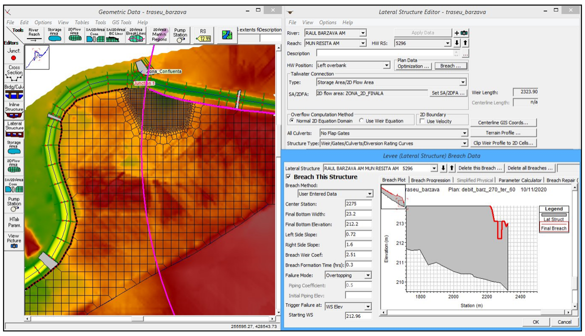


Figure 8. Selections associated with the side structure 5296: SA / 2DFA, OverFlow Computation Method and setting the uncertainty parameters for the left bank embankment Bârzava river

Following this discretization process with (Δx=20m, Δy=20m) and a thickening of the discrete elements in two important areas of the discrete numerical model: the upstream area with (Δx = 5m, Δy = 5m), respectively, around the gap yield with (Δx = 3m, Δy=3m). Over the entire area in 2D (ZONA_2D_FINALA), the Manning roughness coefficient on the surface was considered of approx. n = 0.060.

In conclusion, the whole discrete numerical modeling contains on the 1D route, 12 type crossing structures: road bridge, pedestrian bridge or support structure (eg for a crossing pipe), two fictitious lateral structures through which the elevations of the dam from the left bank of the river Bârzava, on a length of approx. 3115.42m (2323.90m at structure 5296 and 891.52m at structure 2898), and on the discretized 2D model 4092 elements resulted.

2.3 INITIAL AND BOUNDARY CONDITIONS

From (Figure 6) choose the parameters with the probability of exceeding 0.2% that define the yield gap of the defense dam on the left bank of the river Bârzava and then enter the discrete whole numerical model, as seen in the graphical presentation in (Figure 8).

The boundary conditions on route 1D are given for: Bârzava river → the transit flow with a certain probability of exceeding (max. Q0.2% = 204.15 m3 / s) introduced as a known flood hydrograph, in the section upstream at "6042 , 80 ", hydrodynamic slope (i = 4.017 ‰) in the final downstream section of the numerical model marked metrically with" 9 "; the Ţerova tributary → the transit flow with a certain probability of exceeding (max. Q0.2% = 60m3 / s) introduced as a hydrograph of known flood, in the upstream section marked metrically with "56", and for the initial conditions (at start) , the initial flows are known for: Bârzava river → Qini = 50 m^3/s; the tributary Ţerova → Qini = 14.5 m^3/s, and in the confluence node → Qini = 64.5 m^3/s.

For the initial conditions in 2D, the discrete surface 2D ("ZONA_2D_FINALA") is coupled to the fictitious lateral structures associated with the left bank ("5296" and "2898"), respectively, the hydrodynamic slope (i = 4.017 ‰) is introduced on the condition lines of edge of the discrete surface in 2D ("BC_2D_1" and "BC_2D_2").

The actual numerical simulation of liquid flow transit takes place in known time and period, starting on November 22. 2017 at 10.30, until November 24. 2017 at 2.30. The execution analysis has a time step of Δt = 2 seconds, and the storage of the results is done at a time interval of 10 minutes

3. NUMERICAL SIMULATION AND RESULTS

Following the execution of the actual numerical simulations, all constant or time-varying parameters were obtained regarding: levels, flows and speeds, in all cross sections of the 1D numerical model, on the 2D domain associated with the Bârzava river (discrete 2D surface marked with " ZONA_2D_FINALA ") which is connected to the fictitious side structures on the left bank, where the current notations on the model are:" 5296 "and" 2898 ". The presentation of the results after the post-processing in final graphic form on the 1D / 2D model in the RasMapper Area or in the Main Menu, is shown below

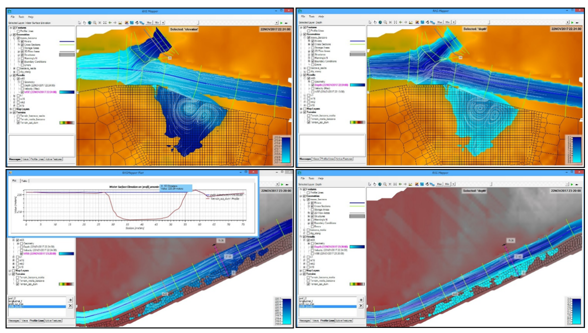


Figure 9. Plotting the trajectories of particles superimposed on the level surface (in mAOD) and the variation of the water depth (in m) on the 1D / 2D model at the current time:

22/11/2017 at 22.24; Plotting the trajectories of particles superimposed on the level surface (in mAOD) and the variation of the water depth (in m) on the 1D / 2D model - approx. 1800m upstream, at the current time: 22/11/ 2017 at 23.20

• Plotting the trajectories of overlapping particles: over the level surface (in mAOD) and over the variation of the water depth (in m), in the vicinity of the failure gap on the left bank - graphical representations at the current time: November 22, 2017, 22.24 in the location when reaches the flow at the entrance on the river Bârzava of approx. Q = 189.25m^3/s - (Fig. 9 above);

Drawing the trajectories of overlapping particles: over the level surface (in mAOD) and over the variation of the water depth (in m), in the upstream location which is approx. 1800m from the area of the failure gap - graphic representations at the current time: November 22, 2017, at 23.20 when at the entrance on the Bârzava River the flow is in the vicinity of the value of approx. Q = 189.31 m^3/s - (Fig. 9 below);

• Tracing the trajectories of overlapping particles over the speed distribution (in m/s) on the 1D / 2D model - graphical representations at the current time: November 22, 2017, 22.24 when at the entrance on the Bârzava river the flow of approx. Q = 198.31m^3/s – Figure 10.

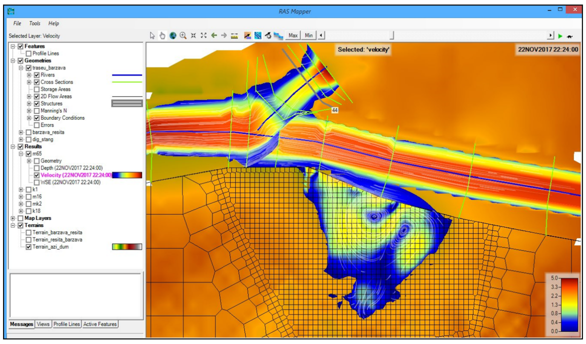


Figure 10. Tracing the overlapping particle trajectories over the velocity distribution (in m/s) on the 1D/2D model at current time: 22/11/2017 at 22:24

• Variation of the piezometric line (in mAOD) in a cross section in 1D (main menu) and on a 1D / 2D route (Ras Mapper menu) - graphic representations at the current time: November 22, 2017, at 22.24 when at the entrance on the river Bârzava reaches the flow of approx. Q = 189.25m^3/s – Figure 11.

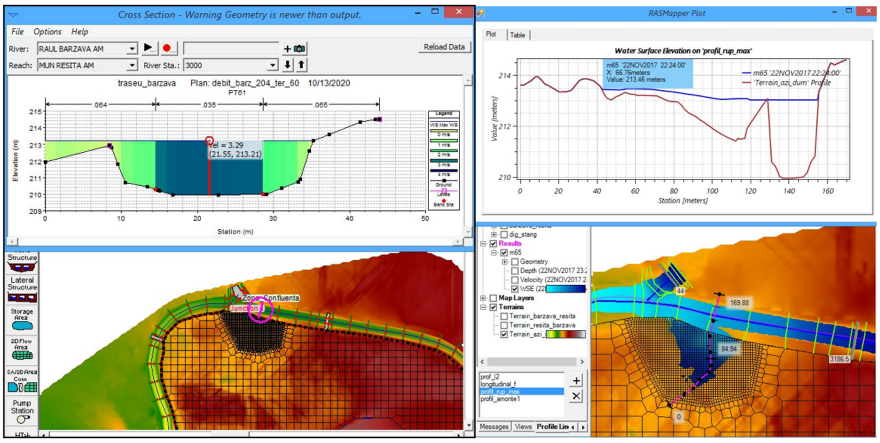


Figure 11. Piezometric line variation in the cross section "3000", respectively on the 1D/2D route as well as through a current profile (in Ras Mapper), at current time: 22/11/2017 hour 22:24

• The variation of the piezometric line (in mAOD) in the longitudinal profile on the 1D route - graphic representations at the current time: November 22, 2017, at 22.24 when at the entrance on the Bârzava river the flow of approx. Q = 189.25m^3/s – Figure 12

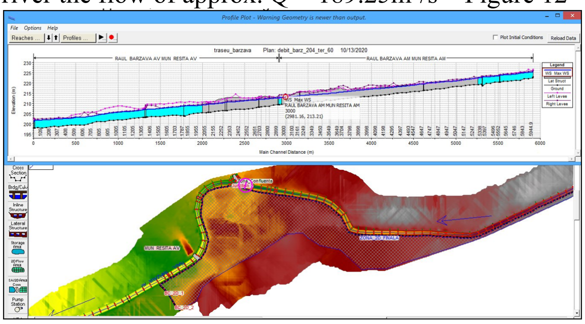


Figure 12. Piezometric line (mAOD) in a 1D longitudinal profile at time step 22 /11/2017 hour 22.24

• The variation of the piezometric line (in mAOD) at two characteristic crossing structures: on the Bârzava river where a hydraulic under pressure transit occurs (it is a restrictive situation, at a normal verification it requires a free level), respectively, on the Ţerova tributary (where it is a situation normal under pressure) - graphic representations at the current time: November 22, 2017, time 22.24.- Figure 13

• The time variation of the piezometric line (water level - quotas in mAOD) and the flow variation (in m^3/s) in the input section (with the metric notation "6042.80") in the discrete numerical model (Figure 14).

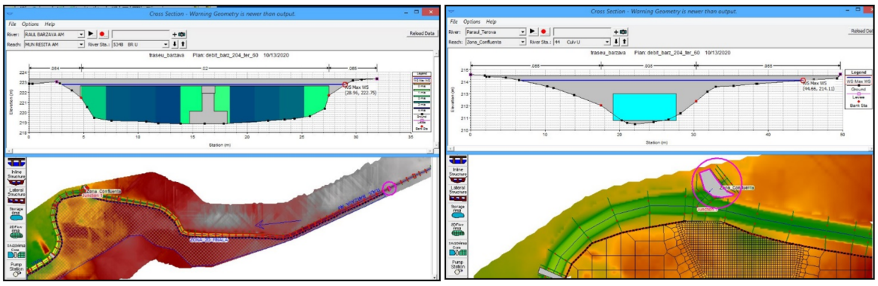


Figure 13. Piezometric line (mAOD) and two velocities distribution in cross sections of two hydraulic structures

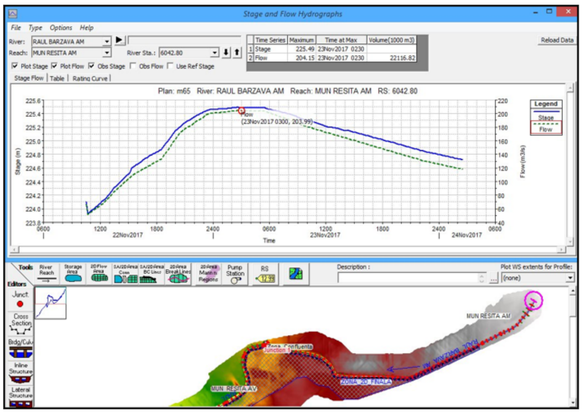


Figure 14. Piezometric line and flow time variation (mAOD) at the entrance section, with peak flow of Qmax= 204,15 m^3/s

4. CONCLUSIONS

It is observed from this numerical modeling that the water transit is made through the minor riverbed, the major riverbed and over the defense dam on the left bank of the river Bârzava, on an appreciable length and the development of a breach with a base length of approx. 23.20m, in a vulnerable area in the vicinity of the confluence area, at the transit of an extraordinary flood wave when the flow is reached with the probability of exceeding 0.2% (max.$Q_{0.2\%}$ =204.15m^3/s). From the graphical representations (Figure 11-left and Figure 12) it is observed that the piezometric line in section “3000” (which includes the central area of the yield gap and where the elevation of the dam is at about 212.91mAOD), reaches the maximum value of 213.21 mAOD, and at the edge of the profile in the floodable area (Figure 11-right), the maximum value is approx. 213.46 mAOD.

Therefore, in the situation when the water-rare dam on the left bank around the yield gap rises by approx. 0.65m (difference: $\Delta = 213.46-212.91 + 0.10 = 0.65$m) on a length of approx. 140 m, then a precinct is provided in the vicinity of the defense dam and becomes a non-floodable area even when passing through a hydrograph of extraordinary flood

In conclusion, it can be stated that the variation of water levels reached in the floodplain area, signaled and obtained by hydraulic calculations in non-permanent transit regime (with the HEC-RAS software package version 5.07, respectively, with McBreach © version 5.07, used as an external control application that quantifies the uncertainty), reflects the current situation on the ground, obtained from existing topographic surveys.

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