# 2D Numerical Embankment Dam Breach Modeling due to Accidental Highwaters Transitation

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***Abstract:*** *The safety in operation of the hydrotechnical constructions, in the case of the retention ones from local materials, is a particularly important issue, involving numerous technical, economic and social implications. The phenomenon of failure, an event of utmost importance, is particularly complex both in terms of genesis and development. Leaving aside the exceeding of the resistance capacity of the materials, the partial or total failures of the earth dams and / or boulders, the most numerous due to the accessible materials, can be due to infiltrations through the construction body, generating suffusions and leaks.*
*The paper presents a 2D numerical modeling of the liquid flow transit on the Gladna River, Timiș County, Romania, in the Surduc accumulation section, at the appearance of an accidental flood wave.*
*The reservoir has a maximum volume of over 51 million cubic meters and is created by an embankment dam with a concrete mask with a maximum height of 35 m. The peak flow hydrograph used is similar with the peak flow hydrograph of April 2012 flood event.*
*The discrete numerical modeling of the transition of flood event is made with the help of the HEC-RAS 5.0.7 software package, assuming a fictitious scenario of accidental overtopping of the embankment dam, which determines a possible failure of this hydraulic structure. The geometric development of the dam breach is estimated with the help of a specific additional facility from the employed software.*
*Apart from the position of the yield section and its final geometric shape, the numerical simulation estimates the development over time of specific phenomenon's hydraulic parameters - flows, levels, velocities - in all points of the modelled domain.*

***Keywords:*** *2D hydraulic modeling, embankment dam, highwaters flow, crest overflow, dam breach, numerical modeling*

## 1. General considerations

The embankment dam and the online reservoir are situated on River Gladna, tributary of River Bega, located in Poiana Rusca Mountains, in Timiș County. Surduc embankment dam construction was done in two steps, started in 1972, and finalised in 1986, retaining 51 million cubic metres. The main purpose of the reservoir is to provide drinking water, to protect against floods, and for recreation. Having an appreciable water surface of approx. 460ha, is the largest reservoir in Timiș County. The valleys along Gladna River are with steep slopes and river sections' width up to 200 meters. Upstream of Surduc dam, the valley opens suddenly and can reach important widths of approx. 1500 ~ 2000 meters.

The retention embankment dam Surduc (Fig.1) has a maximum height of 35m. The dam has two bottom circular outlets, with a length of 70m and diameter of 1.40m each, with a maximum capacity to discharge of approx. 2x17.0 $m^3/s$= 34 $m^3/s$. The spillway channel width is B=6 m, located on the right slope of the valley (Fig.2) the spillway is a concrete structure, free, without any flow control structure. The downstream end of the spillway channel a stilling basin connects with Gladna River.

In order to model the reservoir, the embankment dam and River Gladna reach (reach length of approx. 9235m), a 3D surface was considered (Fig.3). HEC-RAS 5.0.7 [3] software was used to build the numerical model discretisation.

Along the River Gladna study reach, and the adjacent areas, a database was created based on 2823 topographic survey points and 204 profiles (from the channel towards the flood plain).

**Fig. 1.** Upstream view of Surduc Dam

**Fig. 2.** Spillway channel and Surduc Dam downstream view


**Fig. 3.** Plan view of Surduc dam and reservoir – "GOOGLE MAPS" 2019

## 2. Numerical modeling - general presentation

In order to graphically represent a 3D terrain, Earth Explorer utility is usually used. In the documentation [1], a very useful and easy method of graphical processing of known topographic data from the actual topographic surveys is presented.

This method uses a specialized topographic program of 2D graphical interpolation, in two directions (Ox, Oy), from which a 3D shape surface (shx extensions) can then be generated [1]. In this case, too, a known file from the topographic database was used (it includes approx. 2823 points: x, y and z coordinates - point elevation) resulting in a 3D surface (Fig.4a). This surface is loaded into ArcMAP 9.3 [2], divided by discrete triangular elementary spatial surfaces of a triangular shape and then a final digital form results in the real 3D space of type TIN (Triangulated Irregular Network - (Fig.4b) - here, in addition, several updates were made in the cross sections related to the area downstream of the dam, in the channel and floodplain, excluding some defects due to the small number of cross sections in the downstream area).

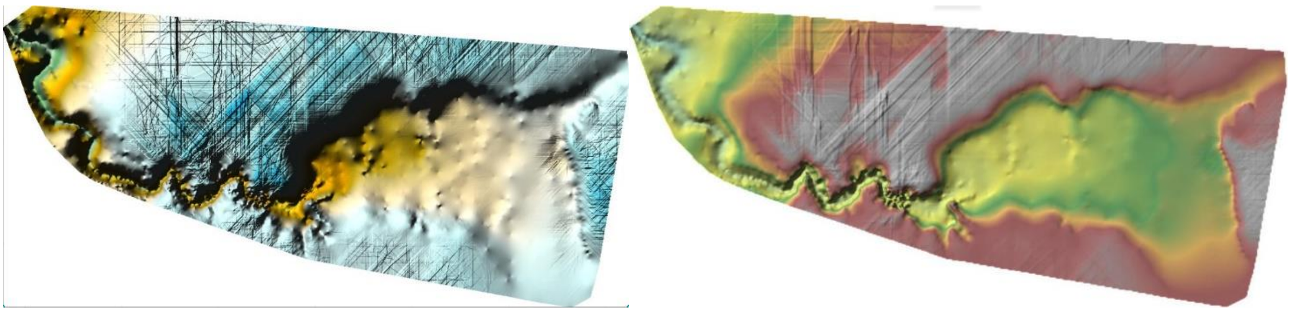

**Fig. 4.** a. (Left) – 3D topographic plan view of Surduc establishment; b. (right) – 3D updated DTM plan view

In order for this shape to be recognizable by the RAS Mapper module (HEC – RAS 5.0.7 graphics post-processing module), it has been converted to an accessible grid-type file - DTM (Digital Terrain Model) [1, 4, 6]. At the beginning, the geographic coordinate system was chosen, then, this final form of the natural terrain (extension “.FLT”) is loaded with the RAS Mapper module within the HEC – RAS 5.0.7 program. The 3D spatial surface thus obtained is also observed in the graphic presentation in (Fig.5). If more information is desired, respectively the sequential generation procedure, as well as the conversion mode, it is recommended to consult the documentation [6] and / or the presentation work [1].

It can be said that on the “satellite” model of 3D representation, the discretization of the arranged land is almost realistic, even if it is obtained by this easy method of data processing. Although the representation of the discretized model is based on a small number of points (obtained from topographic processing – 2823 points), it still satisfactorily meets most of the requirements in the system arranged by 3D graphic representation. Therefore, the initial terrain model was used (Fig.4b) considering the same project name and then the 2D analysis domain called: surduc_gladna is generated. From the Explorer Window area (Fig.5) the 2D Flow Areas facility was chosen and then draw the discretization contour of the 2D analysis domain and final name Perimeter 1. The grid spacing points in meters (Dx = 50m, Dy = 50m) were chosen, the points associated with the facility are generated (Generate Computations Points) as well as the related tables that include the associated properties for discrete points (Compute Property Points). A grid thickening operation is then performed in the channel and floodplain area, (Fig.5) with new distinct spacing points in meters (Dx = 20m, Dy = 20m)

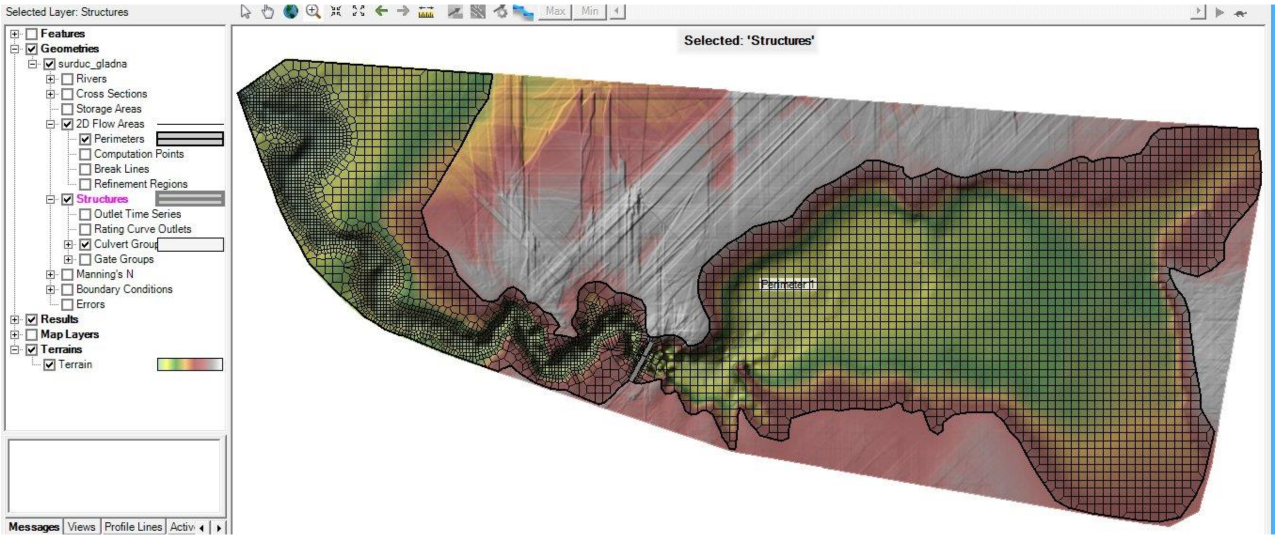


**Fig. 5.** 3D plan view of grid network representation of the area of interest

Define a grid line in the direction of the dam axis and similarly, a cell thickening operation is performed in the area associated with the dam, choosing additional and distinct spacing points in meters (Dx = 5m, Dy = 5m) as seen in (Fig.6).

The Break Lines have two important and distinct purposes. The first goal is to align the grid cells according to the direction of the dam axis. The second purpose is the most important and necessary at the same time when, it is desired to define a connection structure (it is an internal connection area on a 2D model and represents a subdivision inside the discretized interior of a surface that can be: an area - 2D Area or a polder - SA).

For this reason, a connection structure will be inserted on this line (in the main menu the SA / 2D Area Conn facility is used) which will represent the geometry of the dam.

Therefore, this option defines the connection between the two close areas that include the construction of the Surduc dam, in the discrete 2D numerical model (the present case is 2D Area).

From the upper area Geometric Data choose the facility with which to draw the direction of the connection structure – SA / 2D Area Conn (this direction overlaps the grid break line – Break Lines) and then define the geometric shape of the dam crest using the facility on the left main menu (Fig.7).

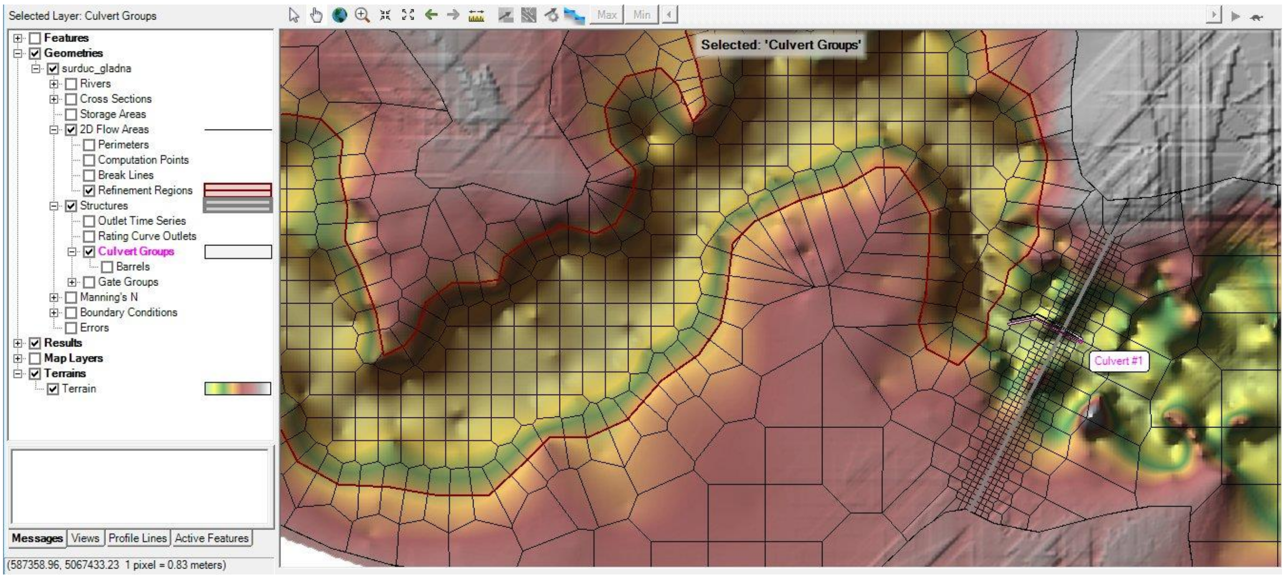

**Fig. 6.** Detailed model network discretization, at Surduc Embankment Dam and River Gladna

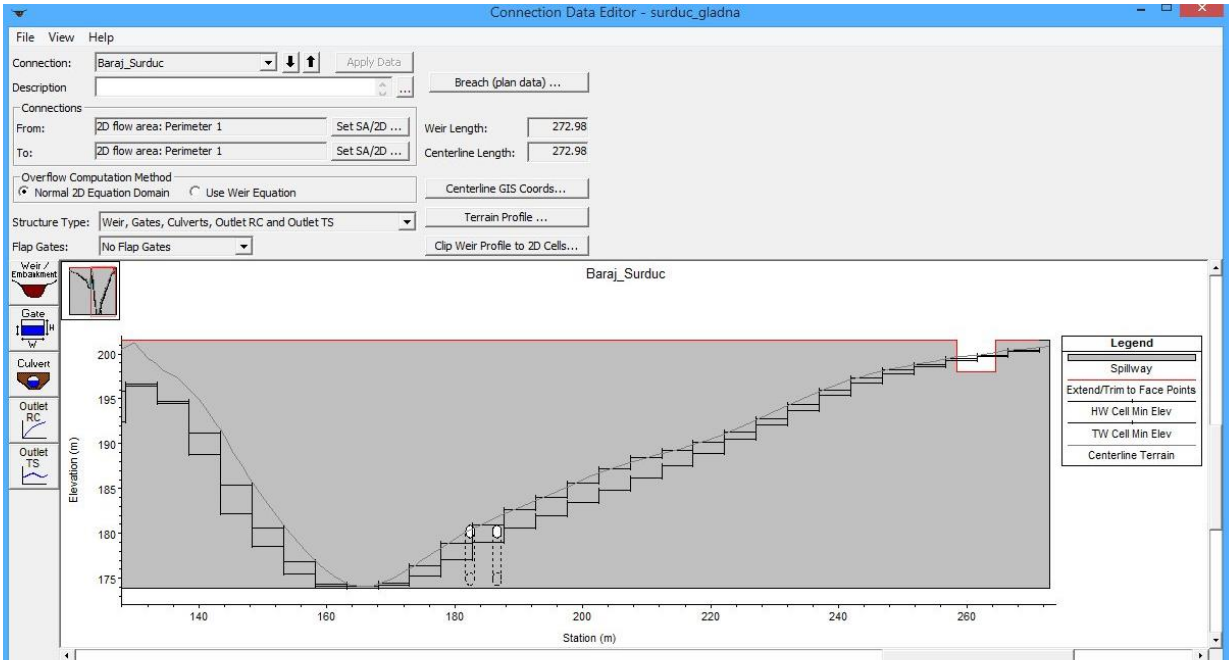

**Fig. 7.** Geometric elements used to define the connection structure of Surduc Dam on River Gladna

Choose the Culvert tool from the left menu, and enter the two outlet pipes with the available known geometric coordinates (X, Y) of the route definition points, respectively, enter the geometric and hydraulic characteristics of the pipes as seen in figure 8.

When selecting Breach tool (plan data), a graphic window opens (Storage Area Connection Breach Data, figure 9), from which we chose the Parameter Calculator tool. This last tool creates the breach section geometry (calculates width, slope, breach hydrograph and cross section selection method – Froehlich 2008) by user through hydraulic and geometric parameters user specification.

Therefore, after specifying the parameters that define the dam breach (it is also necessary to enter in the left side boxes by the user the selection elements: Center Station 167.5; Final Bottom Elevation 180.5; Breach Weir Coef. 2.6; selection of failure mode Piping; Initial Piping Elevation 185.5; Starting WS 197.5) as well as method selection: Froehlich (2008). The Breach Plot option is chosen, which will lead to the appearance of the graphical window in which both the chosen and the calculated parameters are presented.

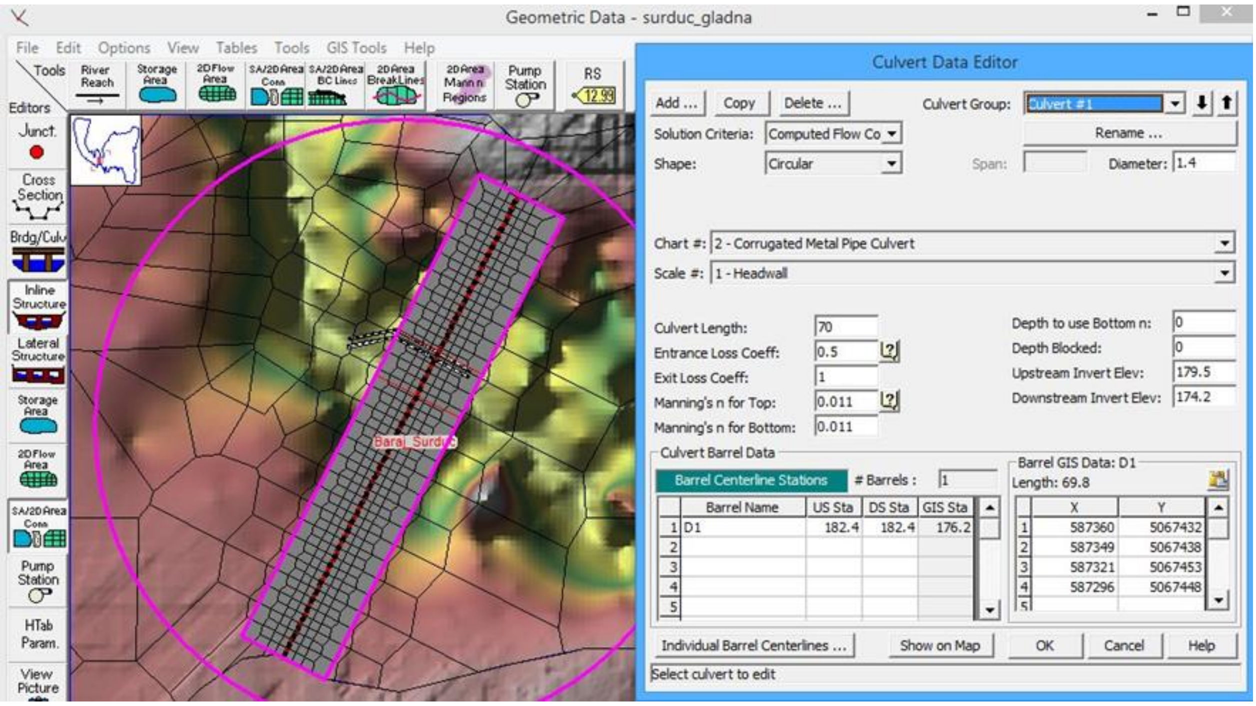


**Fig. 8.** Geometric elements to define the river reach and the hydraulic and geometric bottom outlet parameters

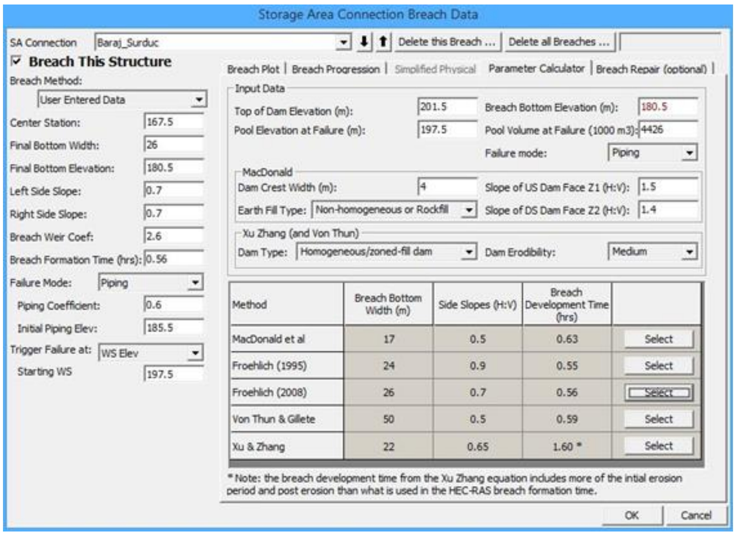


**Fig. 9.** Dam breach computation section and selected parameters

These parameters define the geometric shape and position of the yield section as seen in the graphical representation in Fig. 10.

## 3. Initial and boundary conditions

With the selection tool, two sections were defined for roughness coefficient Manning's n (downstream of the dam) comprising some discrete cells to which are attached the new numerical values appreciated for the Manning roughness coefficients (left floodplain: n = 0.075 and right floodplain: n = 0.082), as can be seen in the graphical representation in (Fig.11).

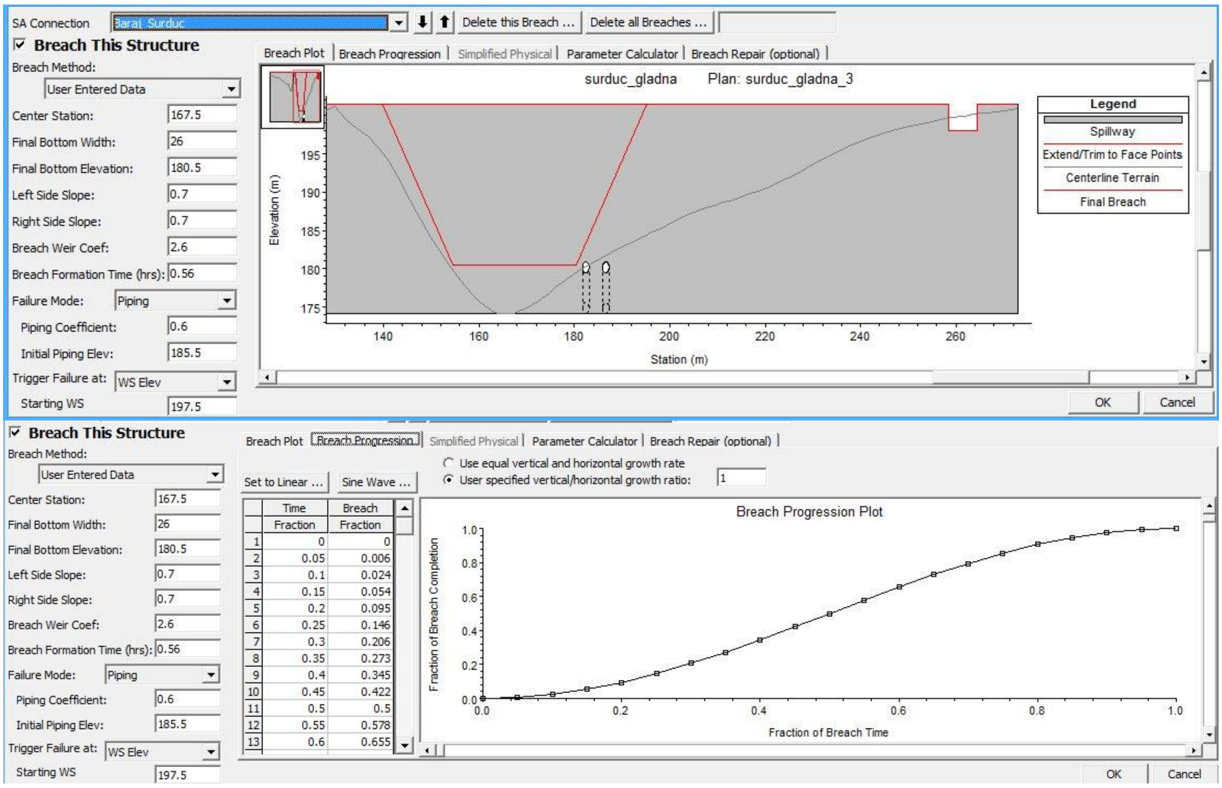


**Fig. 10.** Dam breach parameters, Surduc Embankment Dam

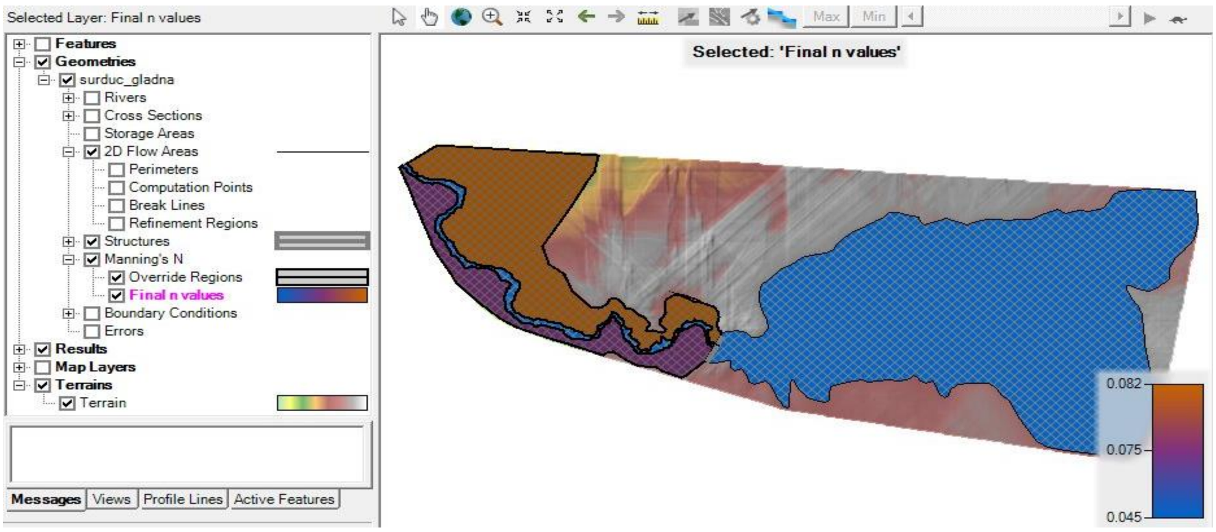


**Fig. 11.** Manning's n roughness coefficients distribution

The 2D numeric model requires the definition of the boundary conditions from the main menu in Geometric Data using the facile line type edge condition (BC Line) and therefore the option SA / 2D Area BC Lines (Fig.12). In the case of this 2D domain, two routes have been defined: a route in the upstream area BC_S2D_11, in which the flood hydrograph with the energy slope of the water is introduced and a route in the downstream area, respectively, BC_S2D_22, on which the hydrodynamic slope of the water is introduced downstream.

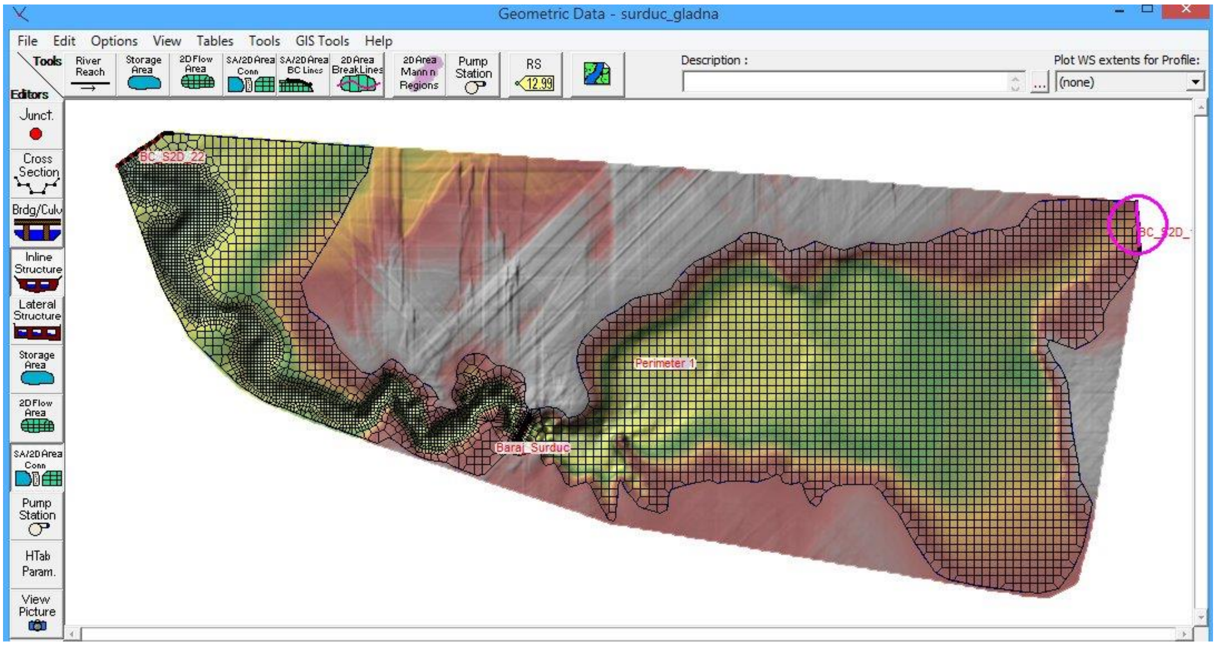


**Fig. 12.** Model plan view with boundary condition locations

The configuration of the flood hydrograph on the Gladna River associated in numerical modeling reaches the maximum value of 106.72 $m^3$/ s, and the energy slope in the entrance area is 0.0015205 and is applied on the associated line - BC_S2D_11 (with this energy slope the HEC-RAS 5.0.7 program will final distribution of the input flow on the edge condition line).

The hydrodynamic slope with the numerical value 0.000852 was introduced in the downstream area and is applied on the associated line - BC_S2D_22.

## 4. Numerical simulation. Results summary

The actual numerical simulation of the transit of flood flows takes place in known time and period, starting on April 15, 2012 at 1.00, until May 1, 2012 at 7.00.

The actual execution analysis is performed, however, in the short time interval, from April 15 at 1.00 to April 17 at 23.00, has a time step $\Delta t$ = 5 seconds, a mapping interval of 1 minute, and storage of results final is done at an interval of 1 minute.

Following the execution of the numerical simulation, constant or time-varying parameters were obtained, referring to: levels, flow rates and speeds, on each cell of the 2D numerical model. Following graphical post-processing operations, the numerical results are stored in separate files which can then be viewed for each cell or on specific and user-set paths (usually only in the 2D area), using the options in the RAS Mapper area [6].

When presenting the results in 2D graphic form obtained after post-processing, two significant representations – distribution of level surfaces in 2D presentation and model longitudinal outline – are selected at predetermined time moments over April 16, 2012 (figure 13): at 12:23, before the initiation of the piping breach, when the bottom outlet discharge is approx.36$m^3$/s; at 12:45, when the flow through the breach is already approx.613$m^3$/s; at 12:51, when the breach is completely formed and the flow through it is approx.4053$m^3$/s; at 12:58, when the breach discharges approx.3806$m^3$/s; at 13:25, when the flow by the breach is approx.3069$m^3$/s and the maximum height of the flood in the Surducu Mic area is reached; at 16:19, when the breach discharge drops to approx.512$m^3$/s; and at 19:52 and at 23:00 respectively, when the breach discharge diminishes to approx.7.3$m^3$/s and 5.9$m^3$/s.

In the graphic representations with predilection, the level surface and the level configuration were chosen in a longitudinal outline that crosses the entire route through the area of the trough.

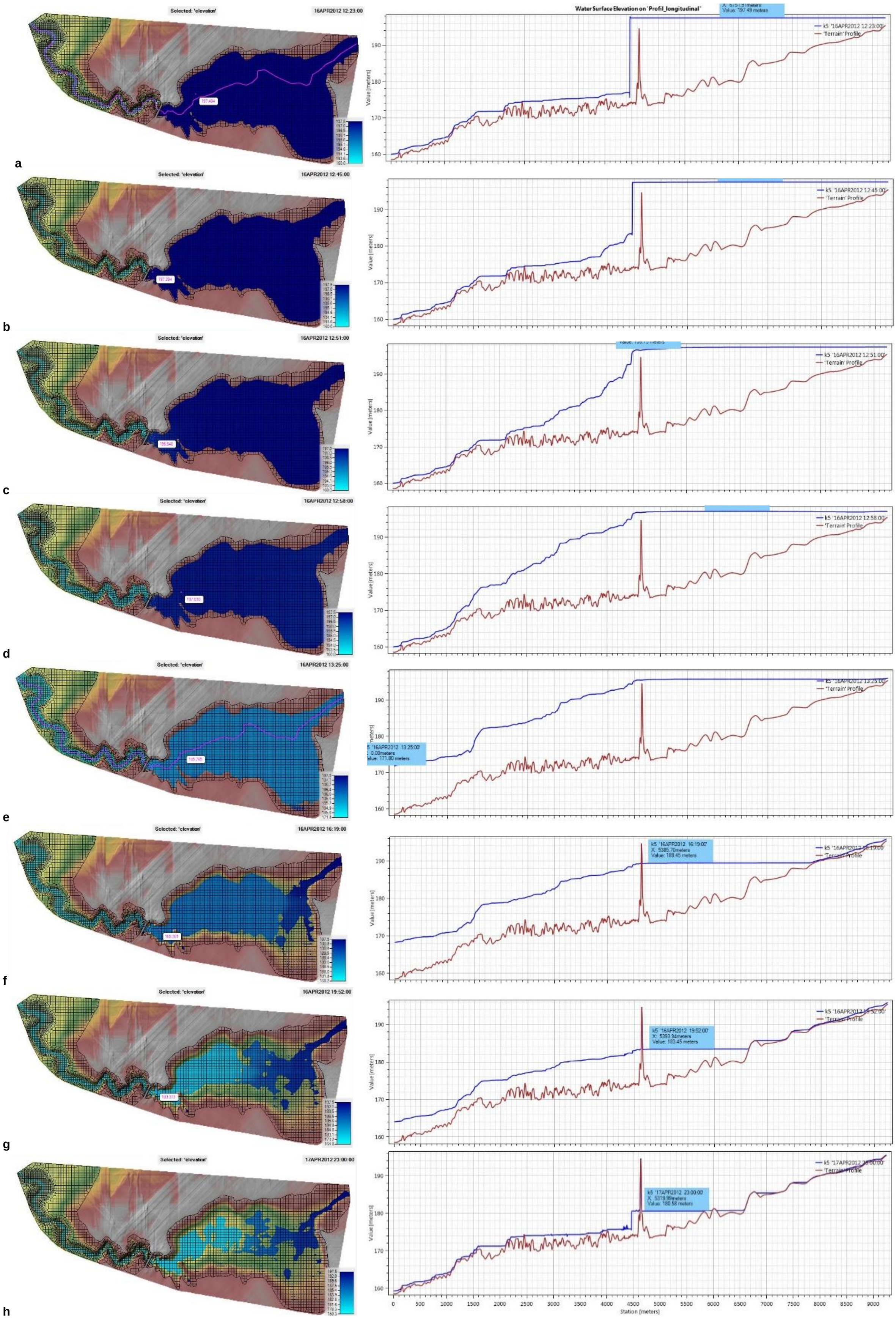


**Fig. 13.** Distribution of level surfaces in 2D presentation (in maSL) and water surfaces level longitudinal outline with respect to terrain profile, at significant predetermined time moments

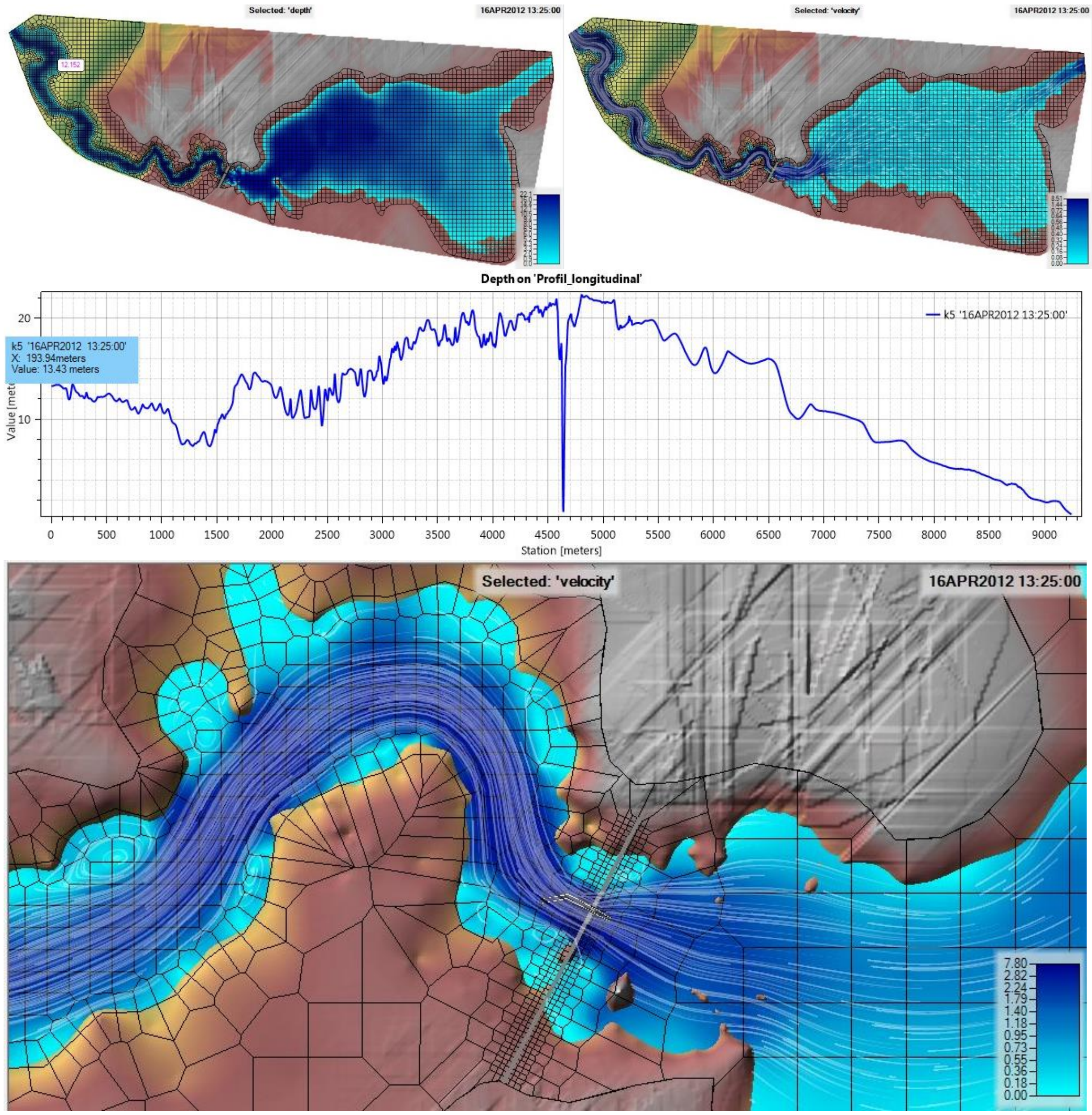


**Fig. 14.** Surface level distribution in 2D (in maSL), tracing the trajectories of overlapping particles over the speed distribution (in m/s), depth variation in the longitudinal outline (in m), respectively and a detail in the dam area at 13:25 on April 16, 2012, and flow through a gap of approx.3070m$^3$/s

## 5. Conclusions and recommendations

Flood wave assimilated with a synthetic allure and known period: April 15 - May 1, 2012, which transits the Gladna River, reaches the maximum recorded flow of 106.72 m$^3$ / s and corresponds to a probability of exceeding 0.1%. The water level in the accumulation lake recorded at the start time in numerical modeling was at the level of 196.11 maSL. At the appearance of the accidental flood wave that brings a significant volume of water, the level in the accumulation lake increases continuously from the elevation of 196.11 maSL and reaches on April 16, 2012 at 12:23 the elevation of 197.50 maSL (Fig.13a), and the flow through the two bottom emptying reaches the value of approx.36.13 m$^3$ / s.

It is found on the discrete numerical model that the beginning of the formation of the circular breach is on April 16, 2012 at 12:32, as a location in the reference area associated with the quota of 185.50 maSL, and the flow infiltrated through the breach reaches the value of 0.04 m$^3$/s. Further the breach develops and at the current time 16 April 2012 at 12:45, the infiltrated flow reaches the value of 613.15 $m^3/s$ (Fig.13b).

With the time, the breach develops and reaches its final shape on April 16, 2012 at 12:51 pm, when the flow through the breach reaches the maximum value of 4053.37 $m^3/s$ (Fig.13c). The level in the accumulation lake decreases continuously which leads to the decrease of the flow through the breach and thus on April 16, 2012 at 12:58 it reaches the value 3806.11 $m^3/s$ (Fig.13d).

In the graphic presentation from (Fig.13e) it is found that with time passing (April 16, 2012 at 13:25), the water level in the end area of the numerical model has increased and reaches the maximum value in the area of Surducu Mic of approx. 171.80 maSL, and the flow associated with the breach has the value of 3069.83 $m^3/s$. Similarly, in the graphic presentation from (Fig.13g and h) the situation of flow transit is observed when the level in the accumulation lake reaches the quota of 183.45 maSL, respectively, the quota of 180.58 maSL (quota representing the level in the lake, in the final situation at the expiration of the analysis time). In the graphical representations from (Fig.14) for the analysis time at 13:25 on April 16, 2012, it is observed that the wave height in the longitudinal outline, in the end area, in the trough (at a distance from the end $\rightarrow$ approx. X: 193.43 m), reaches the maximum value of 13.43 m, and compared to the land level of Surducu Mic, of approx. 7.43 m. It is also observed that the maximum speed selected on the entire discrete numerical model reaches the value of 8.51 m/s, respectively, a value of 7.80 m/s in the graphical presentation updated in detail.

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