MODELING OF EARTH DAMS FAILURE

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Abstract

The safety of hydrotechnical structures is a very important element that must enter the concerns of designers and society in general, given the fact that these are important works , with large investments. In the case of their distruction due to accidents, other activities from the area, the settlements and human lives may be strongly affected. These accidents are called hydrological hazards. Breaking dams accidents do not occur suddenly but almost always there are signs of danger that would allow preliminary measures to limit or even avoid disasters. One of these measures may be modeling the failure of a dam. In order to model the behavior of a structure made of local materials discharghed by water over the crest or affected by water evacuation due to a breach in its body, it will be used Mike 11 mathematical model (hydrodynamic module). Its calibration is performed with the hydrological module Mike by DHI-NAM.

In the case of a breach development at the crest level, after recording the discharghe of the dam, the dam behavior must be addressed by specifying the breach slope at the initial moment and at the final one. The breach evolution in time is calculated from the moment it begins to develop. The description of the breach development can be made using Engelund-Hansen equations, which analyze sediment transport driven from the dam through the breach. The development of the breach can be specified as evolving over time or can be calculated based on sediment transport capacity in the gap formed.

Key words: dam, soil, modelling, discharge, breach, flood

Hydrotechnical structures and facilities are important works, executed with great investment and that can affect, in the case of their destruction due to accidents, the other activities in the area, especially the settlements and human lives.

The purpose of this paper is to consider the many damages that may occur due to human negligence or most of the time due to accidents, for example, the breaking of a dam. The failure of a hydraulic structure, important event that may occur during its existence, is a very complex phenomenon, both in terms of cause and the manner in which it is conducted. Regarding the time interval, this phenomenon can take place within a longer or shorter period of time. The slow or sudden character is given by the way the limit state is reached, state in which the construction collapses (Lopardo R.A., 1983)

Although there were taken technical measures for the design, construction and operation of hydrotechnical constructions and facilities, there were recorded destructions or accidents. From the statistical studies made, it results that the average risk of destruction of a hydrotechnical structure is about 0.5% and the risk of shutdown for a long period, due to accidents is about 2% - 3%. From the analysis of dam breaking, it was found that the percentage of destruction risk is much higher in dams of small heights than in the ones of large heights. Dams from local materials are less secure than concrete ones because they are subjected to specific phenomena related to construction materials, such as uneven settlements (Hartford D., 2004) .

In a study done by the International Committee on Large Dams (ICOLD) on damages in hydraulic structures, it was concluded that the geological, design, execution and operation risk factors, are a fact proven by the destruction of about 2 % and serious damaging of other about 6% of the approximately 16.500 existing dams in the world. (Abdulamit A., 2009)

Currently the company has become very sensitive to safety issues that technical developments imply. Dams and hydraulic structures in general, are today the subject of special attention and rigorous controls in terms of security.

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MATERIAL AND METHOD

Modeling of dam failure can be addressed in different ways: by developing a breach at the crest level after discharge and / or failure of plant, disposed in the dam, followed by the development of a breach in the dam body. In order to model the behavior of a structure made of local materials discharghed by waters over the crest it will be used the mathematical model Mike 11, hydrodynamic module, its calibration being performed with the hydrological module Mike by DHI-NAM (Danish Hydraulic Institute, 2014).

The breach can be modeled initially considering it of trapezoidal form or as being initiated in the bottom discharghe. Thus, in the fist moment the breach has trapezoidal shape in the case of discharghe over the dam and in the case of failure in the bottom discharghe area, the opening is considered having circular form (Abbott M.B., Jefsgaard J.C., 1996).

During the breach development the trapeze dimensions increase, suffering modifications in dimensions and slopes. The initial opening can be described by three parameters (*figure 1)*:

- Base breach elevation (HB);
- Base breach width (WB);
- Breach slope (horizontally and vertically) (SS). The slope on the left is considered equal to the slope to the right so the gap development is considered symmetrical to the trapeze axis.

The breach development can be specified as evolving over time or can be calculated from the sediment transport capacity in the formed gap.

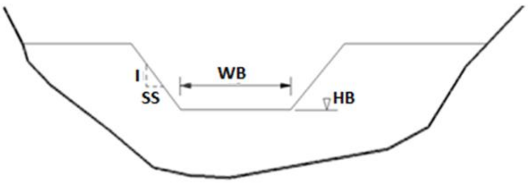

Figure 1 **Breach geometrical parameters**

Breach parameters can be simulated as a time series and consist of boundary conditions of the analyzed domain. T_0 is the time when the gap begins to develop. In the analyzed time frame , used parameters are obtained by linear interpolation for a breach of trapezoidal shape. The lower level of the gap has a lower elevation in comparison with the crest.

Flood wave propagation caused by the breaking of a dam is carried out in the downstream area of the dam on a certain length that depends on the spatial characteristics. In terms of hydraulic calculation, the model is based on St. Venant equations. These equations are suffering simplifications when addressing a hydrological problem. These simplifications are induced by knowing some parameters based on previous measurements.

Analysis models of rain discharge phenomenon analyze all discharge components, so by default even the periods without precipitation, when the flow discharghe is made only of basic discharge. In the internal structure of the hydrological system is found also the continous modeling of soil humidity. So, when a high rainfall that will generate flood flows is produced, soil humidity is known, and thus rain-flow process modeling is more realistic (Crăciun I., 2014).

Mike 11 by DHI, NAM module (Nedbal Afstrømning Models / The Rain – drain module) is a conceptual model that reproduces the terrestrial phase of the hydrologic cycle. There is simulated surface flow, intermediate flow and the base flow in a river basin, as a function of the amount of water stored in four reservoirs of the basin, interlinked.

As input data for the model there can be used the hydrologic cycle parameters such as temporal variation of evaporation, soil humidity, aquifer recharge and aquifer water level evolution.

As simulation results there can be obtained the evolution of the hydrological cycle parameters such as flow on slopes, intermediate flow and base flow.

As a case study it was used Granicesti facility, located on the Horaiț brook, left branch of the Suceava River, in the village Granicesti, Suceava county, having fishing use, irrigation and flood control. During 17.06-2.07.2010 there were significant amounts of rainfall in several rounds of 2-3 days, which, in combination with high atmospheric pressures over the Russian Plain and in the central western Europe, have led to a dangerous development of hydrometeorological phenomena in Superior Siret, Suceava and Moldova river basins (Boboc V., 2014).

To calibrate Mike by DHI-NAM model (*figure 2*) it was realised a climatological and hydrological database for Granicesti dam, located in Horaiț catchment, Suceava County. The basic data neccessary for rainfall-runoff modeling approach consisted of defining the model parameters, setting the initial conditions, meteorological, hydrological measurement data related to the hydrographic network.

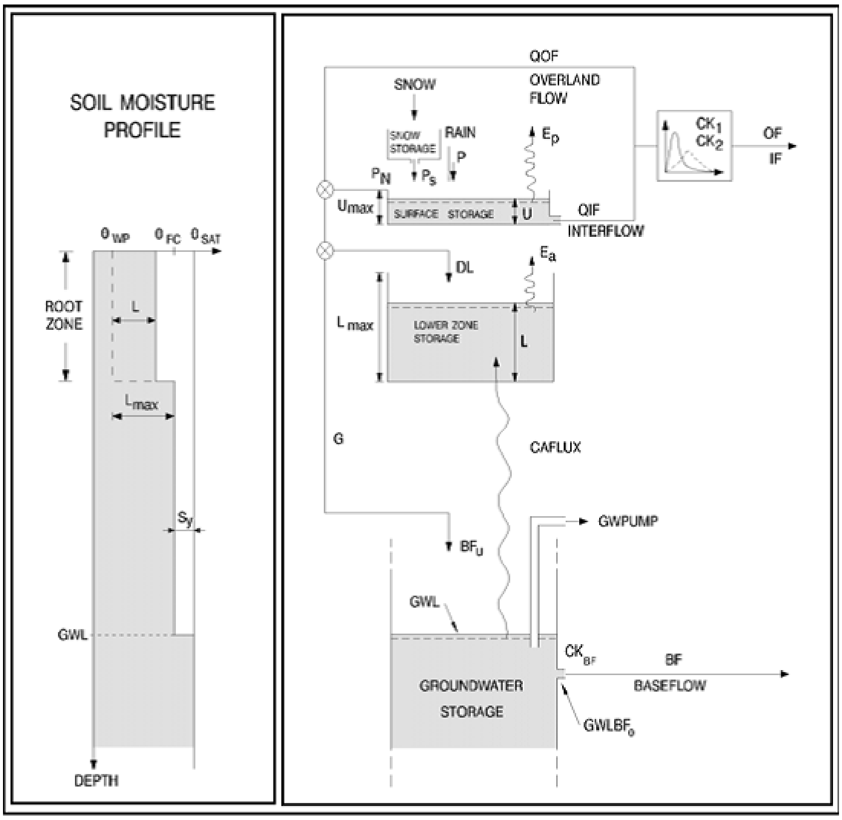

Figure 2 **NAM Model scheme**

The calibration of Mike 11-NAM model was done by the autocalibration procedure. It is a process that can address the most important simulated parameters. Automated calibration routine includes nine parameters: maximum surface water quantity (Umax); maximum water content from the active area for plant roots (Lmax); surface flow coefficient (CQOF); infiltration time constant (CKIF); flow time constants (CK1,2); the threshold value of the unsaturated zone at which the surface discharge is initiated (TOF); the threshold value for initiating infiltration (TIF); time constant for base flow (CKBF); Aquifer recharge threshold limit (TG).

In the case of Horaiț hydrographic basin, the calibration was performed for R2 Nash-Sutcliffe coefficient having the value 0.40, an acceptable one. Also, the simulated discharghe volume is equal to the observed discharghe. Autocalibrated parameters are presented in *table 1*.

Tabelul 1

Autocalibrated parameters

Parameter	Value
Umax (mm)	10.4
Lmax (mm)	106
CQ_{OF} (-)	0.327
CK_{IF} (Hour)	223.7
$CK_{1,2}$ (Hour)	47.9
T_{OF} (-)	0.193
T_{IF} (-)	0.0184
TG (-)	0.527
Cnow	2.3
CKBF (Hour)	1130
Cqlow (-)	52.5
Cklow (hr)	11008

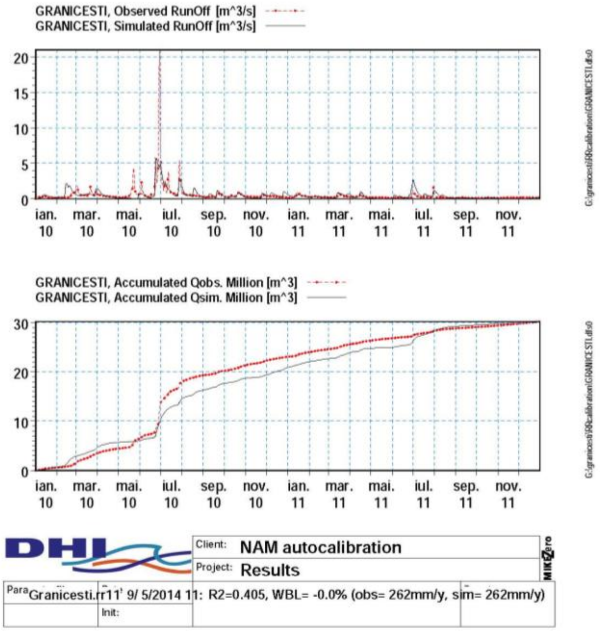

Figure 3 **Mike11-NAM model calibration result for river Horaiț hydrographic basin**

To determine the flood hydrographs in the event of breakage of the earth dams homogeneous, with height under 15 m, the following considerations are made: the failure is gradual due to erosion; erosion is growing rapidly and the massive is washed in a short time.

In the case of discharge, upstream and downstream limits of the crest decline in a uniform manner (Lopardo R.A., 1983).

RESULTS AND DISCUSSIONS

In *figure 4* is presented the water level in the dam axis at 40 minutes after breach initialization. Maximum flow in the axis of the dam (193 m^3/s) obtained by dam discharge simulation, is identified with the maximum discharge with probability of exceeding of 0.5% , discharge that was recorded after reconstitution calculations made after the extraordinary rain of 117 l/m^2 recorded in Horaiț hydrographic basin on 30.06.2010 (given the fact that for the specified basin cumulative amounts of rainfall reached 247 l/m^2 between 29.06 - 1.07.2010).

Figure 5 presents velocities evolution which lead to the erosion and washing of the dam body after the discharghe over the crest, at the lower level of the breach. It appears that between the time of the breach initiation and the one in which the lower level of the breach is reached, the water velocity reaches up to 3.0 m/s, which causes the development in height and width of the breach and the washing of the material from the dam. Structures made of local materials, that is various sorts of soils, can not avoid such erosion occurs if the discharge of the crest is produced or if breaches occur in their body. For this reason the structures designed to be discharged, are protected with coverings able to withstand erosion caused by these velocities (concrete, asphalt).

During the flood wave propagation, downstream from the discharged infrastructure, due to topography and large volumes of discharged water, propagation velocity increases, according to the simulation, at a distance of 500 m from the dam at 6.0 m/s, lowering to 5.6 m/s at a distance of 1000 m from the dam. Velocity is reduced, condition that determines the attenuation phenonema in the riverbed.

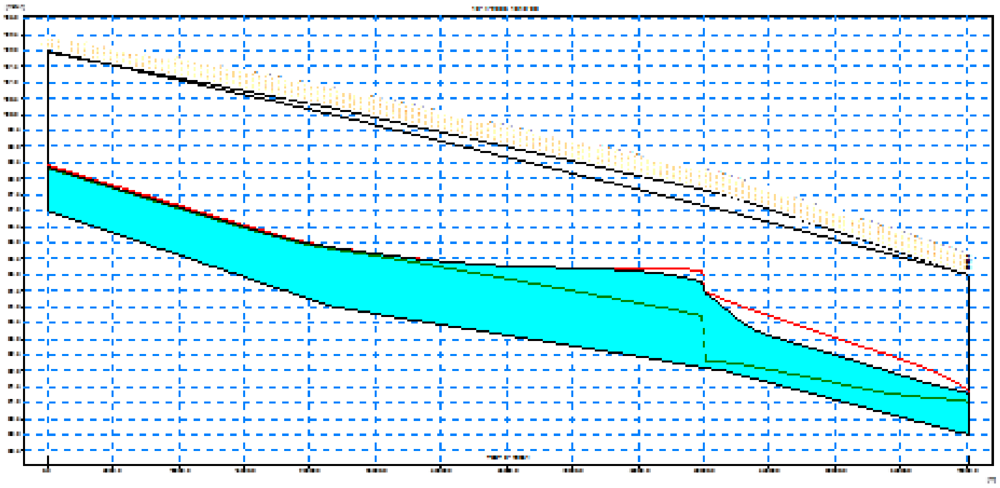

Figure 4 **Water level evolution at 40 minutes after breach initialization**

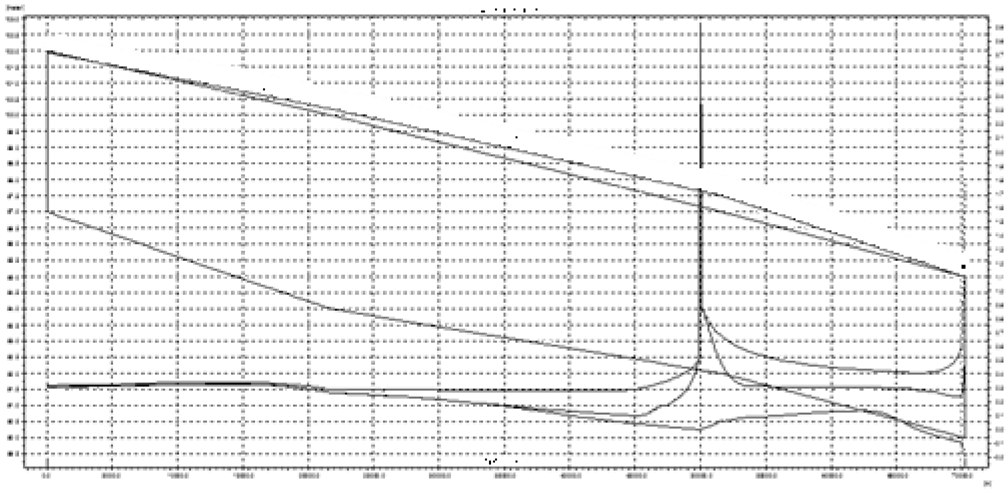

Figure 5 **Water velocity evolution during dam body erosion when the lower level of the breach is reached**

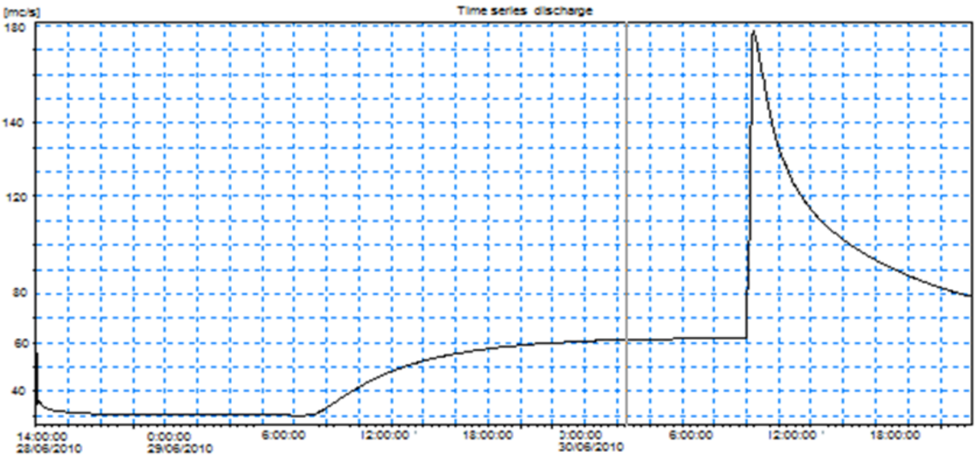

Figure 6 **Flood hydrograph at a distance of 500 m from the dam**
(Maximum flow rate of 180 m^3/s) caused by the discharge of the dam and the breach initiation

Flood hydrographs caused by crest discharge and breach development in the dam body have maximum values of discharghe of 193 m^3 / s in the axis of the dam, this value being reduced as we position ourselves towards the downstream of the dam: 180 m^3/s at 500 m from the dam, 168 m^3/s at 1000 m from the dam, 154 m^3/s at 3,000 m from the dam, 147 m^3/s at 5,000 m from the dam and 130 m^3/s at 7,000 m from the dam.

Downstream propagation created by the breaking wave has a strong three-dimensional character. Changes along the main riverbed flow (narrower sections alternating with large ones, tributary streams, bridges, control structures) produce accelerations with vertical and horizontal components on the flow axis. Water can flow laterally extending in open areas or to the tributary streams beds (Giurma I., 2003).

CONCLUSIONS

The results of the flooding study can be better used if they are integrated into a GIS model (Geographic Information System). By overlaying technique, all data of interest can be stored with specific representations for levels, velocities, time, etc.

The flooding strips determined after calculations and numerical simulations can contribute to the achievement of evacuation plans and emergency alarms for protecting people and economic assets located downstream of the accumulation.

Determination of the flooded area through calculations and flow characteristics in this area must take into account the high values of the peak flow and water depths associated, rapid flooding of the main riverbed, very irregular shape of the free surface and oblique shocks presence, flow over normal dry land, suspension transport of lake eroded material from the lake and eventually of fragments of the dam, border limits at the confluence with the tributary streams.

The results of the flooding study must include at least the initial flow before the arrival of the breakage wave, maximum discharge, the time at which the maximum discharge is produced, the initial level of the water, the highest level reached, the time at which the maximum level is reached, maximum flow velocity.

Map of flooding must indicate location of calculation sections, outline the flooded area as an envelope of the maximum levels achieved in the calculation sections, contours of flooded areas in successive intervals of 0.5 h after breakage and the time needed to get to peak value in the calculation section, measured from the initiation of the breach.

Numerical simulation enables not only more accurate reproduction through calculations of observed natural phenomena , but also incorporates assumptions related their development, aspect which can solve risk impact analysis and hydraulic structures safety.

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