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OUTFLOW HYDROGRAPH AS A BASIS OF FLOOD WAVE PROPAGATION CAUSED BY EARTH DAM FAILURE

Jerzy Machajski

In the paper the principles of outflow hydrograph determination from breach of earth dam body as a base of flood wave propagation are presented. Thus it is admitted that outflow hydrograph constitute one from the most important elements of failure consequences complex analysis, having a bearing on the estimation of the whole event progress, in this the resultant flood freshet propagation along the river valley.
Discussing procedures of determination of breach final parameters and outcome outflow hydrograph, attention was turned not only onto time of duration of dam washing away course and breach section formation, but onto duration time of the whole failure process as well, in this time of reservoir emptying.
Moreover the attention was paid to values having the impact on final computational effect, in this selection of soil geotechnical parameters whether parameters characterizing resistance on erosional caving of outer dam slope. Presented consideration are illustrated by computational example.

1 Introduction

Requirement of inundation extent determination, form in result of breakdown of dam of storage reservoir, is connected with valid in Poland regulations related to safety of hydrotechnical structures. Usually they include the failure cause determination and its effects, connected with outflow of flood wave having definite parameters and its downstream propagation in valley. Range of inundation downstream of structure is usually determined as an envelope of maximum filling of valley with water outflowing from formed breach. Usually also inundation range divides into zones, differentiating their character. We get then quantitative knowledge about potential range of flood threat and outcome possibilities of counteraction this threats.

Material losses accompany every breakdown, also casualties can accompany to it. Number of victims will depend, first of all, on size and range of inundation, number of inhabitants on that area and on disposable time and above all on efficiency not only of warning system but also of civil defence services, functioning on given area.

Determination and recognition of conditions that can lead to dam failure and prediction of such failure is not easy. From literatures' data it result e.g. that from over 11.000 of casualties of dams breakdown that took place on the world in last 200 years, almost 60% are due to failure of large dams, such as dam in Vaiont in Italy (1963), Johnstone in Pennsylvania (1889) and Machlu II in India (1974). In every of these cases local population was not adequately early or not at all warned. Time of warning is the most essential parameter conditioning number of potential victims, e.g. according to data from 1985 the average number of failure victims, re-counted per one dam, is 19 times bigger in case of inappropriate warning.

Analysing an occurrence of dam failure, we should command or try to elaborate the efficient tools for estimation of different possible cases of failure. Such analysis should include all possible threat scenarios and also possible progress of that failure. Usually also the failure should be considered as three-phases process – first phase is a dam washout and outflow of flood wave, second one a propagation of resultant wave along river valley downstream, third one the consequences of that outflow. In the paper the first stage of that process is described.

2 Dam washout and outflow of flood wave

Simulation of dam body break process and also determination of formed breach parameters are loaded with serious errors. The reason of them is that most of existing solutions are based on data from occurred in the past and documented dam failures or on results from numerical models, procedures of that have been based on such events descriptions. Unfortunately they do not give completely either mechanism of earth dam washout or real parameters of flood wave outflowing from breach.

A number of different failures that occurred in the world have not been precisely described, so only limited information concerning the final depth, width and the shape of breach in the dam body, value of maximum outflow, time the dam break have been arrised and formation of the final breach shape and size, and also time the storage reservoir have been completely emptying. Data coming from available dam failure descriptions do not give sufficient basis for determination of time minimum needed for initiating the dam body breaking process, breach forming time and total time the breach will have achieved its final shape. It could be resulted from the fact that often failure descriptions were given by incidental people without knowledge of proceeding processes, usually also not understanding for them. Elaboration of methodology of earth dam failure analysis consists usually in determination of:

- prediction of outflow hydrograph from breach in the dam body,
- transformation of predicted hydrograph along river valley and adjacent left and right side area.

Solution of problem related to wave transition through breach in dam body and also along river valley downstream is relatively less complicated, for that purpose standard broad used numerical models are applied. More difficult problem is connected with simulation of dam breach formation process. It resulted from the fact that many of available models not directly simulates the process leading to failure but threats characeristics of washout process as input data given by user. Available methods applied to above considerations are divided into four categories, from which usually the first one is used, based on physical equations, predicting breach extention in dam body and resultant outflow hydrograph (Boss DamBreach Model applied by paper author). In that model are used: erosion model, hydraulics rules, bed load mechanics rules and soil mechanics.

For the necessity of risk analysis caused by earth dam failure the most significant is accuracy of dam body breach parameters forecasting. It is essential for real obtaining – quantitative assesment of outflow and resulting from it inundated area downstream of dam. Breach parameters simulation gives the most uncertainty, from all flood modelling aspects as consequences of dam break. Usually meaning of parameters describing breach is related to storage reservoir capacity. For large reservoirs maximum outflow occurs when breach achieved its maximum size. In this case breach forming is accompanied with relatively small water levels changes in reservoir. So the accuracy of breach shape and parameters forecasting is very essential. For small reservoirs breach forming is accompanied with substantial water levels changes and resultant maximum outflow through breach occurs before entire shape of breach have been formed. In this case it is essential to determinate correctly breach forming speed.

3 Breach shape and parameters

Breach in earth dam body arise in every failure risk situation. It could be resulted from overflow over dam crest, uncontrolled filtration along reservoir bottom outlets, uncontrolled filtration through earth dam body or hydraulic piping in subsoil the dam is based on. As a result through newly created breach in earth dam body an outflow of flood wave come after, which such parameters as discharge, velocity and height depends mainly on two factors – final breach parameters and initial time of dam washout process in connection with time of breach formation.

Breach in the dam body could be described by the following geometric parameters:

- breach depth defined as vertical distance, measured from dam crest to breach base,
- breach width, defined as value of mean width of hole fordem in dam body or as independently width of lower and upper hole edge,
- breach side-slopes inclination, defined as value that together with height and width fully determine a breach shape in the dam body.

Breach shape and parameters at the beginning were determined on the basis of available descriptions of dam failure events. It appeared that breach shape changes from triangular to trapezial together with washout sizes progression. More problems occurred with trial of breach width defining, from analysis of well documented earth dam failures it appeared that washout width usually vary from two to five times of dam height. Describing breach parameters, as a very interesting factor appeared so called breach formation factor, defined as product of water volume outflowing through breach and water depth above lower edge. With this factor the volume of material extracted from breach during washout process have been connected. On that basis it have been stated that range of the breach slopes inclination should vary from 1:1 to 1:2.

During analysis concerning shape and parameters determination, a lot of attention have been pointed out on breach depth. In observed cases it happened that breach reached subsoil of dam or stopped at certain level above subsoil. It appeared also that breach formed above dam basis had a triangular shape whereas strictly at dam basis it had trapezium shape. Earth dam failures documentations analyses led to statements that on breach parameters and shape essential influence had dam characteristics – body soil (easy or hard washout), method of dam body proofing (concrete lining on upstream slope, clay core inside dam body), dam crest width, presence and sizes of coping wall, resevoir capacity, water damming level in reservoir and possibility of dam crest immerse. Usually breach caused by water flowing over earth dam crest is broader and is characterized with faster side erosion than in case of breach made by other causes.

4 Time of washout initiation and time breach forming

On flood wave propagation progress caused by dam failure essential influence have not only time breach forming, but also time related to washout initiation process. This time can vary from 1 to 4 hours.

Initiation time is comparatively important for breach forming conditions and resultant outflow. Differentiation of initiation and breach froming time, have proved that dam body washout process is not immediate as it was supposed earlier and that during its progressing two phases having places, in which mechanism and washout speed can change rapidly. As a beginning of washout initiation process the occurrence of first small outflow from dam body can be taken. The structure has not been damage yet and outflow source can be e.g. insignificant – local dam crest immerse or seepage through channel forming in dam body in piping processes. If during of this phase it could be possible to react against these processes, avoiding of dam failure is still possible, if not initiation time of this process ends and simultaneously process of breach forming time begins, which stay till the moment its entire shape and parameters have been formed.

In situation when dam failure is caused by overtopping, beginning of breach forming succeeds as a result of progressing downstream slope erosion and rising crack increases its parameters towards the dam crest. If erosion processes will have been initiated so in view of their rapidly increasing outflow, it is less probable to stop at this stage the discharge from reservoir and protect dam against washout.

Introduced as an additional phase of dam body washout process the initiation time, it directly impact on early warning time and evacuation plan of population living downstream dam and reservoir. Warning time becomes thereby the sum of initial time, breach forming time and time that flood wave need to propagate to aln development. As literature' data show, casualties can vary from 0,02 % at warning time equal 90 min. to 50 % when this time is lower than minutes.

In Poland is obligatory the division on four risk zones caused by dam failure. These zones are determined on the base of time which have to pass from the failure beginning till the moment flood wave will reach computational section. Division on zones take into account lack of possibility or possibility to organize an effective evacuation action of population from threat areas.

Zone No I consists of area in which wave front reaches from failure source to the end of this zone within 15 minutes. Zone No II consists of area in which wave front reaches from failure source to the end of this zone within 30 minute. Zone No III consists of area in which wave front reaches from failure source to the end of this zone within 45 minutes. Zone No IV consists of area in which wave front reaches from failure source to the end of this zone within 60 minute. Below the last zone it is assumed that freshet wave loses its destructive character.

Reach time of freshet wave equal to 15 minutes is considered as a time in which there is no possibility to organize an effective evacuation action. In this moment it is important to quick recognize the risk of dam failure by reservoir service and their proper reaction i.e. the alarm system switching on. It gives chances to run away to higher located areas. The area within this time zone is considered as the most subjected on destructive impact of freshet wave treated as shock wave, without practically any possibilities for counteraction of its consequences.

Reach time equal to 30 minutes is considered as a time in which it is possible to warn local population enough to that they will be able to take away their most valuable things. This time also closes the area in which freshet wave impact is as dangerous as in Zone No I.

Reach time equal 45 miutes gives certain chance for organizing an evacuation action, thereby it ensures to save by local population a majority of their things. This time consists the zone in which imact force of freshet wave gradually disappear. However it strictly depends on local conditions – morphology, slope, land use on the way of flood wave propagation.

Reach time equal 60 minutes is considered as sufficient time to inform local society by common communication systems i.e. phones, radio etc. At shorter reach time of flood wave local populity information ought to be done with fast means of communications – systems switched on by radio or special cable systems.

5 Computational example

Computational example of time duration of earth dam washout process have been carrid out for Kamieniec Zabkowicki storage reservoir situated in 102,2 km of the Nysa Klodzka river course. It is a structure actually being under designing process, this reservoir will be the fifth storage reservoir on the Nysa Klodzka river, at the same time the first of reservoir cascade, receiving actually not regulated flood wave from the upper the Nysa Klodzka catchment. Simultaneously outflow from this reservoir will constitute inflow to downstream localized other cascade reservoirs.

Designed storage reservoir Kamieniec Zabkowicki will belong to multifunctions reservoirs. This reservoir will have the same functions as other reservoirs: Topola, Kozielno, Otmuchow i Nysa. As a basic function is flood protection, however a secondary functions are: low flow smoothing, aggregate exploitation from reservoir area, hydro-power, tourism, water supply (if such demands will occure).

As expected effect of Kamieniec Zabkowicki construction it will be the essential flood discharge reduction on located downstream reservoir inflow, and in consequence flood discharge reduction of outflow from the cascade lowest reservoir in such way to be significantly reduced in the mouth cross section of the Nysa Klodzka river to the Odra river, what is important for Wroclaw flood protection.

Computational discharges of the Nysa Klodzka river for main hydraulic structures of reservoir taken on the basis of valid in Poland regulations – for earth dams classified to I class, not founding on the rock (main dam) are as follow:

- design discharge: $Q_m = Q_{0,1\%} = 1994\ m^3/s$,
- conrolled discharge: $Q_k = Q_{0,02\%} = 2972\ m^3/s$ (with estimation error).

Taking designed reservoir capacity division on particular layers – flood and usable, water – economic demands attributed to reservoir were regarded. From calculations results that flood capacity given efficient effects of valley protection downstream reservoir is value V_p equal to 60 mln m^3. Warranted secondary demands need usable capacity V_u equal to 40 mln m^3, from that total reservoir capacity V_c equal to 100 mln m^3.

Downstream of designed Kamieniec Zabkowicki reservoir on the Nysa Klodzka river there are four storage reservoirs:

- reservoir Topola (km 97,0),
- reservoir Kozielno (km 94,4),
- reservoir Otmuchów (km 79,8),
- reservoir Nysa (km 66,9).

These reservoirs create cascade, from that consequences of each other failure can influence on structures localized below. Particularly it is important for Kamieniec Zabkowicki situated at the cascade beginning.

Kamieniec Zabkowicki resevoir will create main eart dam, made of local materials taken from reservoir area. Length along dam crest is equal 2260 m, maximum height – 18,70 m, dam crest width – 8,0 m, upstream slope inclination – 1 : 2,5, downstream slope inclination – 1 : 2. Dam will be constructed as homogeneous with clay core. Dam body materials are sand-gravel-clay mix of the following geotechnical parameters:

- natural humidity – $W_n = 10{,}17 \div 28{,}10\ \%$
- bulk density – $\gamma_d = 19{,}2 \div 22{,}6\ kN/m^3$
- internal friction angle – $\Phi_u = 25^o \div 34^o$
- cohesion – $C_u = 2 \div 40\ kPa$
- filtration coefficient – $k_f = 2{,}5 \times 10^{-7} \div 2{,}9 \times 10^{-4}\ cm/s$.

For elaboration ”Feasibility study of Kamieniec Zabkowicki storage reservoir”, paper author carried out initial simulation of earth dam washout process of this reservoir applying model BOSS DamBreach, the american firm BOSS International (6300 University Avenue, Madison, Wisconsin, 53562-3486 USA). Model in details analizes breach forming process in body of earth dam, caused by overtopping or by piping. Modelling of dam body washout process needs to give several geotechnical parameters of dam body soil, such as: shear stresses, cohesion, internal friction angle, and also needs description of protection form of washing out downstream slope – vegetation protection or other. Model also includes form of dam body proofing – concrete lining on upstream slope or clay core.

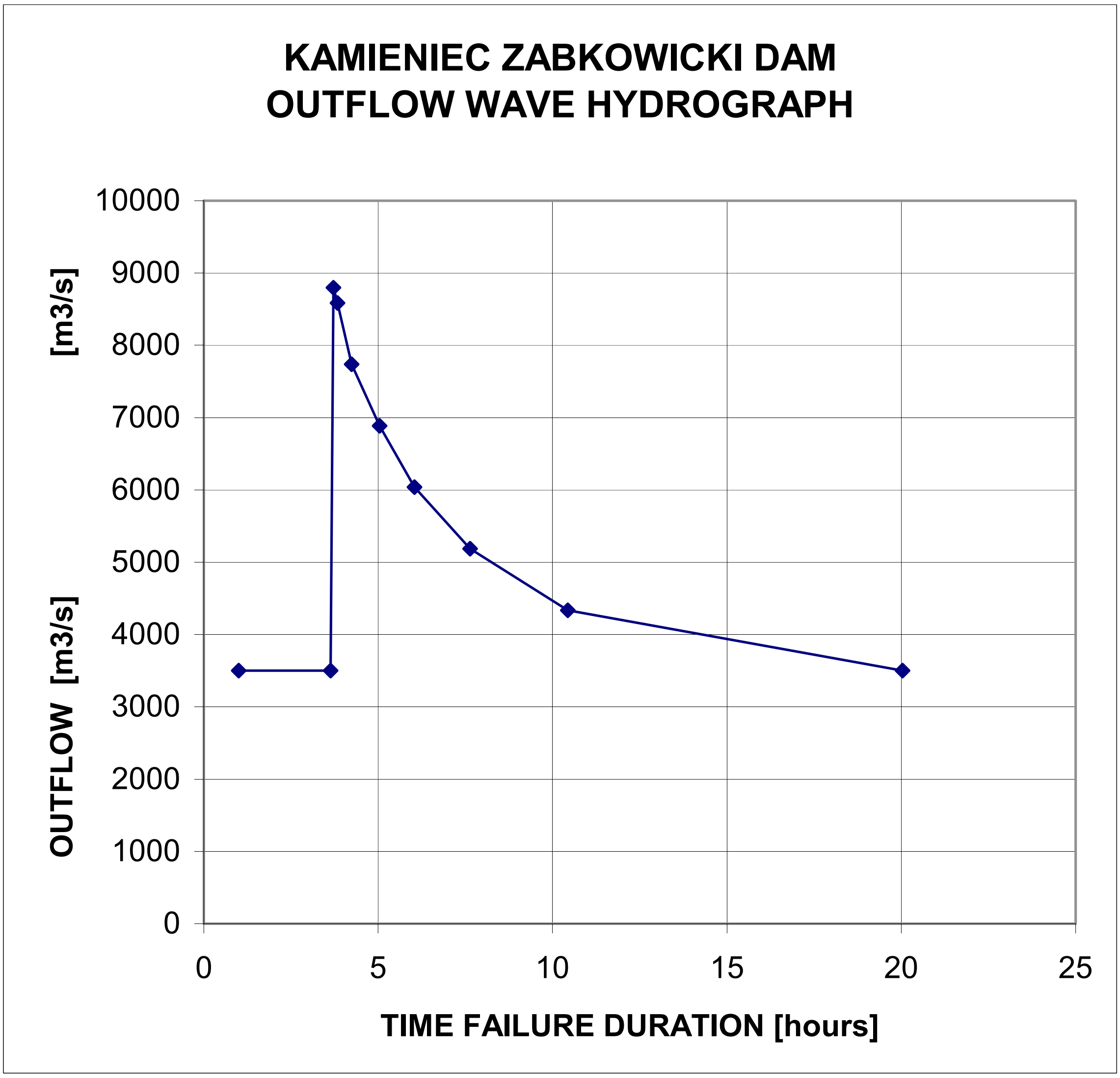

Figure 1 Breach-out flow hydrograph from Kmieniec Ząkowicki reservoir

Simulation was carried out on the basis of taken geometrical dam parameters, dam body soil parameters, designed reservoir parameters (capacity and inundation area curves) and on assumed catastrophic inflow to reservoir equal to

3500 m^3/s, causing hypothetical dam and reservoir failure by overtopping. Results of calculations are shown below.

6 Conclusion

According to regulations valid in Poland every new designed storage reservoir should have determined the consequences of hypothetical failure of its main structures on area downstream the dam. On the basis of them te activities are established that have to be done in case of failure situation occurrence, the warning system is chosen, evacuation paths are planned, activities of particular emergency services are planned. Presentd computational example shows necessity of precisely determination of dam washout time duration, time that is needed for effective evacuation action organization. More precisely this time will be determined and if it will be more reliable the rescue action will be more efficient, and risk for population downstream the dam will be lower.

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