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Estimation of condition of maximum flood passage through Mietkow storage reservoir on the Bystrzyca river

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In the paper an analysis of outlet installation operations of Mietkow storage reservoir, under changed hydrological conditions is presented. Introduced in 1997 new classification of hydro-engineering structures forced a change of class of importance of this object and in consequence change of computational discharges – design and control, remaining the outlet installation capacity ability the same. On the basis of carried out flood wave transformations through reservoir, it is shown a threat possibility of dam crest overtopping, resulting from insufficient outlet installation capacity ability. In connection with flood control and possible to obtain prepared storages, the possibilities of their reductions are shown. Simultaneously, Authors proposed a new principles of water management on the reservoir.

1 Introduction

Mietkow storage reservoir was given to exploitation in 1986. It is multitask reservoir with total capacity of about 86 mln m^3, which exploitation is associated with mineral aggregates output from its bottom. This gives a permanent enlarging of its capacity, within a year from 0,5 to 1,0 mln m^3, and it has an influence on improvement of this object an exploitation safety – *Machajski (2010)*. The reservoir outlet installation was designed on discharges in amounts: design equals $Q_m = Q_{0,3\%} = 366\ m^3\ s^{-1}$ and control $Q_k = Q_{0,05\%} = 647\ m^3\ s^{-1}$. Due to changes of valid in Poland regulations concerning the technological conditions of hydro-engineering structures, the reservoir class of importance has been changed from II to I, and as a consequence the computational discharges changed. They have increased and at present are equal to, respectively: design $Q_m = Q_{0,1\%} = 548\ m^3\ s^{-1}$ and control $Q_k = Q_{0,02\%} = 805\ m^3\ s^{-1}$. Because a total capacity ability of existing outlet installation of Mietków reservoir remain the same and is equal to 648 $m^3\ s^{-1}$, Authors undertook a trial to determine a guarantee of exploitation safety for reservoir in situations of new computational discharges occurrence. In such situation a question comes into being, whether change of technical class of hydro-engineering structure resulting from regulations changes should force the changes of computational parameters of object.

2 Object description

Mietkow storage reservoir on the Bystrzyca River is a multitask reservoir, its basic tasks are: flood protection of the downstream Bystrzyca River Valley, supply in water the Odra Waterway during droughts, mineral aggregates exploitation, water storing for energetic purposes of small hydroelectric power station with installed electric power 0,55 $m^3 s^{-1}$ and recreational use on aims of water sports and an angling – *Machajski (2010)*.

Mietkow storage reservoir is located on the Bystrzyca River in km 45+030. It is created by earth dam with total length at the crest level equals to 3 220 m. Homogeneous dam body is built with gravel and sandy-gravel taken from reservoir bottom. Maximum height of dam is equal to 17 m, a width at a base is about 80 m, a width at crest level is equal to 5,0 m. Slope of dam body from upstream is 1 : 2,5, downstream dam body slope up to half of its height is 1 : 2,5, and higher is 1 : 2. Upstream face is protected by reinforced concrete screen of 0,20 m thickness, placed directly on dam body ground. From upstream, depending on thickness of permeable layers, a clay-concrete cut-off wall is introduced into a ground on depth 4,50 ÷ 17,50 m. Downstream face is protected by soil and grass, at half of its height a berm of 3,0 m width is constructed. At downstream slope base a stoneware tubular drainage system with diameter of DN 0,30 m is placed, closed in two-layers filter prism. Drainage is controlled by concrete wells of diameter equals to DN 1,0 m, spaced in 50 m distance.

Outlet installation of reservoir consists of two spans spillway of 2 x 12,50 m width with flap gates and three conduits of bottom outlets with dimensions of 1,90 x 2,20 m, closed from tailwater by radial gates as service gates and from headwater by vertical lift gates as emergency gates. Flood waters overflowing the weir crest enter a stilling basin with dimensions: width – 29,0 m, length – 31,25 m, depth – 2,90 m – Fig. 1. Capacity ability of weirs at opened flap gates and damming up level in the reservoir NPP 170,60 m a.s.l. is estimated on about 60 $m^3 s^{-1}$, at maximum damming up level Max PP 172,30 m a.s.l. is estimated on about 268 $m^3 s^{-1}$, whereas at damming up level responding to absolute damming up level Nad PP 173,60 m a.s.l., is estimated on about 470 $m^3 s^{-1}$. Capacity ability of three bottom outlets at damming up level NPP is estimated on about 170,0 $m^3 s^{-1}$, at maximum damming up level Max PP is estimated on about

180 m^3 s^{-1}, and at damming up level Nad PP, is estimated on about 190 m^3 s^{-1} – *Novak (2007), Khatsuria (2005)* (Fig 2).

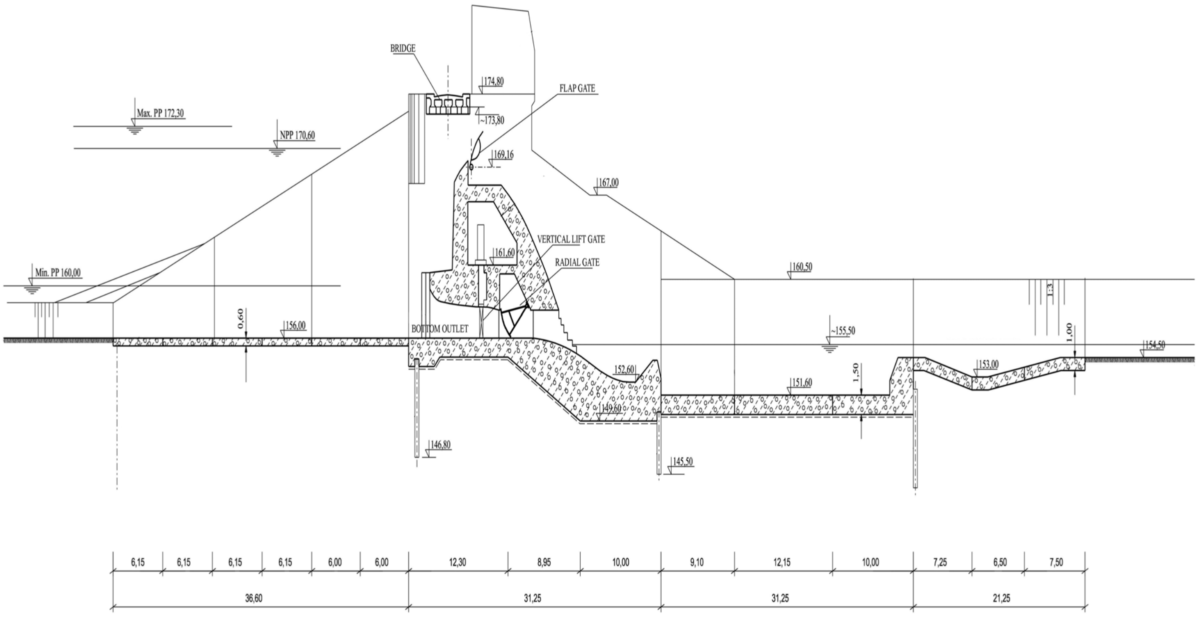

Figure 1: Cross-section of monolithic concrete structure of Mietkow reservoir

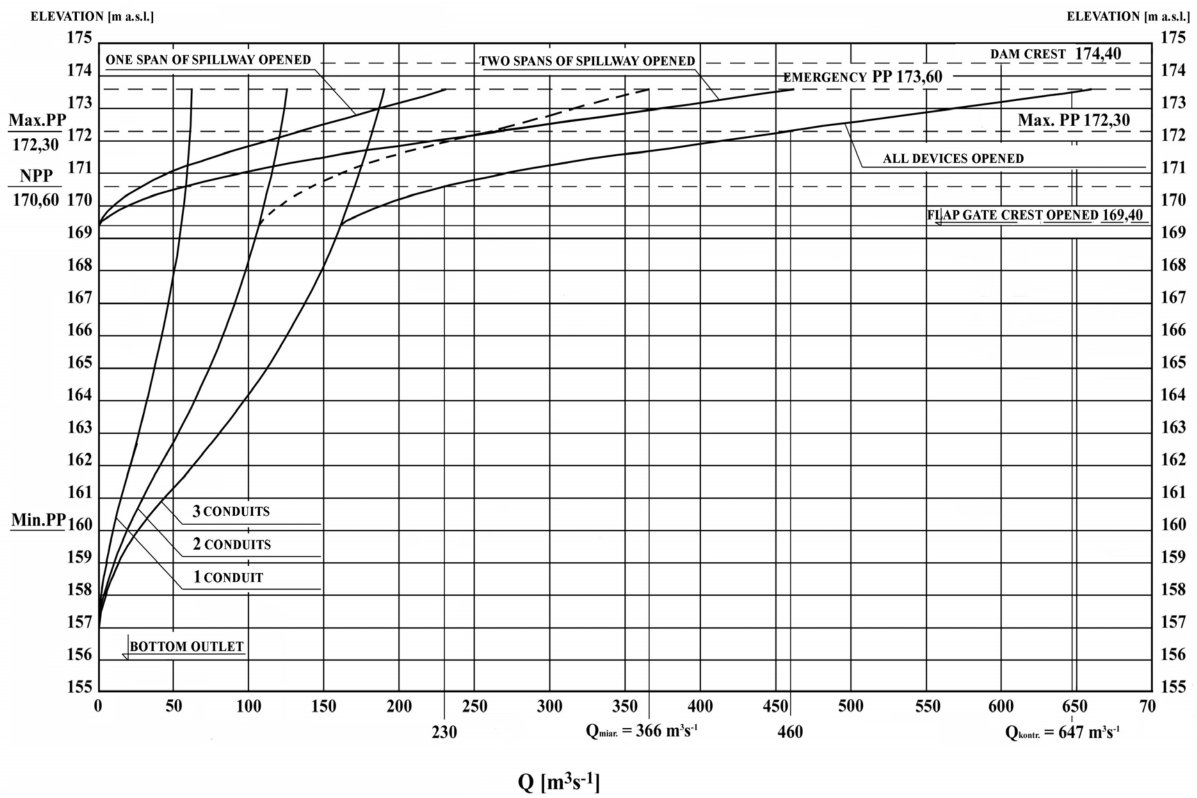

Figure 2: Total capacity ability of outlet installations at full opened gates

Characteristic capacities of Mietków storage reservoir are given on the basis of designed data in 1986 and data from reservoir bottom sounding in 2008. During design phase the following water damming up levels were fixed: minimum Min PP 160,0 m a.s.l. with corresponding reservoir capacity of 3,711 mln m^3, normal NPP 171,80 m a.s.l. with corresponding capacity of 62,747 mln m^3 and maximum Max PP 172,30 m a.s.l. with corresponding capacity of 70,561 mln m^3. At present (2008) under conditions of damming up level NPP 170,60 m a.s.l., the reservoir capacity is equal to 63,26 mln m^3, from which a dead capacity is 2,11 mln m^3 and active capacity is 61,15 mln m^3. At maximum damming up level Max PP 172,30 m a.s.l. the reservoir capacity is equal to 76,98 mln m^3, resulting difference makes flood control capacity equals to V_{ps} = 13,72 mln m^3. At absolute damming up level Nad PP 173,60 m a.s.l. total reservoir capacity equals to 87,84 mln m^3. Minimum damming up level Min PP is fixed on elevation of 160,00 m a.s.l. with corresponding reservoir capacity of 2,11 mln m^3.

3 Hydrological characteristics

The Bystrzyca River is a left-sided tributary of the Odra River with its mouth in 266,5 km. Total River length equals to 95,2 km and catchment area equals to 1767,8 km^2. Average slope of catchment range from 21,2 % in the upper part of catchment to 7 % in the lower part of catchment. A drainage density is about 0,55 1 km^{-1}, afforestation range from 54 % in mountainous part to15 % in the lower part of catchment. River bed is incised on depths 0,50 – 2,0 m, width of river bed bottom range from 2,0 to 10,0 m. In 75,2 km of the Bystrzyca River watercourse the dam of Lubachow storage reservoir is located of total capacity 12 mln m^3. Valley slopes are gentle but clearly contoured. The change of terrain level equals 20 – 40 m. On the section to the reservoir, the Bystrzyca River is supplied by left-sided tributaries: Zlotnica, Witoszowski Potok, Jablonie and Pilawa. In 45,0 – 50,5 km of river watercourse, there is Mietkow storage reservoir– *Machajski (2010)*.

All discharges were determined at main for reservoir gauging station Kraskow and were transferred into reservoir cross-section according to the catchment area growth, applying the method of extrapolation in the following form:

$$Q_Z = Q_M \cdot \left(\frac{A_Z}{A_M} \right)^{2/3} = Q_M \cdot 1{,}34 \qquad (1)$$

where: Q_Z – discharge at reservoir cross-section,

Q_M – discharge at Kraskow gauging station,
A_Z – catchment area at Mietkow dam cross-section,
A_M – catchment area at Kraskow gauging station.

Characteristic discharges are as follow (Polish abbreviations): minimum NNQ = 0,175 $m^3 s^{-1}$, average low flow SNQ = 0,712 $m^3 s^{-1}$, mean SSQ = 4,56 $m^3 s^{-1}$, average maximum flow SWQ = 68,0 $m^3 s^{-1}$, maximum WWQ = 198 $m^3 s^{-1}$ – *Machajski (2010)*. Maximum discharges with a given probability of exceedance were determined on the basis of multiyear time series of observations. Long time series were checked under regard of inhomogeneity, both genetic and statistical one, and carried out analysis proved that they fulfilled the conditions of homogeneity. Characteristic discharges given in a Table 1 constitute the input data for hydraulic calculations of capacity ability and a way of hydro-engineering structures use, which determined in a proper way should ensure a safety of these objects during flood waves passage – *Machajski (2010)*.

Table 1: Maximum discharges with a given probability of exceedance $Q_{maxp\%}$ at Mietkow reservoir cross-section

Maximum discharges with a given probability exceedance p % [$m^3 s^{-1}$]							
50	10	1	0,5	0,3	0,1	0,05	0,02
40,1	117	285	352	409	548	651	805

4 Analysis of exploitation safety of object

Hypothetical waves to Mietkow reservoir cross-section were constructed on the basis of real waves observed at Kraskow gauging station in period 1964 – 2002. Hydrographs were constructed on the basis of highest flood waves analysis, above threshold discharge that correspond with warning water stage – *Ghosh (2006)*. Probabilities for computational discharges for reservoir of I class of importance, which dam is founded on rocky ground, are equal: $p_m = 0,1$ %, $p_k = 0,02$ %. They for these probabilities are equal respectively: $Q_m = Q_{0,1\%}$ = 548 $m^3 s^{-1}$, $Q_k = Q_{0,02\%}$ = 805 $m^3 s^{-1}$.

For reminder, storage reservoir was designed for computational discharges determined for II class of importance, i.e.: Q = 366 $m^3 s^{-1}$ (design discharge), Q = 647 $m^3 s^{-1}$ (control discharge). Also, to check, transformations of flood waves for object of II class of importance (but for currently valid regulations), for verified maximum discharges with a given probability of exceedance were carried out. For similar as above conditions of dam construction and foundation, probabilities for computational discharges equal respectively: $p_m = 0{,}3$ % and $p_k = 0{,}05$ %. Maximum discharges equal then: $Q_{0,3\%}$ = 409 $m^3 s^{-1}$, $Q_{0,05\%}$ = 651 $m^3 s^{-1}$. All analyses and calculations were carried out on the basis of general assumptions, which are as follow:

– I class of importance of object due to reservoir capacity (V > 50 mln m^3),
– safe height differences between dam crest elevation and water levels: 1,30 m and 0,30 m respectively for design and control discharges,
– design and control discharges for object of I class of importance, i.e. probabilities equal 0,1 % and 0,02 %,
– two hypothetical waves as input data with peaks equal $Q_{0,1\%}$ and $Q_{0,02\%}$,
– during control flood wave passage through the reservoir all outlets installation are opened,
– tabular relationships between water levels in reservoir and related to them capacities and discharges of each outlet installation are recognized as correct,
– characteristics of spillway and bottom outlets elaborated on the basis of model investigations are recognized as correct.

The main purpose of calculations was the determination of maximum water levels in reservoir and reduced discharges on the basis transformed flood waves. From various methods of flood wave transformation the method which use a continuity equation in differential form was chosen (3) – *Jain (2001)*:

$$\frac{\partial Q}{\partial x}+\frac{\partial A}{\partial t}=0 \tag{3}$$

where: Q – discharge, $m^3 s^{-1}$,
x – co-ordinate consistent with flow direction, m,
A – flow cross-section area, m^2,
t – time, s.

Equation (3) after integration from x_1 to x_2 and modification take the form in which we can show a water capacity stored in or flowed out from reservoir:

$$Q(x_1) = Q(x_2) + \frac{\Delta V}{\Delta t} \tag{4}$$

where: x_1 – co-ordinate at inflow cross-section,
x_2– co-ordinate at dam cross-section,
$Q(x_1)$ – reservoir inflow, $m^3 s^{-1}$,
$Q(x_2)$ – reservoir outflow, $m^3 s^{-1}$,
$\Delta V/dt$ – changes of reservoir capacity in time.

Knowing a flood wave hydrograph, reservoir storage curve and characteristics of outlets installation, calculations of flood wave transformation through the reservoir, using equation (4), were carried out, using Puls method – *Ghosh (2006),* with additional assumptions:

- during design flood wave routing Qm one bottom outlet and one spam weir are excluded from exploitation,
- alternatively wave routing for flood of Qm was checked for all opened outlets,
- during control flood wave routing Qk all outlets are opened,
- maximum water level in the reservoir that cannot be exceeded for the sake of reservoir safety equals (Polish abbreviation) Nad PP = 173,60 m a.s.l.,
- during flood waves routing the weirs and bottom outlets are fully opened,
- calculations were carried out for three initial water levels in the reservoir:
  - 170,60 m a.s.l. – normal damming up NPP,
  - 169,40 m a.s.l. – weir crest elevation for fully opened flap gates,
  - 160,00 m a.s.l. – minimum damming up Min PP (dead capacity).

Analysis of calculations for reservoir of I class of importance let to state that there are possibilities for safe routing of hypothetical waves through Mietkow reservoir. However, during design flood wave passage there is no possibility of preserving, required in regulations, a safe dam crest height above the maximum water level in the reservoir equal to 1,30 m, in this:

- 173,67 m a.s.l., i.e. 0,73 m to dam crest in an initial state of reservoir fulfillment of normal damming up NPP = 170,60 m a.s.l.,
- 173,24 m a.s.l., i.e. 1,26 m to dam crest in an initial state of reservoir fulfillment of 169,40 m a.s.l.,
- 171,78 m a.s.l., i.e. 2,62 m to dam crest in an initial state of reservoir fulfillment of 160,00 m a.s.l.
- During control flood wave passage a safe dam crest height above the maximum water level in the reservoir, required in regulations, is preserved and equal to 0,30 m, in this:
- 173,53 m a.s.l., i.e. 0,87 m to dam crest in an initial state of reservoir fulfillment of normal damming up NPP = 170,60 m a.s.l.,
- 173,40 m a.s.l., i.e. 1,0 m to dam crest in an initial state of reservoir fulfillment of 169,40 m a.s.l.,
- 172,49 m a.s.l., i.e. 1,91 m to dam crest in an initial state of reservoir fulfillment of 160,00 m a.s.l.

5 Proposal of water management during flood wave routing through a reservoir

A fact is worthy of notice, that almost total reservoir emptying before flood wave forthcoming, has a significant influence on discharges reduction and maximum water level settlement in reservoir. This fact can have a significant role in downstream area protection due to relatively quick flooding on adjoining areas and generating flood damages in a consequence.

Prerelease from a reservoir should be realized after receiving an information that warning water stage at Kraskow is exceeded. In the first stage a prerelease should be dropped by a middle bottom outlet in amount not exceeding 5 m^3 s^{-1}. After receiving an information that at Kraskow gauging station an alert water stage is exceeded, a middle bottom outlet should be excluded from operation with simultaneous gradual opening of outer bottom outlets to not exceed a total outflow in amount of 20 m^3 s^{-1}, and in a case of predictions of further increasing of inflow to a reservoir, a total outflow should not exceed 40 m^3 s^{-1}. During a prerelease an upstream water stage should be observed and when it is lowering, prerelease established amount should be kept, and simultaneously water stages at Kraskow gauging station should observed. If they are lowering, outer outlets should be gradually closed with simultaneous opening of middle outlet, having on attention allowable, for a given period, damming up levels in a reservoir. In a situation of predicted inflow of particularly large flood freshet of amount higher than 200 m^3 s^{-1}, a prerelease should start at once, increasing gradually an outflow, however not exceeding a permissible discharge Q_{doz} = 40 m^3 s^{-1}, and in particularly justified cases a flood discharge Q_{pow} = 120 m^3 s^{-1}. In that period weather reports should be analyzed, with possible corrections in predicted amount of inflow to reservoir. When an inflow increase is expected, bottom outlets should be gradually closed and outflow should be released by the spillway.

The Bystrzyca River has very changeable hydrological regime. It is difficult to unambiguously determine which of main tributaries, will have an essential influence on forming the freshets in the Bystrzyca River, it is also difficult to predict how located upstream Lubachow storage reservoir will operate regarding possibilities of flood discharges reduction. Hence, there are no exactly defined rules which should be valid for reservoir during creation and usage of flood storage. In case of Mietkow reservoir the flood storage is considered as control, prepared, accidental and surcharge.

Capacity of flood control storage is imposed, it should be kept on fixed level in a given period. In that case a possibility of flood prepared storage creation becomes a significant issue, because flood accidental storage, which is connected with active storage depletion, is difficult to unequivocally predict. On Mietkow reservoir there is a possibility to create a flood prepared storage, because outlet installation capacity ability allows on it, however decision of making prerelease should be strictly connected with inflow prediction, understood as volume and peak of freshet. Such decision should be taken quickly, as it is connected with certain discharge limitations downstream a reservoir. Determined permissible discharge according to many available opinions is too high and its occurrence downstream a reservoir will quickly cause a local inundations what is accompanied by protests of local society living on that area.

In threat situation of flood waves forthcoming, everything should be done for optimal use of flood control storage. First possibility assumes quick filling of flood control storage, spillway set working and then, by gradually opening of bottom outlets, controlling of damming up levels in reservoir. In that case it is difficult to obtain satisfactory effects of wave reduction on reservoir. Second possibility assumes a reaction on inflow amount through gradually opening of individual bottom outlets conduits according to changes of inflow. Controlling an outflow downstream and the conditions of filling a flood control storage, it is possible to reduce a wave to discharges that cause the smallest harmful effects.

6 Requirements of downstream area protection

A release (Q_{wyp}) in amount of $Q \leq 20$ m^3 s^{-1}, is a consequence of actual capacity ability of the Bystrzyca River bed downstream Mietkow reservoir. Amount of this outflow results from taken settlements, every greater outflow should be agreed-upon with flood protection services. Release can be increased to about 40 m^3 s^{-1}, which correspond to permissible discharge (Q_{doz}) and do not cause any flood damages in river bed and on adjacent areas. This discharge, obligatory on river section from Mietkow to mouth of the Strzegomka River to the Bystrzyca River, results from capacity ability of river bed and correspond to river banks flow. Greater in cubature flows locally can inundate the adjacent areas causing some flood damages. Release from Mietkow reservoir in amount of 120 m^3 s^{-1} is named a flood discharge (Q_{pow}). It is a threshold flow for flood damages, over which damages growth very quickly. Outflow in amount greater than 120 m^3 s^{-1} is named catastrophic discharge (Q_{kat}). When such flows occur all operative devices are opened and the reservoir loses its operational possibilities.

7 Recapitulation

On the basis of computer simulations connected with estimation of floods routing through reservoir, with peaks corresponding to computational discharges, it is shown that there is a possibility of safe passage such discharges without any risk of dam failure, for example in case of crest overflow. Simultaneously, on the basis of simulations a new instruction of water management for reservoir was elaborated, which contains the appropriate regulations concerning conditions of maximum flood routing through reservoir, according to its design and at present realized functions, but also according to requirements of downstream areas protection against flood.

8 Literature

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