HYDRAULIC MODEL OF HARCOV HISTORICAL DAM

[a]MARTIN KRÁLÍK, [b]MILAN ZUKAL

Czech Technical University in Prague, Faculty of Civil Engineering, Department of Hydraulic Structures, Thákurova 7, 166 29 Prague 6, Czech Republic
email: [a]kralik@fsv.cvut.cz, [b]zukal@fsv.cvut.cz

The paper was written with financial support of the Ministry of Culture project No. DF11P01OVV009 "Methodology and prevention and preservation tools of cultural heritage endangered by floods".

Abstract: The article deals with increase of safety of dams in connection with increasing safety standards, and it focuses on intelligent and careful methods of saving their cultural and historical value. The example is the historical dam Harcov: here, the hydraulic solution allowed to increase the safety of the dam in agreement with technical norm TNV 75 2935 „Considering safety of dams in case of flood", and regulation No. 590/2002 Sb., about technical standards for dams, and at the same time, the original historical nature of the dam could be preserved. To evaluate the suggested change on the spillway, hydraulic physical modelling was used. The technique has its justification if complicated construction settings of safety spillways are tackled – safety facilities of dams and their capacity and safety. In case of Harcov Dam, a new shape of the overflow surface with a low-pressure regime of water flow was designed for floods higher than Q_{20} (20-years-flood). For evaluating the original and the newly designed condition of the safety spillway and objects related to Harcov Dam, a physical model at a scale M – 1:20 was used which accurately describes circulation on this object. The capacity of the newly designed spillway is at surface level of safety limit water level 373,80 m a. s. l. 76,3 $m^3.s^{-1}$; that in sum with a bottom outlets is adequate to flow rate $Q_{10\,000}$. The project documentation for reconstructing the dam will be properly solved on the base of results of the physical model research.

Keywords: Cultural Heritage, Hydraulic Research, Dam Safety, Physical Modelling.

1 Description of the dam

Harcov Dam, sometimes also called Liberec dam, is situated near the centre of Liberec. Originally it was built on the edge of the city, but in course of last one hundred years it became an integral part of city environment as the city had naturally developed. The dam with wooded slopes nearby is a pleasant part of Liberec, serving for rest and recreation through the year. The uniqueness of the dam is confirmed by the fact that it can be found on the list of cultural heritage of National Heritage Institute since 1958. The impulse for construction was a series of damaging floods in the second half of 19[th] century.

The dam consists of a masonry gravity dam, built into arch with radius of curveness 120 m, height 19 m above foundation fissure and length 157 m in crest. Flood and safety facilities consist of two bottom outlets and crest spillway. The bottom outlet is a 16-meter-long pipe with an 800 mm diameter conducted in a tunnel. Both outlets have steel sluice gate on the upstream side and cast iron V-shaped sluice valves on the downstream side.

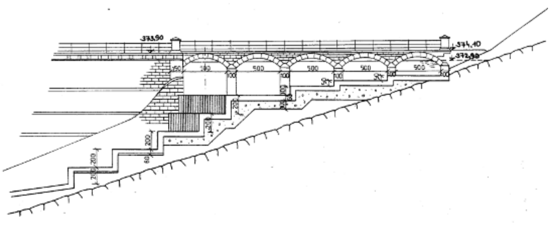

Fig.1. Harcov Dam – spillway from the downstream site

The crest spillway has five segments (one segment is 5 meters wide); above them there are vaults with deck of bridges; slide and stilling basin follow immediately after spillway. Among other components there are hydrometric profiles necessary for directing and manipulation with water in the dam and sedimentation partitions which retain pushed sediments in valleys of dam inlets. The main purpose of the dam is to retain flood flows of Harcovský potok and their lowering to a harmless flow 6,7 $m^3.s^{-1}$. Furthermore, the purpose is to create an accumulative space to assure consumption 0,150 $m^3.s^{-1}$ for industrial and other purposes in the city and last but not least, recreation, fish farming and sports fishing.

In the last several years, the attention of the dam administrator, the Labe Basin Authority state enterprise, has been focused on the issue of the dam safety during extreme flood discharges. Because of that a number of studies have been made. Firstly, hydrological data were considered. It is obvious that the original data used for projecting more than 100 years ago will differ from data nowadays used for evaluations of the safety of dams. The value of protection required increased from Q_{100} to the value of a higher order, i. e. $Q_{1\,000}$ (1000-year flood). In case of important dams, even the situation of 10000-year flood $Q_{10\,000}$ is examined.

2 Flood flows in consideration

Entering hydrological data are closely related to the safety of dams. They may considerably change with a dam being in operation. Such a change of hydrological data is expected in all cases when the hydrotechnical constructions operate longer than hydrological data were observed until the beginning of the construction.

When dams were projected and constructed at the beginning of the previous century in the Czech Republic, flood flow Q_{100} was considered for designing safety facilities. To assure quality of hydrological data, the period when necessary results from flow observation were collected has to be as long as possible; that was almost impossible at the beginning of the previous century. That is why the highest flood flow value available was considered for designing safety spillways of the dams, after evaluating hydrological data from a short period of time. After many years of operation the hydrological data were precised; it contributes to evaluation of the safety of a particular dam as for the really existing flows.

From the point of demands to a spillway as a safety facility of a dam, it is the possibility of overloading the overfall object above the designed capacity that has the essential meaning without the safety of a dam being endangered. The experience with extraordinary floods between years 1996 and 2012 proved that the real flow could be markedly higher in case of extreme flood. Due to that there has recently been an obvious pressure to evaluate the border safety of dams (including the less important ones) related to extreme floods (in agreement with the methodical instructions of Ministry of Environment of the Czech Republic - TNV 75 2935 „Evaluation of safety of dams in case of floods"). That is why the up-to-date knowledge of hydraulic function of spillways in case of exceeding the suggested limits is becoming a very important presupposition for safe operation of a dam as a whole.

In recent years the evaluation of extreme floods in dams has changed in favour of a dam safety. The flow of an extreme flood repeated in 1000 or 10000 years (depending of the category of the dam) is used for the evaluation of safety facilities' capacity. To find out the value of extreme flow $Q_{1\,000}$ and $Q_{10\,000}$, extrapolating methods and models of the precipitation-runoff processes are used. These values are further analysed and serve as a minor condition of designing a safety spillway in relation to maximal safe surface level in a dam. The value of an extreme flow is a limit for evaluation of the safety of dams and usually it is $Q_{10\,000}$ (in case of dams of lower category it is $Q_{1\,000}$ flow, rarely lower).

3 Issue of capacity of a spillway

Recent capacity of safety spillway (5-segment) was calculated to the value 16,31 $m^3.s^{-1}$ and the capacity of both bottom outlets to a flow ca. 12 $m^3.s^{-1}$. Just to remind: the highest flow observable at Harcovský potok during projecting Harcov Dam was 20 $m^3.s^{-1}$ (July 30, 1897). Nowadays the Q_{100} value is 30,1 $m^3.s^{-1}$.

The safety spillway of Harcov Dam was evaluated on the base of a hydraulic calculation for a spillway:

$$Q = \sigma_z m b_0 \sqrt{2g} h_0^{3/2}$$

where: Q – flow discharge [$m^3.s^{-1}$], σ_z – downstream water coefficient, m – overfall coefficient, b_0 – effective spillway crest length [m], g – gravity acceleration [$m.s^{-2}$], h_0 – overflow head (including velocity head) [m].

Fig.2. Safety spillway and chute

It is necessary to remark that the preciseness of calculations was given by geometry and complicatedness of the construction that directly influences the capacity of the object. The shape of the construction was necessary to be taken into account by coefficient of side narrowing, coefficient of a spillway over the wide crest of the bridge and coefficient of spillway influenced by the vault of the bridge. All factors influencing the spillway capacity at various water surface levels in the dam were impossible to consider, and it is also impossible to separate individual coefficients for the particular hydraulic phenomenon. Out of these reasons it is better to concentrate on a single coefficient while it is necessary to have certain experience in the field of applied hydraulics to insert the coefficient into a spillway equation. The aim of hydraulic calculations was to describe the measuring diagram of the safety spillway as precisely as possible by means of analogy with spillway already measured.

Hydraulic phenomena, water flow and hydraulic characteristics may be observed on an existing dam, but out of objective reasons the research is very complicated; therefore, a small-scale model in a lab is observed as a more accessible option. Starting, border and limiting conditions are provided by a dimensional, force and weight analysis proceeding on the conditions of observing phenomena on a model using Froud's law of mechanical similarity.

Increase of a dam capacity can theoretically be realized by various technical acquisitions: increase of a capacity of present safety spillway (e. g. by lowering spillway edges of fields); construction of a new bottom outlet; adding another safety spillway (e. g. a side type on the right bank) etc. However, when choosing a solution it is absolutely necessary to have all the responsibility for not damaging both the overall historical nature of the dam and its surroundings and environment.

Variants which seem feasible were chosen and further elaborated on the base of expert recommendation. Nevertheless, before the choice of the final solution of increase of dam capacity it will be necessary to evaluate also the capacity of a cascade under a safety spillway. Water flow over a cascade is a very complicated hydraulic phenomenon that cannot be described with a simple calculation.

The aim of the research was to judge the existing safety spillway and slide for the purpose of a study of steps to safe transfer of $Q_{10\,000}$. It was to be done by means of a physical hydraulic model and hydraulic calculations.

4 Hydraulic model research

The aim of the model research was to certify and precise the calculations of safety spillway and slide. Capacity of spillway is influenced by a shape of overfall surface, roughness of overfall surface, pillars between single fields, the zone in front of the spillway, vaults of decks of a bridge and downstream water from a chute. All these details had to be considered at physical modelling to get the most reliable results possible. The results of this research are followed with another phase which is going to answer questions about choosing the most suitable variant of a safety spillway and slide for transferring a control flood with flow $Q_{10\,000}$ = 194 $m^3.s^{-1}$. The model of Harcov Dam (forefield, safety spillway, cascade, vault of deck of a bridge, stilling basin and riverbed under the dam) was designed and modelled at a scale M – 1:20.

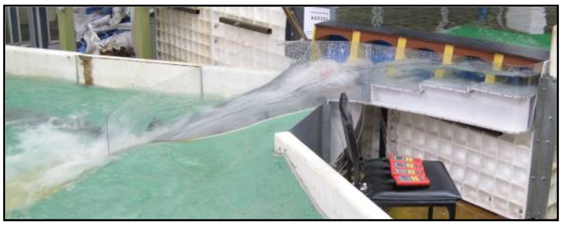

Fig.3. Photo from measurements in the Water management laboratory CTU in Prague

5 Results of experiments

In sum there were 17 different variants of measuring of disposition and construction settings of a safety spillway and bottom outlets as well as various solutions of transferring flood flows. A sequence of simulated N-year-flood-discharges was carried out on the model of Harcov Dam. For all these variants, surface levels in the dam, slide, stilling basin, riverbed under the quay were observed, pressure ratios in slide and speed fields at the end of the stilling basin were measured (by means of hydrometric micropropellers). A new design of a shape of the overfall surface, ribs in the spillway and layout of the zone in front of the spillway were undertaken.

Measuring diagrams (capacity) of both the existing and the newly designed safety spillway (spillway edge lowered by 0,4m) and the influence of widening the forefield were observed. Combinations of opening the bottom outlets transferring flood flows and their influence of flow relations in stilling basin and riverbed were observed. When the calculated measuring diagram of the spillway and the one measured on the hydraulic model were compared to each other, differences in capacity up to 17,5% on the surface level were found out (on the dam at 373,8 m above sea level). The difference in capacity is caused by inexact calculations of a coefficient of side narrowing, coefficient of a spillway over the wide crest of the bridge, coefficient of flooding and the vault of the bridge.

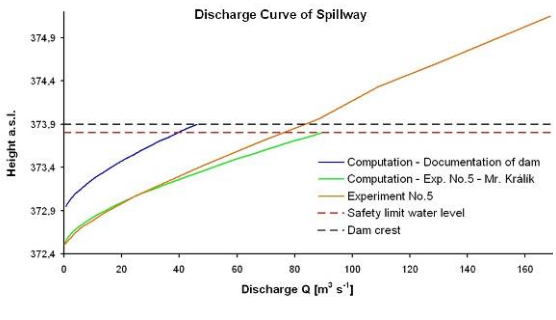

Fig.4. Comparison of current and proposed state of spillway

6 Conclusion

To design and evaluate safety spillway by means of basic hydraulic calculations is possible in simple cases if single hydraulic phenomena do not mutually influence each other and there is no non-standard water flow in the object and its surroundings. The greatest divergence in hydraulic calculations occurs in case of calculating spillway over a safety spillway; there is an outstandingly complicated hydraulic flowing which is difficult to describe with basic hydraulic equations. For these reasons it is very complicated to set a measuring diagram, and the most exact solution is a hydraulic physical research of the particular safety spillway. If an analogy with already observed spillways is used, the hydraulic research has a limited use dependent on a similar geometry of both spillways under observation.

Hydraulic physical modelling plays its role in settling complicated constructions of safety spillways – dam safety facilities and evaluating their capacity and safety. For evaluating the original conditions of safety spillway and related objects and for designing a reconstruction of safety facilities at Harcov Dam, a physical model accurately describing the flow in the object was used.

Results of these calculations and measurings serve for proposing, evaluating and optimalization of partial objects of dam safety facilities. All results will be respected and used for choosing the final solution of a new more capacitive solution for constructing safety spillway. Based on results from a physical model research, a project documentation of a particular dam can be properly solved with respect to the historical value of the object and its preservation. A new overflow surface was designed for Harcov Dam having a low-pressure regime of water flow in case of floods higher than Q_{20}. The capacity of newly designed spillway is at surface of safety limit water level 373,80 m a. s. l. 76,3 $m^3.s^{-1}$, which in sum with bottom outlet is adequate to the flow $Q_{10\,000}$. Check on measuring diagrams of safety spillway will end in precising them, and therefore in precising the data about the water flow in the dam in case of a flood and in better evaluation of floods.

Literature:

1. Broža, V. et al.: *Dams in Bohemia, Moravia and Silesia*. Liberec: Knihy 555, 2005. 63-65 p. ISBN 978-80-86660-11-7.
2. *Harcov Dam, Study of measures to ensure the dam safety in floods*, Vodní díla - TBD a.s., 2008.
3. Satrapa, L. et al.: *Physical hydraulic model of Harcov Dam*, Report about the hydraulic research, CTU in Prague, 2010.
4. Žák, L. et al.: *Dams in the Jizera Mountains*. Liberec, Knihy 555, 2006. ISBN 80-86660-16-8.
5. Čábelka, J., Gabriel, P.: *Mathematical and physical modelling in hydraulic engineering*. Praha: Academia, 1987.

Primary Paper Section: A

Secondary Paper Section: AL, JN, BK