Reconstruction of the Znojmo Dam – practical application of hydraulic research

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SYNOPSIS. Many dams and waterworks had been built in the Czech Republic during 1950s and 1960s. One of them is the Znojmo Dam. It is an earth dam with a combined spillway block. A nominal discharge of $Q = 355\ m^3.s^{-1}$ was considered for designing the safety spillway. Extreme flood events which occurred in the Czech Republic in 1997 and 2002 evoked questions relating to the safety of dams. The nominal discharge of the Znojmo Dam safety spillway was enhanced up to $Q = 610\ m^3.s^{-1}$. Therefore, the decision on reconstruction of the Znojmo dam spillway block was made. The following modifications were proposed: sinking the existing spillway crest, replacement of the existing flap gates with tainter gates with flaps, installation of breakwater on the dam crest, and necessary modifications of the stilling basin. With regard to the importance of the dam and the volume of the reconstruction planned, assessment on a hydraulic model was necessary. This paper summarises the results of the hydraulic research and its practical application to the processing reconstruction of the Znojmo Dam. It also describes some differences between the modelled situations and reality.

INTRODUCTION

The Znojmo dam is located on the river Dyje close to the town of Znojmo in southern Moravia. The supervisor of the dam is Povodí Moravy, s. p. (hereinafter referred to as the Client). The Znojmo dam had been built between 1962 and 1966. This rock-filled dam with a watertight core is combined with a spillway block which comprises two sections of safety spillway gated with flap gates, two bottom outlets, two small hydropower stations, and water intakes.

The capacity of the safety spillway was exceeded during the 2002 flood, see Figure 1. A flood peak of $Q = 379\ m^3.s^{-1}$ was estimated (Kadeřábková, Krejčí, 2004). A nominal discharge of $Q = 355\ m^3.s^{-1}$ was estimated during

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the hydraulic research performed in 1960 (Rybnikář, et al, 1960). Therefore, a study Glac, et al 2003) with variants of technical measures for safe management of extreme water passage was made. The study investigated a design flow rate of Q = 610 $m^3.s^{-1}$ and a 10 000-year control flood with a peak of Q = 732 $m^3.s^{-1}$. The variant called 2b was experimentally assessed on an hydraulic model. It consisted of the following proposed modifications: replacement of the existing flap gates with tainter gates with flaps and sinking the existing spillway crest. These proposals are combined with enhancement of the watertight core using a concrete breakwater. The above-mentioned modifications should ensure enhancement of the dam safety against overtopping as requested by current standards (TNV 75 2935).

Figure 1. Upstream and downstream air view of the Znojmo Dam during the August 2002 flood

PROPOSED MODIFICATIONS OF THE ZNOJMO DAM

The functional block of the Znojmo dam contains a safety spillway, bottom outlets, and water inlets. The existing safety spillway has two 8.70 m wide sections gated with 3.0 m high flap gates. The sections are divided by a 1.80 m wide central pier. To increase the capacity of the Znojmo dam the designer (VODNÍ DÍLA-TBD a.s.) proposed a modification of the existing spillway surface. Its crest was sunk from 223.00 m a.s.l. to 221.80 m a.s.l. A replacement of the existing flap gates with tainter gates with flaps is also included. There are two bottom outlets under the left section and two small hydropower stations (HPS) under the right one. The inlets of bottom outlets and HPS are divided by 3.30 m wide separating piers, see Figure 2. The stilling basin is 20.8 m wide, 33.0 m long, and 3.5 m deep. The necessary modifications of the stilling basin were designed, including increasing the height of the basin walls. A debris-retaining system in front of the spillway was also designed. With regard to the importance of the dam and the volume of the reconstruction planned, assessment on a hydraulic model was necessary. The Client required:

- verification of the modified spillway capacity and a discharge coefficient evaluation,
- assessment of the spillway surface mainly with respect to the negative pressure occurring during extreme flow rates,
- proposal and design of modifications of the stilling basin at a design flow rate of Q = 610 $m^3.s^{-1}$,
- specification of the designed modifications if necessary.

PHYSICAL MODEL AND MODEL TESTS

For the purpose of hydraulic research of the spillway block of the Znojmo Dam a physical model was built in a length scale $M_L = 35$. The Froude similarity was used for modelling due to the dominating gravity forces. The length scale was used with regard to the spatial and capacity limits of the laboratory.

The dam model was installed in a glass-walled channel which is part of the equipment of the new fully automated Laboratory of Hydraulic Research of the Faculty of Civil Engineering, Brno University of Technology. The channel forms a part of the hydraulic circuit maintaining a stabilised rate of flow of up to Q ~ 150 $l.s^{-1}$. The model consisted of a spillway block with parts of the dam, a stilling basin, and a 157 m length (in real scale) of the Dyje river bed. There are 31 pressure holes in the spillway surface. The upstream face of the dam was covered with gravel with a particle diameter of 10 to 15 mm. The bottom of the channel downstream of the basin step was covered with the same gravel as corresponds to the real riprap material. A view of the model is shown in Figure 2.

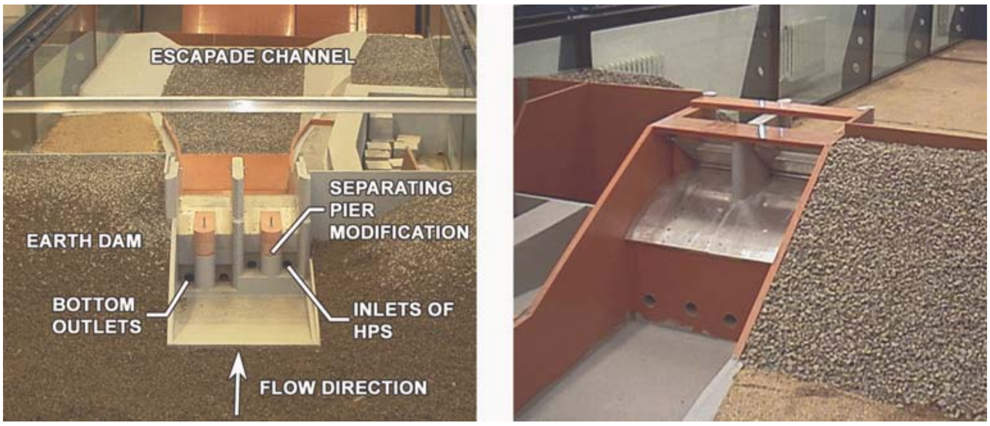

Figure 2. Downstream and upstream view of a model of the Znojmo dam spillway block

RESULTS OF THE HYDRAULIC RESEARCH AND RECONSTRUCTION OF THE ZNOJMO DAM

Reconstruction of the Znojmo dam spillway block has been carried out by the AQUAS vodní díla s.r.o. company (hereinafter referred to as the Constructor). All further values are valid are valid for the real situations.

Tests of modified spillway capacity

Model tests proved that the modified spillway enables safe transfer of a flow rate of 610 $m^3.s^{-1}$. However, the capacity is affected by the modification of the separating piers placed in front of the spillway, see Figure 2. The results of the research led the designer to the decision to sink the pier top elevation from 223.00 m a.s.l. to 221.60 m a.s.l. The influence of the tested pier shape modifications was negligible (Stara, et al, 2005)). It was recommended to sink the piers without any shape modifications, see Figure 3.

The edges of the separating piers were lightly damaged during the sinking of their top face. So, the edges will be chamfered after alignment and effacement. No significant difference between modelled and real situations is expectable because the shape modifications had negligible effect on the discharge coefficient of the new spillway surface.

Figure 3. Recommended and applied modification of separating piers

The values of the discharge coefficient of the modified spillway surface are summarised in Table 1.

Table 1. Values of the discharge coefficient (m) as a function of the discharge (Q), valid for final modification

Q [$m^3.s^{-1}$]	51	143	282	606	725
m	0.392	0.372	0.374	0.398	0.401

No values of pressure sufficiently negative to cause any cavitation effect on the spillway surface can occur even if the extreme flow rate is reached (discharge rate 732 $m^3.s^{-1}$, water level in the reservoir corresponding with the breakwater crest elevation).

A sharp edge between the horizontal and curved parts of the spillway surface appeared at the end of the central pier after dismantling of the flap gates and demolition of the sill where the gates were installed, see Figure 4. This sharp edge was modelled as rounded according to the given plans. The edge could negatively affect the pressure conditions on the spillway surface compared with the modelled situation.

Figure 4. Modelled and realised shape of the spillway surface at the end of central pier

The shape variety of the side pier wall was simplified in the model, see Figure 5. This simplification should not cause significant distortion of the results measured and applied.

Figure 5. Simplification of shape indentation of diffusion at the installation site of the flap gate

IMPROVEMENTS IN RESERVOIRS

Regulation of flow conditions

A model test proved that the contractions at the side piers have no effect on the spillway capacity because the side piers are ahead of the spillway surface. Wakes cause a water level increase of approximately 1.0 to 1.1 m at side piers when the discharge is Q = 610 $m^3.s^{-1}$. An improvement of wake effects, i.e. decreasing the wave crest, was necessary due to the maximum gate opening during floods. Therefore, several tests of flow improvement and wake elimination were performed by using wing-like steel elements attached to the front part of the pier walls. The minimisation of plate dimensions was achieved by taking step-by-step measurements while using different plate shapes and sizes [Stara and Šulc, 2004), see Figure 6.

The stream-leading plates were realised as a concrete body set on the original piers. The grooves of the cofferdam had to be included, see Figure 6. Keeping the shape of the leading face was necessary to ensure good agreement between modelled and real situations.

Figure 6. The stream-leading plate set on top of the lower part of the side pier and its realisation by a concrete body with a groove of the cofferdam

The circular trailing end of the central pier was replaced with the rear part of the NACA profile (Ladson, et al., 1996) with the aim to eliminate the wave formed downstream of the pier. The hydraulic efficiency of the NACA profile is shown in Figure 7. This modification will not be implemented.

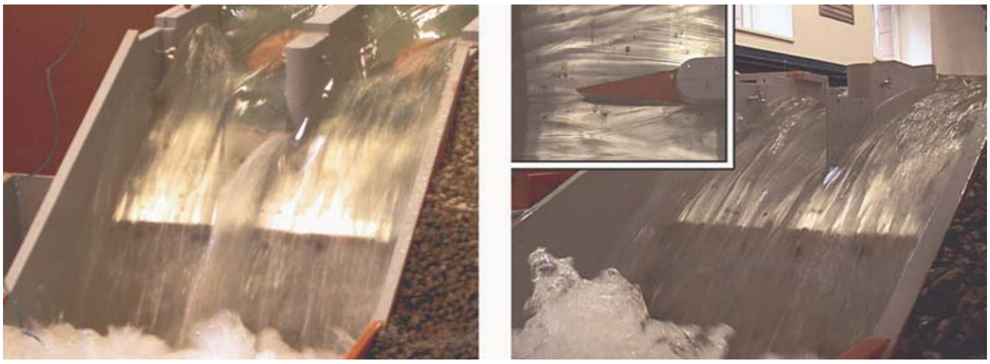

Figure 7. Deformation of the level arising behind the end of the middle pier and its elimination by the NACA profile when Q = 610 $m^3.s^{-1}$

The stilling basin modifications

The first model experiments have shown that the existent stilling basin of the Znojmo Dam (length L = 33.0 m, depth h = 3.5 m) can no longer comply with the requirement for sufficient energy dissipation at a design flow rate of Q_N = 610 $m^3.s^{-1}$. It was necessary to propose its modification. The Client wanted to keep the elevation of the stilling basin bottom at 207.65 m a.s.l., because the bottom is formed by natural rock. Baffle blocks at the bottom of the basin and the chute blocks at the end of the spillway surface with a combination of basin length were proposed and tested basing on preliminary computations (Stara and Šulc, 2004). The criterion for finding the optimum stilling basin modification was the extent of deformations of the bottom of the channel downstream of the sill.

The use of chute blocks had a negligible effect on the total energy dissipation in the basin. The use of chute blocks considerably increased the aeration of the stream entering the space above the basin and spread a more uniform load on its bottom. The use of the chute blocks according to variant 3 was proved as more suitable (Figure 8). A 48.5 m long basin combined with five baffle blocks ensures low deformations of the channel bottom. Baffle blocks may be laid out in one or two rows depending on the chute blocks used, see Figure 8.

The variant with no chute blocks at the end of the spillway surface combined with installation of five baffle blocks laid out in one row at the basin bottom was chosen for realisation, see Figures 8, 9, and 10. A basin length of 48.5 m was also recommended. Due to the spray formed by water impinging on the baffle blocks in the basin, a full concrete barrier about 1.2 m high was added on top of the basin walls. A heavy riprap 15 - 20 m long with concrete filling in an approximately 5 - 7 m long section was recommended as channel bottom protection.

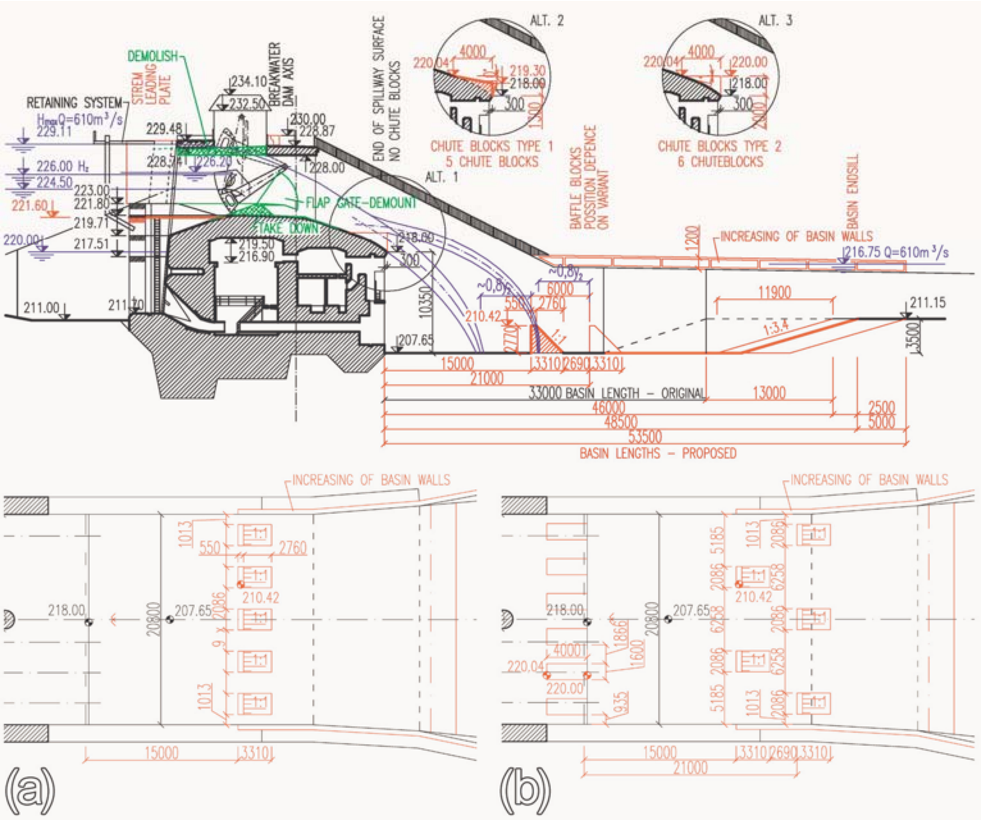

Figure 8. Vertical plane section of operational structure and the possible modifications and ground plan of the optimal layout of baffle blocks: (a) with chute blocks used; (b) with no chute blocks used

During the basin elongation we found a shallow foundation of the basin walls in comparison with the basin bottom elevation. Therefore, additional sinking of the footing bottom with concrete filling and anchoring into the bearing subsoil were performed. Two variants of stabilizing system were proposed, adding conical concrete elements or adding anchored walls, see Figure 9. The second variant was finally realised. The efficiency of the final basin modification was also assessed on a hydraulic model. The results of measurements have shown that the deepest scours occur near the left bank as was expected. The channel bed scours were similar in all cases, of an approximate depth of 1.2 m located some 5 - 7 m far from the basin sill. Thus it is possible to surmise that the final modification of the stilling basin has negligible effect on its efficiency, see Table 2.

Table 2. Comparison of the volume of bottom deformations for particular modifications of basin walls

Variant	Max. scour depth m	Position m	Max. deposition height m	Position m
(1) original proposal	1.13	6.0	0.27	10.5
(2) conical elements	1.09	23.0	0.12	33.0
(3) anchored walls	0.93	5.2	0.23	9.0
Note: position means distance from the basin sill				

Figure 9. Upstream view of the basin bottom with five baffle blocks laid in one row and variants of modifications of basin walls: (1) original proposal, (2) conical elements, (3) anchored walls

The reduction of stilling basin diffusiveness by left anchored wall (see Figure 9 (3)) positively affected flow in the basin which resulted in symmetrical channel bed scour behind the basin sill and smaller deformations near the left bank.

Figure 10. Upstream and downstream view of stilling basin of the Znojmo dam; a part of the basin is under the cofferdam and the preparation of fabrication of baffle blocks is in progress

CONCLUSION

The construction and reconstruction of dams represent complex problems which demand technical, technological as well as financial expertise of the designer, the constructor, and the investor. The present paper is focused on the proceeding reconstruction of the Znojmo dam from the point of view of hydraulic research. The differences between modelled and real situations are discussed as well as their possible effect on the accuracy of experimental results. Absolute accuracy between the modelled and the real situation cannot be reached anyway, but it is necessary to ensure good correspondence between both the model and the real structure. Hydraulic research is still a very important, efficient, and economical tool for the proposal and assessment of an appropriate design of both new and reconstructed hydraulic structures.

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