Comments on failures of small dams in the Czech Republic during historical flood events

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SYNOPSIS. During the catastrophic floods, namely those in July 1997 and August 2002 and also during local flood events, which occur almost every year in the Czech Republic, more than 100 failures of small dams were identified during last decade. After careful analysis of typical small dam failures, the reasons for dam collapses were found and assessed. During the flood events the most frequent failure of small dams was by breaching due to dam overtopping. The majority of small dam spillways suffer from insufficient capacity, inconvenient structure and arrangement. At some places spillways were blocked by broken gates, clogged jammed racks or floating debris. Moreover, in some cases the bottom outlets were not maintained and out of order. In the paper, several examples of unsuitable spillways and other dam appurtenances are shown.

INTRODUCTION

During the August 2002 flood, which affected the middle and western Europe, about 70 breached small dams were identified in the Czech Republic. This paper deals with the Blatna region in the south of Bohemia (see Figure 1), where 10 small dams were breached. The reasons for failures of two small dams in the area were analysed in more detail (dams of the Metelesky and Melin ponds). The failures caused disastrous damages in the villages of Metly and Predmir located downstream of the ponds, the breach outflow of two dams mentioned caused overtopping and failure of five small earth dams downstream of the ponds and finally flooded the town of Blatna (see Figure 2). In the analysis, the hydrological conditions in April 2002 were assessed in context with the capacity of bottom outlets and emergency spillways of both small dams. Finally the breaching mechanism was reproduced and the peak flood discharge was estimated based on comprehensive field data on the failure process during the night of 12th to 13th August 2002.

Long-term benefits and performance of dams. Thomas Telford, London, 2004

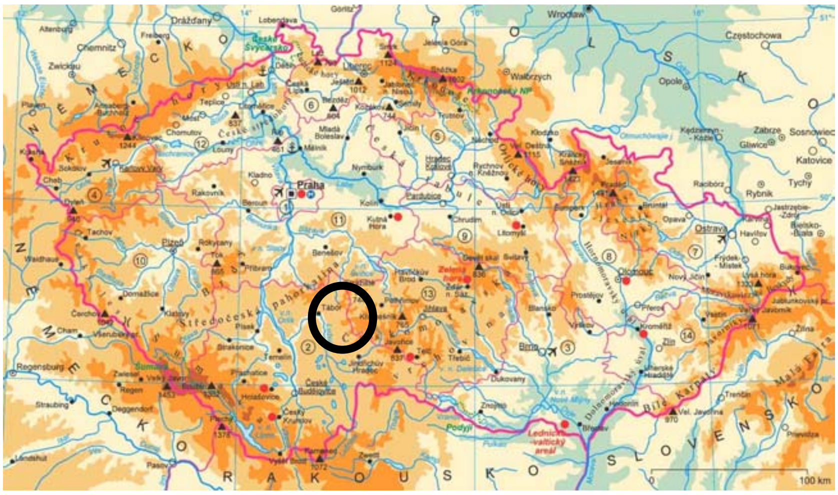

Figure 1: The map of the Czech Republic with the area of interest

Figure 2: Town of Blatna during the August 2002 flood

BASIC DATA

<u>August 2002 flood</u>

On August, 5th 2002 a cyclone developed above the Western Mediterranean, which proceeded northeast and reached the eastern Alps during August 6th. Heavy rainfall occurred over southern Bohemia with local showers of high intensity, which temporarily ceased on the morning of August 8th. After this cyclone the second one followed coming from British Isles to the southeast. On Saturday, August 10th the cyclone regenerated above Italy and continued to the north. During the 11th and 12th August the cyclone reached the Czech Republic, where the long lasting precipitation struck almost all the country. The most intensive rainfalls occurred in the mountainous regions to the southwest and northwest of Bohemia, and in the area of interest the three-day total was about 160 mm. On August 13th the rainfall intensity reduced and on 14th it completely ceased.

As the catchment soaked completely during the first precipitation event, the runoff percentage (runoff coefficient) during the second precipitation event was considerable. Due to the relatively long duration of rainfall an extreme flood was generated throughout the Vltava river catchment. Moreover, at some places local showers of considerable intensity caused runoff concentration at smaller streams. At bigger streams on downstream reaches the discharge exceeded the 500 year flood, and at smaller streams, especially at upper catchment portions it was estimated to be a 1000 year flood. This was the reason for the breaching of a great number of small dams with insufficient spillway capacity. Details of the dams breached during the August flood in the vicinity of Blatna are given in Table 1.

Table1: List of small dams breached in the Blatna region

Name of the pond	Dam height in metres	Total reservoir volume in thousand m^3	Reservoir area in hectares	Reason for failure
Belcicky	6.7	788	39.4	Overtopping
Buzicky	2.7	900	60.0	Overtopping of side dam
Dolejsi	2.6	334	30.0	Overtopping
Horejsi	4.0	232	22.4	Overtopping
Luh	3.8	48	6.0	Overtopping and improper outlet location
Melin	6.2	250	11.4	Slide of the downstream slope
Metelsky	8.5	1037	51.4	Overtopping at two places
Mlynsky	2.6	160	12.7	Overtopping
Podhajsky	2.9	225	15.0	Overtopping
Pusty	3.5	65	5.5	Overtopping

<u>Details of the ponds studied</u>

In this paper, the results of the analyses of only two ponds, namely Melin and Metelsky, are given. Both ponds are situated at the Metelsky brook about 12 km to the North of the town Blatna just upstream of the village Metly (see Figure 3). The catchment area of the pond Metelsky is about 15.5 km^2 and is covered by agricultural land (30%) and forests (70%).

The ***Melin*** dam is about 6.2 m high, the dam body is homogeneous, made of sandy clay with estimated hydraulic conductivity between 1.5 x 10^{-8} to 4.5 x 10^{-8} m/s. The upstream and downstream slopes are 1:1.5. The dam crest is uneven with 0.60 m differences in the crest level, and the lowest part of the dam crest is close to the bottom outlets. The dam crest is overgrown by trees and bushes. The root system of the vegetation disturbed the upper portion of the dam body, which is much more permeable than the lower part. The upstream slope of the dam is faced by stone pavement, and the downstream slope is grassed. The pond was equipped by one wooden bottom outlet with the maintenance and service shaft located at its upstream end (Figure 4). The dam is provided with two emergency spillways, one at the left bank abutment, the other at the right one. The total spillway capacity is 10.5 m^3/s for the water level at the minimum dam crest.

The ***Metelsky*** dam is about 8.5 m high with upstream and downstream slopes 1:2. The dam body is heterogeneous, created by upstream clayey blanket and sandy downstream shoulder. At the upper portion close to the dam crest the clayey sealing is missing or is degenerated by the root system of the plants grown on the dam crest (Figure 5). The upstream slope of the dam is faced by stone pavement, and the downstream slope is grassed. The pond is equipped with two wooden bottom outlets in a bad condition due to ruptures permitting seepage and rinsing of the sand from the dam to the pipes. At the left abutment the dam is equipped by an emergency spillway with a capacity of about 9.5 m^3/s. An auxiliary spillway (capacity 2.5 m^3/s) is formed by the local right bank road.

Hydrological data

Both ponds are constructed and operated as through-flow. The Melin pond is fed by three streams, the pond Metelsky is fed by two tributaries with total catchment area 15.83 km^2 with the peak level 712 m above sea water level (SWL). The N - year discharges at the dam sites are given in Table 2.

Table 2: N-years discharges Q_N in [m^3/s] at the dam sites

N	1	2	5	10	20	50	100
Q_N - Metelsky	5	7	10	12	15	19	23
Q_N - Melin	3.3	-	6.8	8.9	11.0	15.0	18.0

The flood hydrograph corresponding to the "natural" August 2002 flood at the dam profiles was derived using a rainfall – runoff model (Figure 6). The results of the modelling were compared with results obtained from the calibrated hydrodynamic model. The flood routing model calibration was based on the traces of the flood at the site. The flood routing in the area downstream of both ponds was considerably influenced by their collapse.

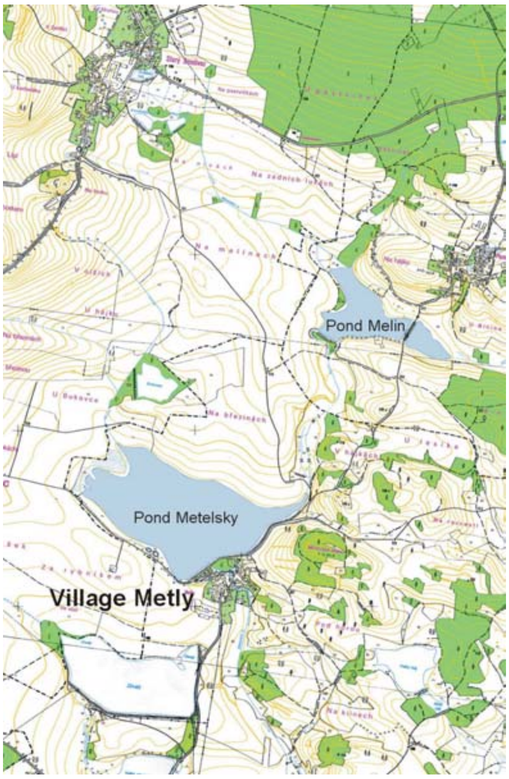

Figure 3: The detailed map of the ponds and Metly village

Figure 4: Melin – dam breach with remaining service shaft of the bottom outlet

Figure 5: Dam Metelsky - the cross section at the right breach

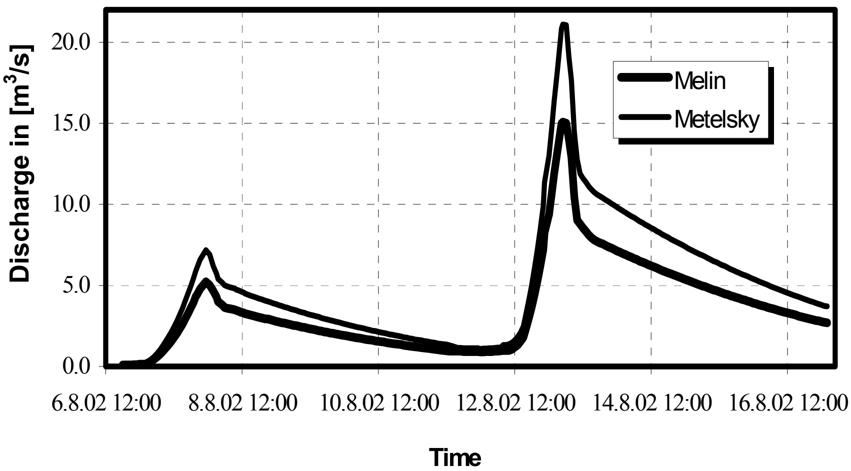

Figure 6: Derived flood hydrograph in August 2002 at the dam sites

ANALYSIS OF THE FAILURES OF THE SMALL DAMS

General comments

When comparing previous data about spillway capacities with flood hydrographs, it is obvious that the main reason for the dam failures was insufficient spillway capacity. Nevertheless, the purpose of the study was to provide a complex analysis of the event. Therefore, the following effects and their combination were assumed:

- dam erosion due to overtopping;
- loss of the dam body stability due to slide of the downstream face;
- internal erosion of the dam body.

The detailed analysis showed that the failures of both dams were caused by the combination of effects mentioned above. The analysis was carried out in following steps:

1. The reconstruction of the event using witness testimony provided by criminal police, local inhabitants and by the traces of water level at banks and upstream face of the dams.
2. The setting up of a numerical model consisting of rainfall-runoff, dam break and flood routing models. During this work, bottom outlet and spillway capacity rating curves were derived carefully.
3. The model calibration was based on the knowledge obtained in step 1. The calibration scenario resulted in the real flood and dam break discharges and possible reasons of the failures.
4. Finally, several aditional scenarios dealing with possible manipulation with bottom outlets combined with the temporary side spillway ‘on-site‘ installation were solved. The main goal of these scenarios was to prove that no measures were capable of averting dam failures.

The upper pond – Melin

Due to very low hydraulic conductivity of the homogeneous dam body, the seepage through the dam material was assumed to be very low. Anyway, the site investigation showed that the upper portion of the dam body of the thickness 0.3 to 0.5 m is composed of weathered grained humus material, the structure of which is disturbed by the root system of the vegetation (Figure 4). This material is of a significantly higher permeability. After the water level reached the higher position close the dam crest, more intensive seepage through the weathered layer probably caused the instability of relatively steep downstream face slope (1:1.5).

Detailed assessment of seepage conditions does not indicate suffosion trends in general. Nevertheless, the old wood pipe was found at the place of the breach, the rest of the pipe having been flushed down and dispersed downstream up to a distance 300 m from the dam site. As the wood pipe was quite old and damaged by cracks, it was concluded that the sandy material of downstream shoulder was flushed off by the pipe and caused the subsidence of the dam crest. This probably contributed to the dam failure.

The results of hydrological and runoff modelling indicated a rapid increase in the inflow discharge to the pond on the evening of 12 August 2002 with the peak discharge approximately 15 m^3/s (Fig. 7), which corresponds with 50 year flood (Table 2). The flood routing through Melin reservoir showed a transformed flood peak discharge 13.5 m^3/s and shift of the peak by 2.5 hours. At the same time, the spillway capacity was about 10 m^3/s at the water level at the dam crest.

The height of the wind driven waves was estimated to be between 0.55 and 0.60 m. The dam was locally overtopped by the wind waves for the period of 3 hours at the place with the lowest dam crest, i.e. at the location of the dam breach.

The Melin dam failure was caused by combined action of leakage through the upper portion of the dam below the dam crest and the wind waves overtopping the dam crest. These factors caused the dam failure in the section of the lowest crest, where its subsidence was probably caused by suffosion of the sandy material into the damaged wooden pipe. The process of breaching was accelerated by slides of the relatively steep downstream face of the dam. The dam break peak discharge at the dam site was estimated to be 150 m^3/s and this was verified by the calibrated flood routing model in the valley downstream of the pond. The resulting dam breach opening was of almost rectangular shape with the 5 m depth and 15 m width.

Dam at Metelsky pond

In case of the Metelsky dam, an overtopping was the primary reason of the failure. During the natural flood, the retention capacity of flood surcharge was exhausted due to malfunction of bottom outlets and unsufficient spillway capacity. At the same time the reservoir inflow increased considerably due to the breach of Melin dam located approximately 2 km upstream from Metelsky pond. Melin dam break peak at the inflow to the Metelsky reservoir was transformed to “only” 130 m^3/s, the flood wave volume corresponding to the Melin reservoir volume was about 600,000 m^3.

The detailed modelling of the event showed that the water level during the flood event was about 0.6 m above the spillway crest. At that time the Melin dam break wave entered the Metelsky pond and caused dam overtopping in two places. The resulting peak discharge was about 550 m^3/s, and the total volume of the flood wave was estimated to be 2.3 million m^3. The widths of two breach openings were 35 m and 27 m, the breach depth was about

7.7 m. Final dam break flood hydrographs compared with the hydrological flood are shown in Figures 7 and 8.

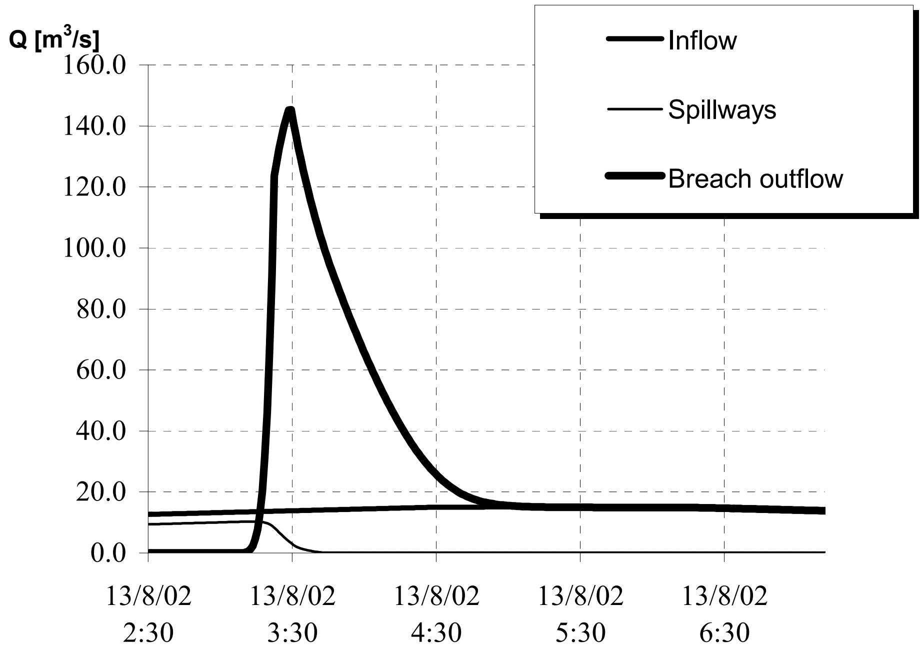

Figure 7: Melin reservoir - inflow and outflow

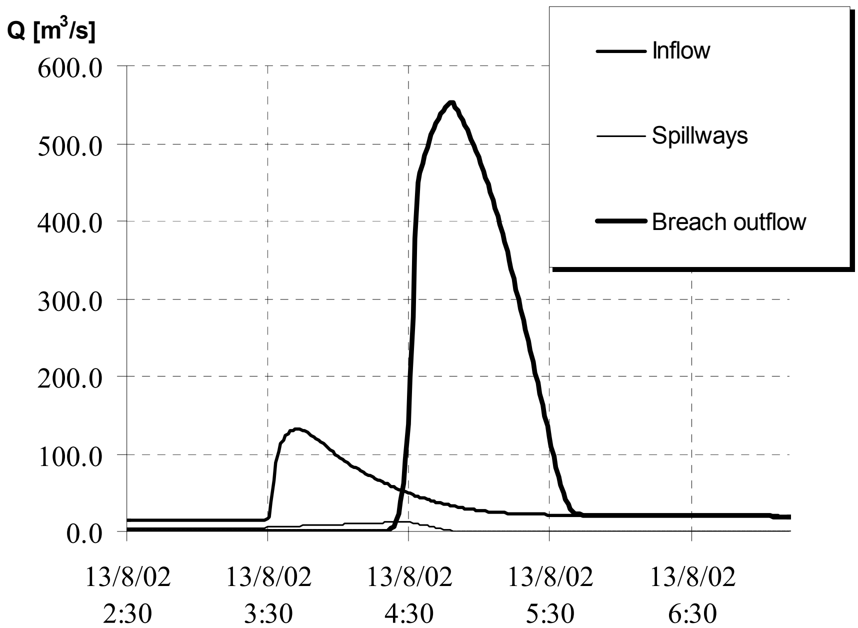

Figure 8: Metelsky reservoir - inflow and outflow

Several additional phenomena contributed to the dam failure and accelerated dam breaching. The 4 hours' action of wind waves of height 0.75 to 0.80 m and local overtopping caused local slides and disturbance of grass cover at the downstream face prior to the dam overtopping and this accelerated the destruction process of overflowing water. Moreover, the upper portion of the dam body was disturbed by the root system of the vegetation and by the action of animals. The left breach opening was located at the place of the old abandoned wooden bottom outlet pipe. The site investigation proved internal erosion and flushing of finer particles to the disturbed pipe (Figure 9) and consequent settlement of the dam body at this location.

Figure 9: The rest of cracked wood bottom outlet

The facts mentioned were not the primary cause of the failure, but accelerated the dam collapse and contributed to earlier overtopping. The important circumstance was inadequate technical safety surveillance of the dam and poor maintenance of dam body and equipment.

CONCLUSIONS

The causes of the failures of two small dams assessed can be summarised in the following statements:

- In case of Melin dam the failure was primarily caused by insufficient capacity of both spillways corresponding to 5years flood discharge (Q_5), while the peak flood was estimated as Q_{50} to

Q_{100}. Additional factors contributing to the failure were local slides of downstream slope, extreme seepage through upper loose portion of the dam, action of wind driven waves, potential privileged seepage paths and suffosion along the wood pipe outlet and malfunction of bottom outlet due to its improper structure.
- In case of Metelsky dam the failure was caused by an extreme hydrological situation combined with the breaching of the upstream dam Melin. The partial factors were practically same as in case of Melin dam.

The following conclusions and recommendations were put forward for further remedial and reconstruction activities at the sites of interest:
- Before the reconstruction of the dams, the revision and carefull surveillance of the state of dam bodies should be carried out. The restoration of the ponds cannot proceed in their present state. Careful assessment must be focused also on the design parameters of dam equipment, namely bottom outlets and emergency spillways.
- The reassessment of present safety classification of small dams should be done with respect to potential danger from insufficiently equipped small dams and based on the new dam safety standards and actual hydrological data.
- The manipulation regulations should reflect the optimal function of the entire reservoir system, which consists of approximately 20 small reservoirs in the Blatna region.
- The potential flood prone area specification should contain the inundation due to potential dam failures.

It is true that during local extreme flood events, on average from two to four small embankment dams (height less than 15 m) are overtopped and breached every year in the Czech Republic. During the extreme regional floods in 1997 and 2002 more than 100 small embankment dams failed and about 50 levees breached in the Czech Republic.

We recognize that the deficiencies mentioned in the structure, arrangement, parameters, operation and maintenance of small dams and their appurtenance are not rare phenomena in the Czech Republic (or in other countries). Remediating the present situation does, however, require time and money and it is also a difficult problem in relation to property and land ownership. Private dam owners (e.g. angling clubs) usually are not able to finance the remedial measures that are required. The state financial support is not systematic and is not steadily anchored in the present legislation, which in many cases is still not prepared for the private ownership of small waterworks.

REFERENCES

Riha, J. et al. (2002) *The Assessment of the Failures of Small Dams in the Blatna Region.* Research Report. Brno Technical University, 30 p., 35 appendices.

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