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SAFETY PROBLEMS OF SMALL EMBANKMENT DAMS IN THE CZECH REPUBLIC

VARNOSTNI PROBLEMI MALIH NASUTIH PREGRAD NA ČEŠKEM

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Abstract

In the Czech Republic there are about 20 000 small reservoirs with dams which in many cases do not meet present requirements for hydraulic and structural safety. Surprisingly, most of the problems arise from improper design, insufficient technological discipline and poor technical supervision during construction, and also from insufficient maintenance. The safety of numerous older small dams has deteriorated due to ageing and inadequate modifications during their operational life. These defects not only decrease dam safety but also cause problems during dam operation. Sometimes the original purpose of the reservoir cannot be fulfilled. This paper focuses on the safety issues of small embankment dams. Typical identified defects, hydraulic and stability problems of individual structural elements are demonstrated and discussed in more detail.

Keywords: small dam, dam safety, defects, bottom outlet, seepage, spillway, hydraulic safety.

Izvleček

Na Češkem je približno 20 000 malih akumulacij s pregradami, ki v številnih primerih ne izpolnjujejo današnjih zahtev za hidravlično in konstrukcijsko varnost. Presenetljivo je, da največ težav izhaja iz neustrezne zasnove, nedosledne tehnologije izvedbe in slabega nadzora nad gradnjo, pa tudi iz slabega vzdrževanja. Varnost mnogih (starejših) pregrad se je poslabšala zaradi staranja in neustreznih modifikacij v obdobju obratovanja. Te okvare ne samo zmanjšujejo varnost pregrad, temveč povzročajo tudi težave ob obratovanju. Včasih celo ni več mogoče izpolnjevati osnovnega namena pregrade. V članku obravnavamo varnostne elemente malih nasutih pregrad. Prikazali in podrobneje komentirali smo značilne opažene okvare ter hidravlične in stabilnostne probleme posameznih delov konstrukcij.

Ključne besede: mala pregrada, varnost pregrade, okvare, temeljni izpust, pronicanje, varnostni preliv, hidravlična varnost.

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1. Introduction

In the Czech Republic there are about 20 000 small reservoirs (Jandora and Riha, 2010), the majority of them are historical ponds older than 100 years; installations older than 300 years are not unusual. According to the standard (ČSN 75 2410) a small reservoir has the total reservoir volume of less than 2 million m^3 with the maximum depth not exceeding 9 m. The technical state of some of these small dams has in many cases been found to be unsatisfactory in terms of both hydraulic and structural safety. Historical dams usually suffer from insufficient spillway capacity due to the poor state of knowledge of hydrology at the time of their origin and also due to the higher level of hydraulic safety currently required than the check flood taken into account when the small dam was designed. In case of new dams, including dry reservoirs, most of the problems surprisingly arise from improper design and also inadequate technological discipline, followed by poor technical supervision by the investor administering the structure. These facts result in hydraulic, structural and seepage safety problems. In some cases these problems lead to operational difficulties when the purpose of the reservoir cannot be fulfilled.

The safety assessment of dams during floods in the Czech Republic is carried out according to the TNV 75 2935 standard (TNV 75 2935). In this paper, experience from such assessment of about 600 small dams is summarized. For technical issues such as the survey, calculation and design of small dams, two Czech national standards (ČSN 75 2410, ČSN 75 2310) are also available. In this context the following specific issues are discussed herein:

- Documentation for the assessment of the safety of small dams.
- An inventory of main defects and deficiencies of small dams.
- Methods of surveillance and examples of observed deficiencies.
- Hydrologic, hydraulic and stability calculations.
- Hydraulic safety.

2. Documentation for dam safety assessment

The quality of recordkeeping and the extent of existing documentation on small dams are varied. At least some archive documentation like design documents and operating instructions is available in most cases. However, documentation on the dam's structure that records its real state is available only in exceptional cases. Commonly available documents include handling regulations and reports on technical and safety inspections and surveys of the dam. One of the basic inputs are check flood hydrographs provided by the hydrological services which elaborate a hydrological study for this purpose.

Particularly for old, small dams, detailed verification of the documentation has to be carried out. It is especially important to carefully verify the conformity between the real geometry, dimensions and elevations of the structure and its design parameters. For this purpose, geodetic surveying of the dam and appurtenant works should be performed. For most of the surveyed small dams, significant differences were found between their design parameters and their real state, and this includes dam crest elevations. Thus, geodetic surveying of the dam is crucial for further assessment.

If no archive documents are available, or in case of doubts about the materials used in the dam, a geological and geotechnical survey has to be performed. Usually, non-invasive geophysical survey methods are utilised. They are typically supplemented by invasive methods (trial pits, boreholes). Part of the survey involves the examination of appurtenant works, namely bottom outlets and spillways. It is desirable to carry out a camera survey of the bottom outlets focused on cracks in the pipes and on seepage into the outlet pipe.

A site investigation by the auditor is an absolutely necessary part of the assessment. During the site visit, the dam body and its slopes should be examined and the basic dimensions verified. The overall inspection aims to find any defects such as uncontrolled seepage or the deformation of slopes, and also to determine the functionality of appurtenant works, etc.

3. Inventory of main defects and deficiencies at small dams

An extensive inventory of the state of small dams has been carried out over the last decade. The inventory was conducted using various methods including visual observation, geophysical methods, geotechnical prospecting, the use of video cameras, etc. The results include the following typical deficiencies and percentages related to all assessed small dams (about 600):

- Poor condition of bottom outlets - 40 %.
- Unmaintained vegetation on the dam body – 35 %.
- Seepage problems, wetted downstream slope and toe - 40 %.
- Variable level of the dam crest and slopes, with depressions - 30 %.
- Poor condition of the spillway -26 %.
- Insufficient spillway capacity - 45 %.

4. Description of observed deficiencies

In the following section, examples of the typical deficiencies related to individual parts of the dam body and its appurtenant works are described and discussed.

4.1 Bottom outlets

There are several typical arrangements of bottom outlets:

- Bottom outlet equipped with a valve tower made of concrete, stone or wood:
  - the tower is located upstream of the bottom outlet, which is usually designed as a free water flow pipe (Figure 1),
  - the tower is located in the dam body, dividing the bottom outlet pipe into two sections – an upstream one with a pressure flow regime and a downstream one with free water flow (Figure 2).
- Submerged structure used mostly in dry reservoirs (Figure 3).
- Combined structure – usually a bottom outlet and a spillway (Figure 4).
- Gated sluice (Figure 5).

Typically, bottom outlets are inspected visually; the conditions inside the outlet pipes are inspected using a movable video camera.

In many cases bottom outlets suffer from improper hydraulic design, which influences their function and also structural stability. Their hydraulic function is also influenced by the maintenance and functionality of the valves.

The outflow pipe should be designed to pass the design discharge with the free water surface. When the valve tower is located at the dam body (Figure 2), the inflow pipe functions as a pressure pipe. The submerged inlet is equipped with a screen and is not normally accessible. In the valve tower the water level is usually maintained by a stop log installed inside the shaft. In many cases the stop log wall is equipped with a valve located at the bottom of the tower. The valve enables water level regulation without adjustment to the stop log. The outflow part of the bottom outlet is usually constructed from concrete pipes ending in a stilling basin. To ensure free surface flow within the outflow pipe, the entrance to the pipe should be equipped with a reduction cone and air inlet. Sometimes the inlet is designed as a submerged structure and cannot be operated during a flood. In this case, supplying air is complicated.

Back flooding of the bottom outlet can usually be expected due to the limited capacity of the downstream channel. It frequently occurs when the downstream end of the bottom outlet is low (Figure 6) and also the end of the spillway chute joins the channel just downstream of the stilling basin of the bottom outlets. A check flood passing through the spillway is usually dominant when compared with bottom outlet flow. When this occurs, backwater propagating upstream to the bottom outlet reduces its capacity. Moreover, in this case the flow regime in the bottom outlet may periodically change from free surface to pressure flow and back again. Such changes cause dynamic loading on the outlet pipe.

Figure 1: *Bottom outlet with upstream tower.*

Slika 1*: Temeljni izpust z vtočnim stolpom.*

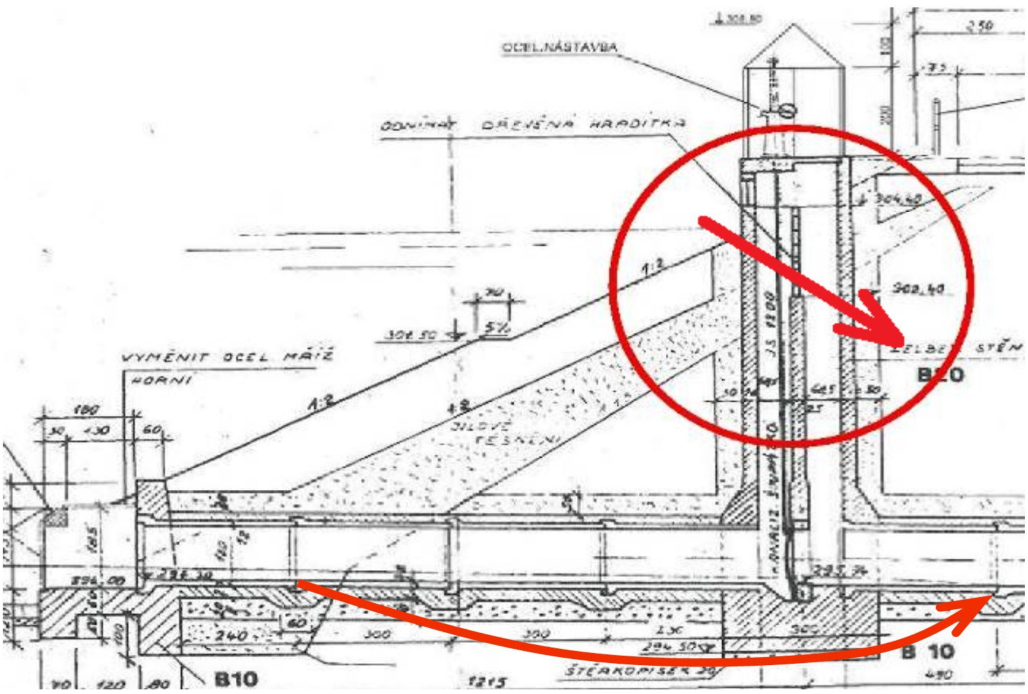

Figure 2: *Improper conceptual design of a bottom outlet. Concentrated leakage is marked with arrows.*

Slika 2: *Neustrezna zasnova temljnega izpusta. Koncentrirano pronicanje je označeno s puščicami.*

Figure 3: *Submerged bottom outlet entrance and its operation during a flood.*

Slika 3: *Potopljeni vtok v temeljni izpust in njegovo obratovanje med poplavo.*

Figure 4: *Combined structure.*

Slika 4: *Kombinirani objekt.*

Figure 5: *Gated sluice with damaged propulsion equipment.*

Slika 5: *Kanalske zapornice s poškodovano pogonsko opremo.*

Figure 6: *Low downstream end of a bottom outlet with submerged drain pipes (arrow).*

Slika 6: *Nizek dolvodni konec temeljnega izpusta z zasutimi drenažnimi iztoki (puščica).*

It is common for bottom outlet pipes to be in bad condition. Camera inspections of bottom outlets frequently show cracks in pipes or damaged joints between socket pipes. This is often due to intensive seepage and the flushing out of soil particles from the space behind the pipe (Figures 2, 7). Cracks and shifts in joints result in the seepage of turbid water, which indicates internal erosion of the soil along the bottom outlet. An additional survey via geophysical methods and boreholes usually completes the information about the conditions at the back side of the pipe. The development of a seepage path with concentrated leakage when it has progressed further can lead to subsidence of the dam crest and also to continuation of the breaching process.

4.2 Vegetation on the dam body

Improper and unmaintained vegetation can affect the watertightness of the dam body by penetrating the sealing element (core, upstream membrane) with its root system. It also complicates observation of the dam and the geodetic surveying of dam displacements. When located at the downstream toe, vegetation can damage and obstruct the bottom outlet and also drainage pipes by penetrating the pipe with its roots.

4.3 Seepage problems

Uncontrolled seepage may result in considerable increases in pore pressures and significantly decrease the stability of an embankment dam body. It also contributes to the initiation and sometimes progression of internal soil erosion in the dam.

The following typical seepage, resp. concentrated leakage locations may be identified within small dams:

- through the dam body (Figure 2),
- along the bottom outlets (Figure 2, 7),
- along the side wall of the spillway (Figure 8),
- through the sub-base.

These seepage modes are frequently combined. Experience shows that at least one of these seepage modes occurs at practically all inspected small dams.

Seepage through the dam body is signalled by wetting of the downstream face. In many cases the wetted area is quite large and its elevation is significantly higher than the downstream toe of the dam. This seepage may be caused by many factors, e.g. improper construction materials, insufficient compaction or an incorrect conceptual design of appurtenant structures. Figure 2 shows a case where the regulating tower is constructed as part of the dam body and "intersects" the upstream sealing element. At this dam, intensive seepage was observed approximately 3 m above the downstream toe of the dam.

Seepage into the bottom outlet pipe (Figure 2, 7) can result in shortcutting and further development of the seepage path, an increase in the hydraulic gradient and sometimes in defect propagation leading to dam collapse. This can also occur in the case of seepage along the side wall of spillways where freezing of soil makes it denser and thus more susceptible to the continuation of seepage and internal erosion (Figure 8).

It often happens that seepage cannot be monitored due to the lack of a toe drain and efficient drainage system. Sometimes the drainage pipes feed into the tailwater below the downstream water level and are subjected to backwater from the stilling basin (Figure 6).

The possibility of the occurrence of internal erosion should be assessed with respect to hydraulic criteria based on the critical mean hydraulic gradient along the seepage path. The true mean gradient at the dam is estimated using the water depth in the reservoir and the anticipated seepage path in the dam, either along the bottom outlet or the spillway chute.

4.4 Variable geometry of dam body

The dam body shape changes over time due to consolidation and rheological processes. Usually the dam crest is subject to settlement, which is typically greatest at the place of maximum dam height. Sometimes, due to poor compaction or even internal erosion, considerable subsidence occurs at the line of bottom outlets. This local deformation also occurs at places with heavy traffic in the form of tractors, lorries, etc. The subsidence of the dam crest, which can even reach tens of centimetres in extent, contributes to dam overtopping. Therefore, for safety assessment the lowest crest elevation should be taken into account. When the dam crest is not paved, it is necessary to include the wind wave run-up height in the hydraulic safety assessment.

Many small embankment dams suffer from inadequately steep slopes. When uncontrolled seepage occurs, cracking and even slope slides may occur.

4.5 Spillway

The spillway is typically designed as either lateral or frontal. It comprises a weir, spillway channel, chute and stilling basin connected to the channel downstream. It is advantageous to perform calculations for each part of the spillway separately and to take its interactions into account (e.g. backward flooding of the weir). The spillway capacity is given primarily by the length of the weir crest and by the overflow head. Local conditions should be taken into account, such as the limiting of weir length by landscaping or by sediments and vegetation.

Weir capacity is often limited by a shallow spillway chute below the weir, especially in the case of a very long weir crest (Figure 9). In such conditions back flooding can be expected.

A crucial section for the back flooding of the weir is usually at the intersection of the chute and the dam crest. At this location the flow is often reduced by a narrow bridge profile, culverts (Figure 10), or by an improperly designed footbridge. These structures cause back flooding of the spillway channel and reduce the capacity of the whole spillway.

Another typical arrangement reducing spillway capacity is a screen placed directly on the weir crest. When clogged the screen may significantly decrease spillway capacity by increasing the elevation of the weir crest.

4.6 Hydraulic safety

Hydraulic safety assessment consists of the following steps:

- Determination of the check flood maximum water level (CML).
- Determination of the maximum "safe" water level (MSL).
- Assessment of the relation between CML and MSL.

The CML is determined by the calculation of check flood routing through the reservoir. Check floods in the Czech Republic are designated according to Table 1.

Table 1: *Required check flood return period.*
Preglednica 1: *Zahtevane povratne dobe za referenčno poplavo.*

Loss	Description of consequences	Annual probability $P \approx 1/N$	Return period N
Extremely high	Considerable loss of human lives	0.0001	10 000
	Fatalities improbable	0.0005	2 000
High	Expected single fatalities	0.001	1 000
	Fatalities improbable	0.005	200
Low	Losses downstream of water structure, no fatalities	0.01	100
	Losses only for the owner, other losses minor	0.02–0.05	50–20

The operation of valves and gates during extreme situations is described in the operating rules of the reservoir. In many cases the options for their operation during a flood (e.g. the opening of valves, etc.) are limited due to the fast arrival of the flood wave, which in the case of most small reservoirs occurs within 5 hours. Also, poor dam accessibility and the condition of the appurtenant works can complicate the operation of valves or gates during a flood (Figures 3, 5).

Figure 7: *Crack in the bottom outlet pipe with turbid seepage into the pipe.*

Slika 7: *Razpoka v cevi temeljnega izpusta s turbuletnim pronicanjem v cev.*

Figure 8: *Dam collapse due to internal erosion along the spillway.*

Slika 8: *Porušitev pregrade zaradi notranje erozije vzdolž preliva.*

Figure 9: *Long, shallow and narrow spillway channel affected by sediment and vegetation.*

Slika 9: *Dolg, plitev in ozek prelivni kanal z vplivi usedlin in vegetacije.*

Figure 10: *Crossing of the spillway chute with the dam by a narrow bridge (left) and culvert (right).*

Slika 10: *Prečkanje prelivne drče ob pregradi z mostičkom (levo) in prepustom (desno).*

Flood routing calculations are carried out to predict the transformation of the check flood wave by the reservoir. The output is the calculated CML expected during the event. It is obvious that the transformation effect is given by the volume of the flood, the flood storage at the reservoir and the capacity of all outlet works and spillways. It is usual that standard ponds operated as water reservoirs have a very limited flood attenuation effect while the dry reservoirs designed for flood protection can have a significant transformation effect.

For hydraulic safety assessment the MSL usually corresponds with the lowest dam crest elevation lowered by the expected wave run-up on the upstream slope.

Hydraulic safety assessment is performed by the comparison of the CML with the MSL. In cases when the CML is higher than the MSL the dam is declared to be unsafe in terms of the requirements of technical standard TNV 75 2935 (TNV 75 2935).

5. Summary

Based on safety assessments performed for numerous small dams in the Czech Republic it can be concluded that quite a large percentage of these dams do not comply with current safety requirements. The reasons for this lie in their design and its parameters, inadequate construction techniques and poor maintenance. The consequence of this unsatisfactory situation is that every significant flood (e.g. in 1997, 2002) results in the breaching of several small dams. Periodic assessments of the safety of small dams and subsequent implementation of remedial measures are necessary for the improvement of the present situation with regard to the safety of small dams.

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