Protection of population and water retention developments

M Axman ¹ and S Krocova ¹

¹ Faculty of Safety Engineering, VŠB - Technical University of Ostrava, 17. listopadu 2172/15, 708 00 Ostrava, Czech Republic

Abstract. This paper deals with the issue of preventive civil protection from emergency incidents in water structures. The first part of the work focuses on the methods of water retention development and its use. Then follows the presentation of current status in the Czech Republic and the world regarding hydro plants. In the last part of this paper the Procedure for Estimating Loss of Life Caused by Dam Failure according to DSO-99-06, used in the USA with parameters of Whaley Dam, is described. The other part deals with possible issues of civil protection in emergency situations in dams.

1. Introduction

Significant industrial development is dated back to the 18th century to the start of the industrial revolution which is associated with the increased water consumption as it was used as primary or secondary raw material. General knowledge and current understanding contributes to more effective water use as a further source of energy; for instance, to produce electrical energy in water power plants. People have always been trying to regulate, control and modify the landscape in their own image. They have been building their residences, houses or agglomerations in consideration with water availability and accessibility, which is vital not only for life itself but also for the growth of various plants and flowers, and also for possible industrial production. Water quality demands and water management requirements will be much higher in future than they currently are [1, 2, 3]. Water consumption and its use will be increasing dramatically in relation to climatic changes. Consequently, the importance of hydro-engineering structures all over the world will be growing more than ever. There was a massive growth in the number of hydro-engineering structures during the last century; nowadays their lifespan is expiring and they may become a threat to people living in the immediate vicinity of these structures, especially those living in the downstream area. A conceptual approach considering possible known existing risks and potential causes of risk events is essential. The implementation itself is to be carried out in compliance with the project design; project documentation is to accept all risks assessed using either stochastic or deterministic methods. Therefore, it is essential to consider the integrated approach for the land, hydrogeology, hydrometeorology data, spatial development and conceptual planning in terms of spatial planning documents while constructing and eventually potential project designing. The Procedure for Estimating loss of life for Dam Failure, used for all damaged dams since 1960, should be used to parametrize and consolidate the results in USA [13].

2. The history of dams in the world

Irrigation of crops in the Nile and the Tigris area in 6000 B.C. marked the beginning of large dam history. The primary purpose was to prevent a flood wave which threatened the crop; the secondary purpose was to accumulate water for possible irrigation. Stone gravity dams, built mainly in Egypt, and later on the earth type dams used in Mesopotamia were one of the first dams ever. In Egypt, stone
flood walls were used whereas Mesopotamian flood walls were of soil and clay with the advantage of their impenetrability [4]. “The oldest continuously operating dam still in use is the Kofini Dam, which was constructed in 1260 b.c.e. on the Lakissa River in Greece “[5]. The dam development in ancient Rome continued. In the 18th century, the use of common gravity dams, made of concrete and mortar, was complemented by the arch-gravity dams. The use of either way was determined by given conditions of the location. Arch dams were used for narrow gaps and openings in rocks where there was enough material ensuring that the dam will not tip over, slide, or rupture; in turn, the massive dimensions will increase the likelihood that the dam can achieve long-term stability in holding back a reservoir. On the contrary, gravity dams were built in shallow, wider areas. Gravity dams work on the basis of the force of gravity pulling vertically down on the dam that provides resistance against pressure exerted horizontally by water in the reservoir [4, 5].

2.1. Dams in the Czech Republic
In the Czech Republic (CR), dams are governed by the Water Act 254/2001 Coll., that defines water management structures as structures used for water impounding and water retention, for artificial regulation of surface water flow regime, for water protection and use, for water utilization, for the protection from harmful effects of water, for the regulation of water regime; for example, dams, dikes, water reservoirs, weirs and pools [6].

The Czech Commission on Large Dams in the CR lists 118 dams located in the CR which are included in ICOLD. Povodí Vltavy states there are 19 more dams which are not registered. Commission internationale des grands barrages International Commission on large dams (CIGB ICOLD) provides registration of new members. The oldest dam in the CR is the Jordán dam built in 1492 [7]. The Dalešice dam – Mohelno reservoir are the most important water power stations or rather pumped-storage hydro plants. The Mohelno reservoir is also a retention reservoir for the nuclear power plant of Dukovany. The most powerful dams in the CR include the Dlouhé Stráně pump-storage hydro plant with the largest installed capacity of 650MW in the CR and the above mentioned Dalešice dam with the power of 480MW [8].

2.2. World status
“Today, there are approximately 850,000 dams located around the world. It is estimated that 24 countries currently generate more than 90 percent of their electrical power from dams, and 70 countries rely on dams for flood control” [5]. On the anniversary of Czech Commission on Large Dam Mr. Satrapa indicates there are 60,000 dams registered in ICOLD [7]. The DAMS newsletter November 2018#-17 by CIGB ICOLD states the same number as Mr. Satrapa. [9] Most countries are increasing extremely their intended construction of new dams or reconstruction of the current ones in order to increase peak energy [10].

2.3. Reasons for building dams
Dams were built to protect areas, housing and crops; however, their function is changing corresponding to the civilization development. Apart from their recreation and shipping purposes, their current purpose/multipurpose is to produce electric energy. According to the ICOLD newsletter, large dams, and their purpose, are spread in continents as follows: Australasia 63.9%, Americas 21.5%, Africa 3.5%, Europe 11%. The main utilization percentage of the large dams included in ICOLD is following: 38% irrigation, 18% hydropower, 14% water supply, 14% flood mitigation, 8% recreation and 8% others (including navigation, fish breeding, and others). Electric energy represents 18% within the overall rate, but it is expected to rise in relation to the environmental thinking development. Most of the world top countries are in favour of reducing nuclear power industry. Some of them have already obliged to reduce these sources or even stop them completely, and substitute them with the absolutely ecologic ones. Hydropower is one of the most ecological source of energy. Figure 1 shows that the amount of new installed capacity in 2018 divided into individual countries is 21.8 MW where 2MW are produced in pumped-storage hydro plants. Figure 2 bringing the world’s total installed capacity to 1,292 gigawatts GW). Floods and climatic changes can significantly affect the dams function; thus the flood control and protection from climatic changes are ineludable parts of new
and even existing dams, as well as their upgrades. It can serve as a raw water storage reservoir for water treatment plants as well as for consumers. To accumulate water in dams is important especially at the time of global warming; on the other hand, it can have an adverse impact in times when there is no inflow at the other side. All information available with respect to progression is taken into account when planning a new dam construction. For this reason, it is necessary to consider possible steps with regard to water utilization. The main objective is to be dams’ safety regarding persons and property, Compatibility with the Environment, Technical, Economic and last but not least Social and Political Acceptance [9]. Multipurpose dams are one of options which can meet all the above mentioned criteria positively. Dam safety was also one of the main topics Question 101 – Safety and Risk Analysis, 17 November, 2018 ICOLD. One of the essential issues of the given topic is A Procedure for Estimating Loss of Life Caused by Dam Failure, see below [9, 10, 11].

3. DSO-99-06
The procedure of mortality assessment resulting from dam failure is an important parameter; the conception of which conception went along with frequent dam failures, especially before 1999 with the death toll of 320 people. In 1985-1994 more than 400 dams in the USA were damaged; fortunately, 98% were without a life loss. All the cases were off the basic ambit of legislation; therefore, DSO-99-06 A Procedure for Estimating Loss of Life Caused by Dam Failure has been made in order to improve the situation. It is used to estimate failures incurred in the USA where every dam with the mortality of 50 and more people and built after 1960 is assessed with the use of DSO–99-06 methodology (DAM SAFETY OFFICE). The methodology was prepared by Reclamation’s Dam Safety Office in September 1999. The comparison of all cases assessments is another positive point. Graham (1999) indicates three basis parameters that affect the losses of life:
1) The number of people occupying the dam failure flood plain;
2) The amount of warning that is provided to the people exposed to dangerous flooding;
3) The severity of the flooding.
The methodology investigates the events in seven steps [12]. Further steps were supplemented during the years, listed in Dams Sector September 2011, which indicates the procedure with 11 steps. “Steps 1 through 5 have been re-sequenced from the original procedure. Steps 6 through 10 were embedded in just one original step titled “Apply empirically-based equations or method for estimating the number of fatalities.” Step 11 involves evaluating uncertainty [13].

4. Whaley dam / bridge
The incident that happened in Whaley dam this year and was followed with high media interest has been chosen as an example. Water spilled over the dam wall; two of ten parts on the concrete spillway shut were destructed and collapsed. In terms of the procedure DSO-99-06:

- **STEP 1** Choose dam failure scenario Failure caused a flood which results in high levels or dam overtopping.
• **STEP 2** Choose time categories is Monday through Friday, 11 pm to sunrise (dark, and most people asleep), summer.

• **STEP 3** it is necessary to consider a failure of the dam wall edge on the spillway, which might be damaged, eventually damaged in a short time. The impact of the inundation on Whaley Bridge is huge as its elevation is lower than the height of the dam. The inundated area would be in the immediate vicinity of the River Goyt, this resulting from pumping over with high-capacity pumps. Not only for this reason 1500 inhabitants were evacuated from Whaley Bridge and nearly 35,000 people were at risk.

• **STEP 4** Estimate the number of people at risk for each failure scenario and time category – Number of People at Risk - High Reservoir Levels or Dam Overtopping During Flood in summer weather at day time the number of people within one kilometre in terms of the method and given example will be taken into account - 60% of the total number of people evacuated which is 900 people at risk at day time; this number is higher at night time, nearly 1,500.

• **STEP 5** and **STEP 6** Estimate when dam failure warnings would be initiated (based on discussions with personnel involved in creating dam-specific emergency action plans) within the real status the evidence and alert without delay were recorded as the short-term weather forecast warned against the increased intensity of rainfall. The inhabitants went to the dam to watch the water running over the dam’s crest but none of them realized the risk related to the situation after the spillway was damaged. People were informed within minutes, even in towns situated further away, such as Marple and New Mills.

• **STEP 7** Under the given conditions the incident relevance for Whaley Bridge is vague because the cracks and damage to gravity field in the night, the situation became precise at day, though some inhabitants refused to evacuate. The same conditions as for Whaley Bridge apply for the other cities and towns; the difference is they are in the possible second wave.

• **STEP 8** – Estimate the proportion of the PAR exposed to each of the three flood severity categories, the value of the above mentioned scenario would be assessed as High. In case of dam’s failure in Whaley Bridge, the number of people at risk would be as high as 750; in other cities - the assessment is: Medium with the victims expectation of 20%.

• **STEP 9** Select appropriate fatality rate based on the flood characteristics in each reach are considered according to the sample model at day number 0.15-0.75 (at night 3 – 67.5), the Whaley Bridge case – at night 563 people, which corresponds

• **STEP 10** Present life loss estimate.

• **STEP 11** will not be assessed [12, 13, 14].

5. **Civil protection in emergency situations**

Basic civil protection system is to result from the safety management of the country by determining basic measures in emergency situations involving state/ private infrastructure in crisis time. At the time when some dams were being constructed, the land-use planning was not as developed as it is nowadays. Not only the economic, social, hydro...studies are to be made in the phase of planning but also the technical and inundation ones with respect to possible risks. In the above mentioned chapter, the potential death toll during the recent emergency incident in Whaley Bridge is set. Based on this information, the technical measures are essential as they are to ensure operability and reaction ability of the structure earlier and in an easier way. The death toll estimation of 563 people during the dam failure is high; thus the appropriate means are advisable to be used to ensure better civil and property protection downstream. For example, monitoring of all inflows, outflows, walls with respect to landslide/rockslide, dam motion monitoring. In the phase of building, the canal built to bypass the river while constructing the dam is not to be closed but is to be used for tertiary drainage of a large amount of water. It is advisable to build facilities to bypass the inflow or just part of it to prevent the dam from overfilling. It is important to construct either some hard concreted surface in the immediate vicinity of the dam to allow heavy vehicles to access the place in case of emergency and under unfavourable weather conditions or a place from which high capacity pumps might be placed on the
water surface used for dewatering and flood control. Regarding Whaley, the Tood Brook river, which flows in the immediate vicinity of the dam and might have been used as a secondary outflow for pumps. There is a mobile pumping station for the Integrated Rescue System in the CR, the power of which is 1,500l/s, and three smaller ones. In Whaley, 23 high volume pumps were used. Last but not least, regular checks of individual parts of the dam are important to be carried out. In Great Britain (GB), in Whaley, the checks were performed once in 10 years. However, the dam owners are to perform min. two checks a year because naturally seeding plants may be a source of erosion. The dams in the CR are divided into four groups; the techno-safety inspection is determined on the basis of the most important ones, and is specified by law every year. In the operating instructions, the operator is to set check periods to avoid dam damage unknown to him including a regular monitoring of determined criteria. Dams are to be equipped with a warning system similar to the one in hydropower dams, which covers localities in an inundation zone, too. The other operating or emergency rules are commonplace [14, 15].

6. Summary
Water retention in dams is a trend of history as well as these days with regard to increasing demands for eco/clean energy and increasing demands on the quality of life. An inevitable part is their safety in the time of climatic variances and changes (floods, torrential rains, flow insufficiency, irrigation, global warming, etc.) It is important to learn from the previous drawbacks and to consolidate their assessment when planning new dams constructions. The procedure in process according to DSO-99-06 for the emergency situation in Whaley Bridge, where, based on the calculations, would be 563 casualties. Civil and dam protections are to be intensified measures stated in the chapter 4 are to be taken with reference to the incident in GB.

Acknowledgments
This work was supported by the Ministry of the Interior of the Czech Republic in the years 2015-2019 and funded from institutional sources VSB-TUO, FSI 2019.

References
[1] Hluštík P 2018 Efficiency of wastewater treatment plants (Albena: STEF92 Technology) pp 321-328
[2] Hluštík P, Václavík V and Dvorský T 2016 Causes and impacts of dropping water consumption on a wastewater treatment plant reduction (Leiden: CRC Press/Balkema) p 419
[3] Dvorský T, Václavík V and Hluštík P 2017 Waste water treatment in North Moravia and Silesia, from the past to the present (Leiden: CRC Press/Balkema) p 389
[4] Dams Sector: Estimating Loss of Live for Dam Failure Scenarios 2011
[5] A History of Dams (Online)
[6] Dams Science and Issues Water Encyclopedia
[7] Zákony pro lidi (Online)
[8] Rok 2018 byl významný i pro přehrady 2018 (in Czech) (online)
[9] Vodní elektrárny: Česká republika 2019 (in Czech) (online)
[10] de Vivo M et al. 2018 The DAMS Newsletter November 2018 (online)
[11] de Vivo M et al. 2017 The DAMS Newsletter March 2017 (online)
[12] International Hydropower Association (IHA) 2019 Hydropower status report: sector trends and insights 2019 (in Czech) (online)
[13] Graham W J A 1999 Procedure for Estimating Loss of Life Caused by Dam Failure (DSO-99-06) (Denver CO: USA US Bureau of Reclamation)
[14] Awford J 2019 OH DAM! Army warns 35,000 people living downstream from crumbling Whaley Bridge dam to ‘pack a bag’ in case they have to evacuate as water is pumped into another swollen river (online)
[15] Technika a prostředky Záchranného útvaru HZS ČR: 4. Dálková doprava vody (in Czech) (online)