PROCEDURE FOR DAM SAFETY RISK ANALYSIS AND EVALUATION OF PARAMETERS FOR LARGE SLOVENIAN HYDROPOWER DAMS

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ABSTRACT

Dam structures represent a large risk for dam safety, as in the case of major damage or failure catastrophic consequences may occur, such as loss of many lives, a great economic loss and ecological consequences. In the world, dam safety risk analyses have recently been widespread and the event tree analysis has become the standard approach. In Slovenia a comparable safety risk analysis for all hydropower dams has not yet been performed. According to the experience gained during the monitoring of dams, dam safety parameters were identified, common to all Slovenian hydropower dams, to be used in the risk analyses for hazard identification. Parameters for the evaluation of dams were included in one of the following three groups: basic parameters of the dam, construction parameters and post construction parameters. Each of these parameters was divided into three or more categories and different weighting factors were given to the categories. Overall evaluation of the dam performance was determined and the hydropower dams were categorized. 'Priority 1' region included the dams with the grades up to 80, whereas the 'Priority 2' region described the dams with the grades over 80 (the threshold value was determined empirically). The higher the grade, the lower potential risk was estimated. One has to bear in mind that the evaluation gives general results and that the dam safety depends on the weakest element of a dam. As expected, the overall evaluation of the dam performance was better for newer dams (built after 1990). The Slovenian hydropower dams are, in general, very well maintained and controlled, but anyway they have high dam safety risk, so the detailed risk evaluation should be performed in the future.

1. Introduction

Dam structures, particularly large dams, represent a large risk for dam safety as in the case of major damage or failure catastrophic consequences may occur, such as loss of many lives, a great economic loss and ecological consequences. In the world, dam safety risk analysis have recently been widespread and the event tree analysis have become the standard approach (the first dates back to the year 1984). The ultimate goal of event tree analysis is to provide insight into the functioning of a dam, and into the associated uncertainties about the way the dam functions. This leads to a quantification of the probability that the system (i.e. the dam), may stop to provide its essential function, which is the probability of system failure [1].

2. Dam Safety Risk Analysis

2.1 Acceptability of risk

The risk can be presented either numerically to the expected value (the sum of the products of probabilities and consequences) or with the graphic representation (pairs probabilities – consequences). Graphical representation of risk is well known as an F-N diagram (Figure 1), where: F – annual probability of failure, N – lives lost, money lost [2].

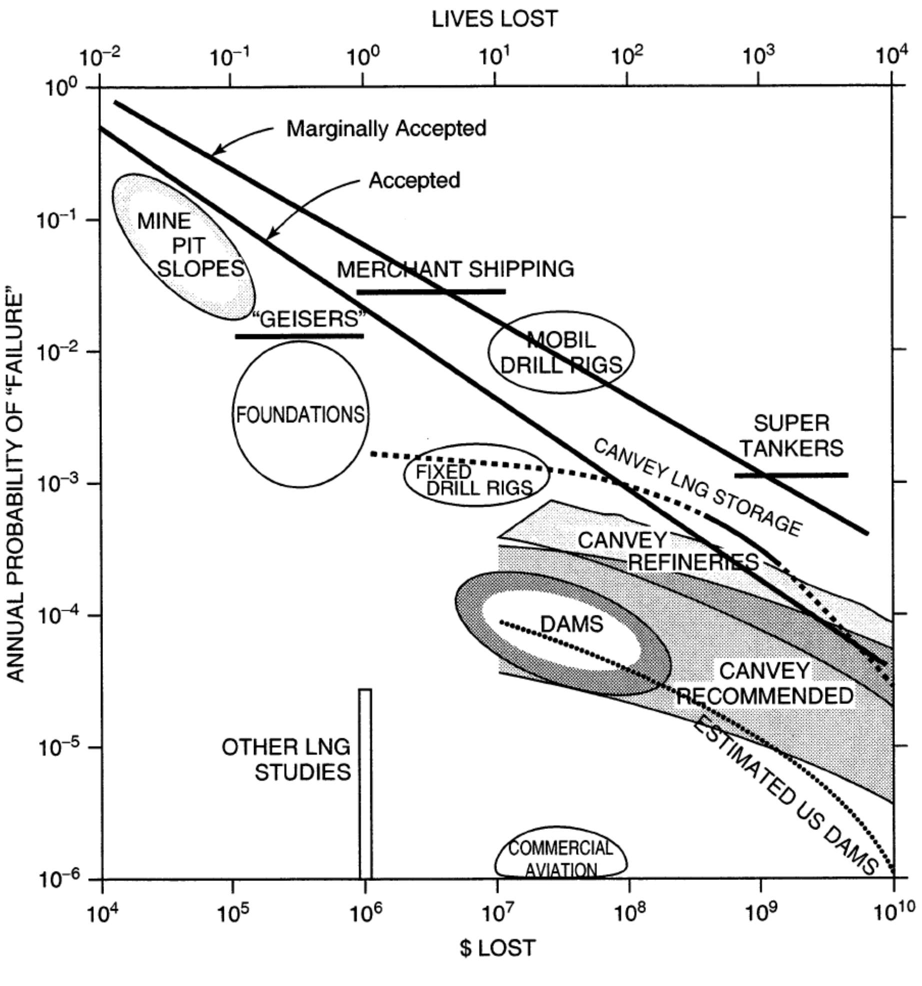

Figure 1 F-N chart showing average annual risks posed by a variety of traditional civil facilities and other large structures or projects (Baecher and Christian, 2003, p. 106)

Figure 2 shows general framework for the tolerability of risk, where three regions of risk can be seen: unacceptable, tolerable and broadly acceptable. In the tolerable region the risk is acceptable for the purpose of providing benefits, but should be As Low As Reasonably Practicable (the ALARP principle) [3].

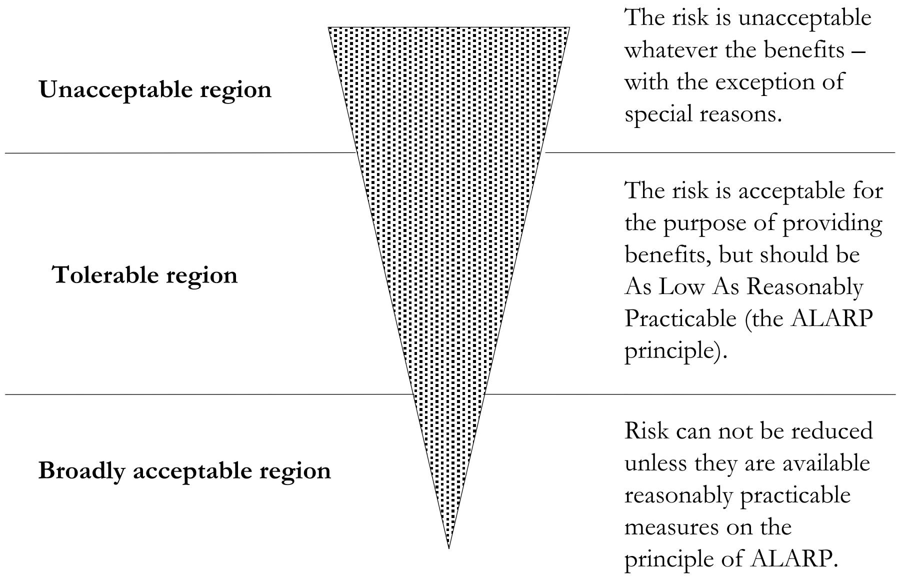

Figure 2 General framework for the tolerability of risk (ICOLD, 2005, p. 92-93)

2.2 Risk analysis process and methods for dam safety

Risk analysis for dam safety seeks to address several fundamental issues including:

- What can happen to cause the dam to fail or be damaged?
- How probable it is?
- What are the various consequences and their associated probabilities?
- What is the probability weighted consequences, or risks?

The risk analysis process for dam safety generally involves the following activities (Figure 3): scope definition, hazard and load identification and definition, probabilistic analysis of hazards and loads, failure mode identification, dam response and failure probability analysis, estimation of consequences corresponding to each failure event, risk estimation, uncertainty and sensitivity analysis, documentation, expert review and/or verification (if possible) and analysis update (if required).

Risk analysis incorporates failure probability and failure extent along with consequence magnitude and associated probability. Expert or peer review verification and analysis update provide quality control and a process to permit the analysis to be used in on-going risk management. The principal methods, available for conducting a risk analysis for dams, are: Failure Modes and Effects Analysis (FMEA), Event Tree Analysis (ETA) and Fault Tree Analysis (FTA). There are therefore a variety of methods for the analysis of engineering risk, but the ETA has become the most common approach in dam safety studies.

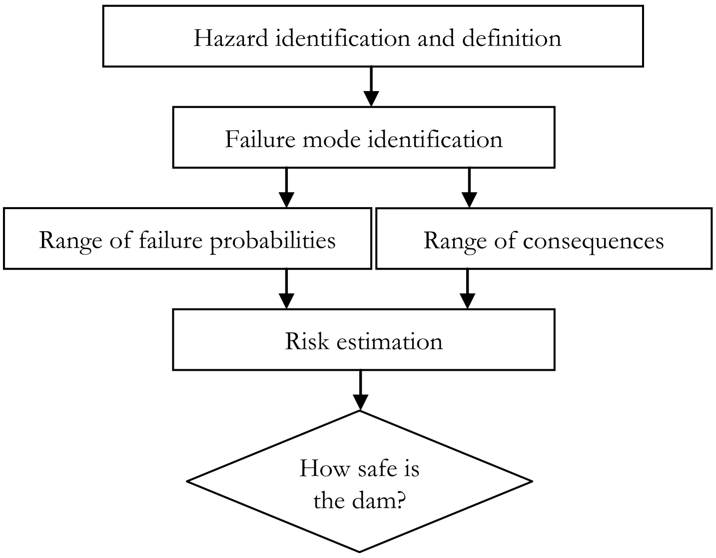

Figure 3 Risk analysis process (Hartford and Baecher, 2004, p. 12)

In Slovenia the comparable risk analyses of large hydropower (HP) dams were not yet performed. According to the experience gained during the monitoring of dams, the dam safety parameters were identified, common to all Slovenian HP dams to be used in risk analyses for hazard identification and definition.

3. Evaluation of Dam Safety Parameters for Large Slovenian HP Dams

3.1 Large Slovenian HP Dams

In Slovenia, 41 large dams are officially registered by the Slovenian National Committee on Large Dams that fulfil the ICOLD criteria: 22 HP dams, 14 dams for water management, 3 historical dams (so-called Klavže barrages from the 18th century) and 2 dumping tailing dams (Figure 4) [4].

In the early 20th century, the development of electrification facilitated the construction of HP dams in Slovenia. At this time, the construction of HP dams began in all three of the most important rivers for the hydropower exploitation (Drava River, Sava River and Soča River), whereas most of the dams were built in the 50th of the last century. The oldest dam in Slovenia designed for power generation is Završnica dam built in 1914.

Figure 5 shows the classification of the Slovenian HP dams as per year of construction. Five large HP dams were constructed before or during WWII – two dams on the Soča River were constructed according to the Italian regulations, three dams were constructed according to the Austrian technical regulations at that time. In civil engineering dam design practice important milestones were technical regulation issued in 1964 introducing seismic design. In 1966 regular monitoring of dams became mandatory and in 1970 technical regulations for dam construction were introduced. In 1984 a modern Construction Act (ZGO) was issued, which was significantly changed in 2002 (ZGO-1). In 2009 the use of European structural design codes and National Annexes (Eurocodes) became mandatory in Slovenia.

Most HP dams in Slovenia (10 dams, i.e. 46 %) are 30 to 40 metres high, 8 dams (36 %) are up to 30 metres high, whereas the other 4 dams (18 %) are 40 to 60 metres high. The highest HP dam is the Moste dam on the Sava Dolinka River with the structural height of 59,8 m. The largest reservoir is the Lake Ptuj (in Slovenian: Ptujsko jezero) behind the Markovci dam on the Drava River with the volume of 23 hm^3 [5].

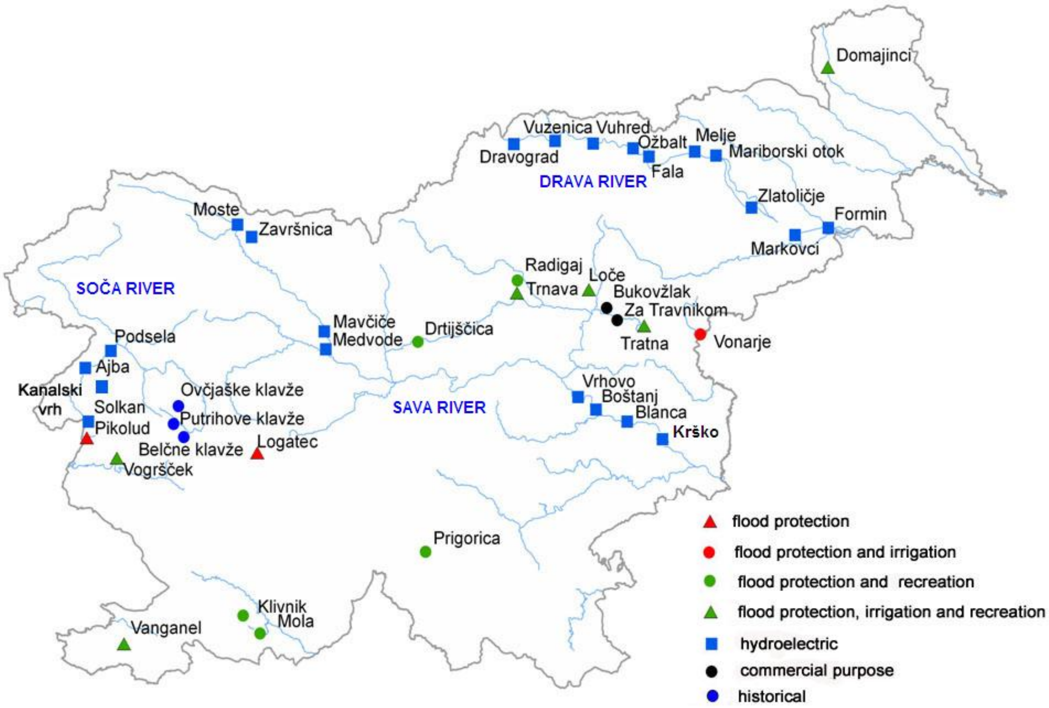

Figure 4 The locations of large dams in Slovenia

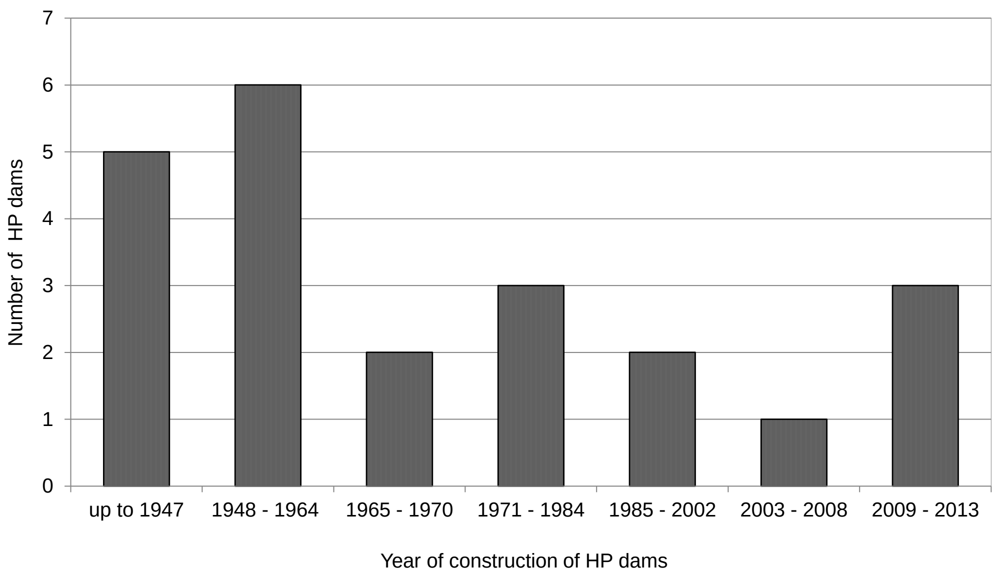

Figure 5 Classification of the Slovenian HP dams as per the year of construction

3.2 Dam Safety Parameters and their Evaluation

In the beginning of the risk analysis, the dam safety parameters, the most important for the dam safety evaluation, are needed. Parameters for the evaluation of the dam safety were included in one of the following three groups:

- Basic parameters of the dam (height of the dam, reservoir capacity, mean annual flow in the dam profile, 100-year flow in the dam profile, maintenance of the dam, accessibility of the dam, system for the control of equipment),

- Construction parameters (design for execution and design of executed works, seismic zone, availability of operational documents, analysis of the failure of the dam, geological and geotechnical data, year of design of the dam) and
- Post construction parameters - regarding states of the structures, foundations and equipment (concrete dam, appurtenant concrete structures, inspection gallery, deformations of the foundations, erosion of the river bed, filtration of water through abutments and under the dam, hydrostatic load on the dam, reservoir slopes and slopes of derivation channels, mechanical and electrical equipment, bottom outlet).

Each of these parameters was divided into three or more categories and different weighting factors were given to the categories [6]. Total weight for each dam was then evaluated as overall evaluation of the dam performance (grades between 20 and 110) and two priority regions were determined. 'Priority 1' region included the dams with the grades up to 80, whereas the 'Priority 2' region described the dams with the grades over 80 (the threshold value was determined empirically). The higher the grade, the lower potential risk was estimated.

Figures 6 and 7 show overall evaluation of the dam performance as per the year of construction and as per the dam height, respectively. The results showed that 14 evaluated HP dams (i.e. 64 %) belong to the 'Priority 1' region and for them more detailed evaluation should be performed in the near future. The other 8 dams (i.e. 36 %) belong to the 'Priority 2' region and further monitoring of different parameters is recommended for these dams. The highest grade (93) belongs to 22,5 m high dam built in 2010, but it should be noticed that with ageing of the dam the grade can change quickly. As expected, it can be seen that higher grades belong to newer dams (built after 1990). These dams are 15 and 40 m high.

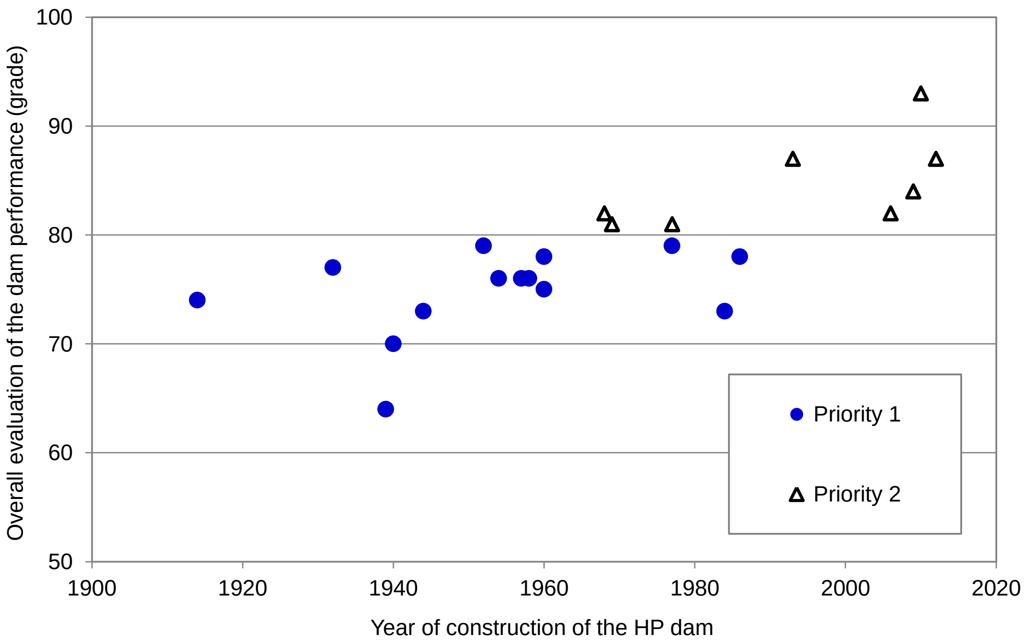

Figure 6 Overall evaluation of the dam performance of HP dams as per the year of construction

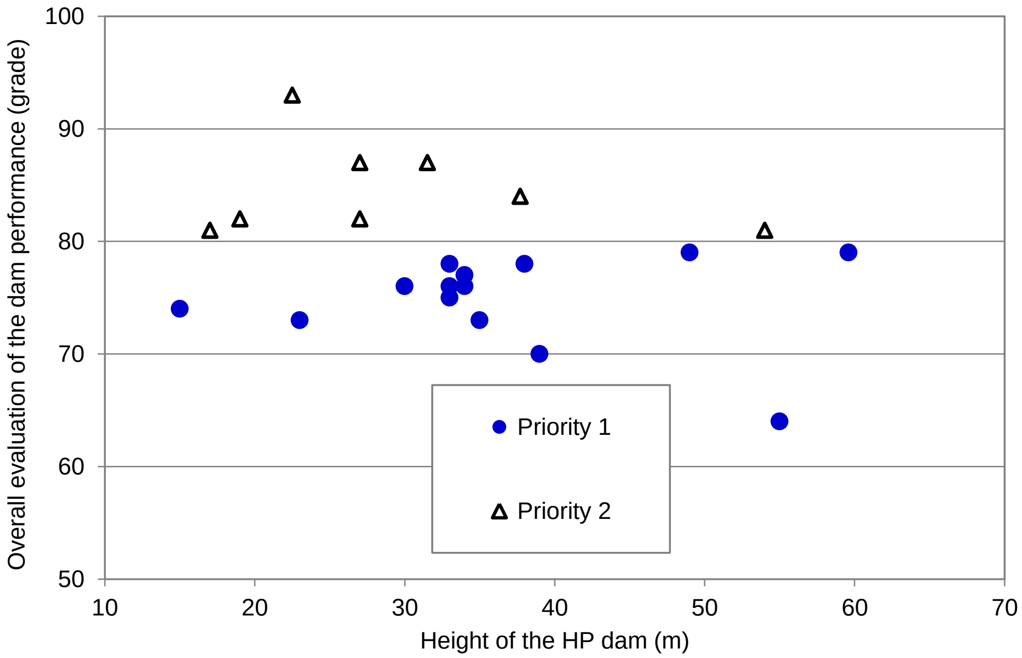

Figure 7 Overall evaluation of the dam performance of HP dams as per their height

4. Conclusions

Dam structures, particularly large dams, represent a large risk for society, so dam safety risk analyses have become an important tool. In Slovenia the comparable safety risk analyses for all HP dams have not yet been performed.

According to the experience gained during the monitoring of dams, dam safety parameters were identified, common to all Slovenian HP dams to be used in the risk analyses for hazard identification and definition. Twenty-two parameters for the evaluation of dams were included in one of the following three groups: basic parameters of the dam, construction parameters and post construction parameters. Each of these parameters was divided into three or more categories and different weighting factors were given to the categories. The results of the overall evaluation of the performance of large Slovenian HP dams showed that 14 dams belong to the 'Priority 1' region and for them more detailed evaluation should be performed in the near future. The other 8 dams belong to the 'Priority 2' region and further monitoring of different parameters is recommended for these dams. As expected, the overall evaluation of the dam performance was better for newer dams (built after 1990). One has to bear in mind that the evaluation gives general results and that the dam safety depends on the weakest element of a dam. The Slovenian HP dams are, in general, very good maintained and controlled, but anyway they have high dam safety risk, so the detailed risk evaluation should be performed in the future.

5. References

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