A Probabilistic Approach to Define the Reliability of Gates at Dams and Weirs

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Abstract

The safety of a dam depends, among other things, on the functionality and the hydraulic ability of the gates. Therefore, a literature study was undertaken by observing national and international research to receive actual failure frequencies of gates and weirs. This information is necessary to extend the so called (n-1)-condition in the actual dimensioning process from a deterministic design concept towards a probabilistic approach. Because of the determined lack of data, a kind of semi-probabilistic approach was developed, to treat varying failure probability of different gate types. The basic principle is to generate an evaluation matrix to assess different gate structures relating to their failure patterns. The result should be a defined "basic-value" for each gate type, which reflects the overall susceptibility. Furthermore, there should be a possibility for design engineers and operators of dam structures to intervene the dimensioning process through an "individual value".

Keywords: reliability analyses, weir, gates, probabilistic approach, (n-1)-condition.

1. INTRODUCTION

The functionality and the hydraulic ability of gates are essential for the operational and overall safety of dams and weirs. Therefore, a reduction of the discharge capacity, through accidental or scheduled blockage, is mandatory in the dimensioning process. In Germany and Austria these requirements are taken into account through a deterministic design concept which includes the so called (n-1)-condition [1]. According to this concept, the design flood must be able to pass the weir with one gate out of function. The probabilistic approach behind this concept is that the coincidence of a blockage of two or more gates with a design flood is very unlikely.

Accidental blockage of a gate can be caused by a variety of mechanical and electronical malfunctions. In the following chapters these eventualities of unavailability are briefly summarized by the term "failure".

2. PSEUDO-PROBABILISTIC APPROACH

In literature the (n-1)-condition usually aims at maintenance activities which lead to an unavailability of the gate [2]. With regard to the editors of DVWK 1990 also the case of an unavailability caused by failure of relevant components should be taken into account through this approach. Therefore the formula was extended by a term considering the maintenance and another one the failure probability [3].

$$(n - a_R - a_S) \times B_F \rightarrow HQ_b \quad (1)$$

where n is the number of gates, a_R is a factor considering the failure of the gate, a_S considering the maintenance, B_F is the clear width of one gate and HQ is the design flood discharge, which has to pass through the total clear width of the structure.

This consideration could result in thoughts, there should be two gates in redundancy, but this is in general not necessary because of the fact that a negative impact only arises if the following three aspects appear at the same time [3]:

- maintenance of one gate,
- failure of another gate and
- the occurring amount of water cannot be discharged by the remaining gates and the safety margin of the construction is insufficient.

3. Reliability Analysis and Data Acquisition

Over the last decades, reliability analysis has gained more and more acceptance in academic circles. These methods consider a probabilistic approach for the design of structures by defining a reliability index or a probability of failure instead of a deterministic factor of safety. To specify a limit state equation that governs the behavior of the structure, for every random variable a probability of failure has to be defined. Therefore, a literature study was undertaken by observing national and international research to receive actual failure frequencies of gates and weirs.

At the moment only a few reliable publications relating to this scientific issue are available [4–9]. An attempt to compare the individual results failed because of the widely varying methodologies of the single analysis.

4. Semi-Probabilistic Approach

Because of the lack of data and analysis, another approach to treat varying failure probability of different gate structures has been developed. The basic principle is to generate an evaluation matrix to assess different gate structures relating to their failure patterns. The result should be a defined "basic value" for each gate type, which reflects the overall susceptibility.

Furthermore, there should be a possibility for design engineers and operators of dam structures to intervene the dimensioning process by increasing the safety. For example, if a structure is equipped with a redundancy measure, the "basic value" can be reduced by an "individual value".

$$(n - (a_B - a_I)) \times B_F \rightarrow HQ_b \quad (2)$$

Where n is the number of gates, a_B is the "basic value" considering the vulnerability to fail, a_I is the "individual value", which can be influenced by the engineers and operators, B_F is the clear width of one gate and HQ is the design flood discharge.

a. Basic value

The concept is to determine a basic value a_B for each gate type which describes the susceptibility of failure. This is done through assessing the individual structure by a defined valuation scheme, which focuses on the complexity of the components. The consideration behind this is, that with an increasing level of complexity also the vulnerability to fail rises.

Five main categories have been specified and rated inspired by literature mentioned in chapter 3. The categories were then further divided to accomplish a detailed rating system (see Table 1).

The first category "control system" includes all kind of electronic devices which are responsible for acquisition, processing and transfer of data, information and signals. According to the probabilistic approach, the likelihood to fail rises with the amount of components. Thus, two subcategories "simple" and "complex" have been defined. The same concept was considered for splitting the second category "mechanics". The subcategories were defined sufficiently abstract to simplify the allocation of components of different weir systems.

A power unit failure, which is mentioned in category three, only includes mechanical or hydraulic infirmities of the drive system. An interruption of the energy supply is not considered, because the probability is independent from the weir type. Therefore, it is important, if during a break down, a release of the gate with a redundant device (e.g. truck-mounted crane) is possible.

The category "abrasion" aims at assessing the resilience of the structure with regard to the applied materials. As an example, a corrosion-resistant metal drum gate is much more resistant to abrasion through flood debris, than a common inflatable rubber weir.

The last category focuses on the revision period, which leads to an unavailability of the weir. To distinguish between different gate types, it is important to characterize the necessary interval and duration of typical revision procedures.

Table 1 - Main categories and subdivisions for the evaluation and determination of the basic value a_B

Control system	*Mechanics*	*Failure of power unit*	*Abrasion*	*Revision time*
simple	weir body	weir moveable	low	short
complex	force transmission	weir immovable	high	average
	support			long
	pressure pipes and valves			
	seals			

b. INDIVIDUAL-VALUE

As already mentioned, engineers and operators should have the possibility to influence the basic value through measures which improve the structure. The individual value a_I depends on the following five categories:

- Number of gates
- Year of construction
- Further redundancy (beyond the state of the art)
- Revision concept
- Possibility to unblock the gate in case of a revision

As already mentioned in DVWK 1990, the failure probability rises with the number of gates installed at one plant. With regard to river characteristics in central Europe the (n-1) approach is valid for up to six gates per facility. Furthermore, a linear growth of the default criterion is assumed, so that in case of twelve weirs, two with failure are suggested [3].

Also the year of the construction can play an important role, although the opinion of experts on this topic varies widely. On the one hand, the technical development reduces the vulnerability of electronical and mechanical components[8], on the other hand there are reports of plants that have worked without problems over the last decades.

As already mentioned, design engineers and operators of dam structures should have the possibility to increase the overall safety of the structure by assembling further redundancy, beyond the required extent. This could be an additional power unit or a gantry crane.

In addition, risk minimization could be achieved by generating a revision plan, which focuses on a reduction of the time period with the weir out of function [10]. Also the possibility to unblock the gate during a revision is significant to reduce the risk. This presupposes that - apart from releasing the actual weir - also the revision gate, which provides dry working conditions, can be opened.

5. CONCLUSIONS

Because of the increasing demand to implement probabilistic approaches to the design of gates at weirs and dams, a literature study was undertaken to obtain information about the failure probability. At the moment only a few publications concerning this issue are available. Furthermore, an attempt to compare the results failed because of the widely varying methodologies behind the individual analysis. To avoid the lack of data, another semi-probabilistic approach was developed. For each gate type a "basic value" was defined by assessing the complexity of the structure. To enable engineers and operators of dam constructions to influence the dimensioning process a further "individual value" was introduced. Through measures, which improve the structure safety, the "basic value" can be improved. This approach is going to be discussed and evolved by an expert committee and could be included in a new guideline for gate dimensioning at weirs and dams.

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