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The Likelihood of a Failure of a Damming Structure

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Abstract

Having an analysis of real breakdowns and damages in Polish damming structures as a basis, and assuming the probability of controlling freshet as a unit, one can calculate the probability of failure of a hydro-technical structure, due to failure of the base, the draining system, anti-filtering safety appliances, the body or the abutments. The results obtained afford an estimation of failure risk at any moment of the structure's operation and an estimation of the overall failure probability. The calculations were carried out for all dam classes. When the dam's elements are in good condition, the overall failure probability is by one order of magnitude greater than the probability that a controlling freshet will occur.

Key words: failure risk, dam

1. Introduction

During calculations of the hazard ratios for Polish hydro-technical structures, the problem occurred: as to how one estimates, even with a high degree of approximation, the probability of failure in a damming structure, when the latter is in good technical condition. Presently, during the design stage, only the probability of failure caused by freshet is estimated (An ordinance 1997, Regulations 1967). Even when the negative source mechanisms are in good condition, this probability is higher than zero, and it can be assumed to be equal to the probability that a controlling flow will occur. In reality it is slightly higher, since a controlling freshet should theoretically pass through the structure without the lattering collaps. However, for the calculated hazard ratio we needed to have an estimation of the likelihood of failure that would also take into account other phenomena, such as an inefficient drainage system, anti-filtering appliances or loss of the body's stability. This paper offers a suggestion as to how to resolve this problem and although it constitutes a supplement to the previously presented concept of hazard ratio (Hrabowski, Opyrchał 1999, Opyrchał, Hrabowski, Jankowski 1999), its results may be the subject of a separate analysis.

2. The Concept of Estimation of Failure Probability in a Hydro-technical Structure

In Poland, since 1992 (Hrabowski 1994, Jankowski 1997) estimations of the technical state of damming structures have been carried out at the Ośrodek Technicznej Kontroli Zapór IMGW (Centre of Technical Control of Dams – Institute of Meteorology and Water Management). Using the 1 – 10 scale (1 – full hazard, 10 – lack of hazard) six dam elements e are assessed independently:

- PO – the base,
- KO – the body,
- UF – filtering appliances,
- UD – draining appliances,
- UU – discharge mechanisms,
- SO – the surrounding, the upper and lower post and the abutments.

The likelihood of failure of any of the quoted elements e of the structure (Hrabowski, Opyrchał 1999, Opyrchał, Hrabowski, Jankowski 1999) is presented in the formula below (1):

$$\log\left(P_e\left(\widetilde{W}_e\right)\right) = \alpha - \beta\widetilde{W}_e, \tag{1}$$

where:

- $\widetilde{W}_e$ – average value of assessment of e element,
- α, β – parameters calculated from boundary conditions:

$$P_e(1) = 1,\ P_e(10) = P_{\min}. \tag{2}$$

The first equation means that with an obtained "1" result, failure is inevitable; with a "10" value – the best – it is stated that the likelihood of failure is minimal and equal to $P_{\min}$. However, as has already been mentioned it does not have a zero value. Transformation of formula (1), applying boundary conditions (2) gives:

$$P_e\left(\widetilde{W}_e\right) = 10^{C(1-\widetilde{w}_e)}, \tag{3}$$

where:

$$C = -\frac{1}{9}\log\left(P_{\min}\right). \tag{4}$$

Thus, in order to be able to calculate the current likelihood of failure, it is crucial that the value of $P_{\min}$ should be known for each of the assessed elements e. The overall probability of a failure of a damming structure, P_{tot}, regardless of which element causes it, equals:

$$P_{TOT} = P\left(\widetilde{PO} \cup \widetilde{KO} \cup \widetilde{UF} \cup \widetilde{UD} \cup \widetilde{UU} \cup \widetilde{SO}\right), \tag{5}$$

where $\widetilde{e}$ denotes the random event that element e causes the failure of a dam. The calculation method for P_{tot} is quoted in (Eadie et al. 1989) and can be calculated using the following procedure. Let six sets of events influencing the structure: PO, KO, UF, UD, UU, SO be denoted as $A_1, ..., .A_6$, and $P(A_i) = P_e$ is a probability of the failure of a structure resulting from the occurrence of event A_i. The total probability of the failure of the structure, P_{TOT}, is calculated according to the following scheme (Eadie et al. 1989), depending on the independence of events A_i:

$$P_{TOT} = \sum_{i=1}^{6} (-1)^{i+1} S_i , \tag{6}$$

where:

$$S_1 = \sum_{i} P(A_i) \quad S_2 = \sum_{i<j} P(A_i) P(A_j) \quad S_3 = \sum_{i<j<k} P(A_i) P(A_j) P(A_k) \quad \text{etc.}$$

The above procedure of calculating the probability of failure represents an intuitive conviction that if even one element is assessed as causing the failure (assessment value 1), then the whole dam would be endangered, i.e. $P_{TOT} = 1$, even if the other elements were in very good state (assessment value 10).

3. Methods of Estimation of $P_{\min}$ value

As has been said, the only value of the probability of failure in a hydro-technical structure ($P_{\min}$), calculated at the design stage is the probability of destruction due to a flood – $P_{\min}(UU)$. For particular dam classes this amounts to (An ordinance 1997):

Table 1. The probability that controlling freshet will occur

Dam class	$P_{\min}$
I	0.0002
II	0.0005
III	0.002
IV	0.005

In order to assess $P_{\min}(e)$, on the other hand, for other elements e it is suggested that the following sequence should be considered:

- failure likelihood, $P_{\min}(UU)$, should be assumed as a unit and $P_{\min}(e)$ should be calculated for other e elements, in accordance with the following dependency (7):

$$P_{\min}(e) = Wg(e) \times P_{\min}(UU) \tag{7}$$

where $Wg(e)$ – weight of e element.

- Weights $Wg(e)$ should be calculated as the relation of the number of occurrences of actual failures in Polish hydro-technical structures, using the following formula (8):

$$Wg\ (e) = \frac{No.of\ failures(s)}{No.of\ failures(UU)}. \tag{8}$$

- Due to the fact that only two failures of hydro-technical structures have occurred in Poland, the number of failures in formula (8) should be replaced by the number of breakdowns and damages.

$$Wg\ (e) = \frac{average\ number\ of\ hazardous\ structures}{average\ number\ of\ hazardous\ structures\ (UU)}. \tag{9}$$

4. Material

The analysis of breakdowns and damages covers the years 1992–1997. From the annual estimations carried out by OTKZ IMGW, it can be judged that the average value of the number of structures that constitute, or may constitute a hazard, being divided in respect of estimated element, equals:

Table 2. The average number of structures constituting, or being able to constitute a hazard in the years 1993–1997, divided into particular elements of the structure

P	K	UF	UD	UU	SO
7.6	12.4	5.8	4.6	7.4	18.0

5. Results

On the basis of formula (8) and Table 2, the following weight values have been obtained:

Table 3. Weights for particular elements of the structure

$Wg(P)$	$Wg(K)$	$Wg(UF)$	$Wg(UD)$	$Wg(UU)$	$Wg(SO)$
1.0270	1.6757	0.7838	0.6216	1	2.4324

On the basis of weights from Table 3 and formula (7), the value of $P_{\min}(e)$ has been calculated for all elements of the structure, divided into dam classes (Table 4).

Using formula (5), the overall failure probability, P_{tot}, has been calculated, on the assumption that the structure is in perfect condition, namely, that each estimation value equal 10:

Table 4. The value of $P_{\min}$ for six assessed e elements and I – IV dam classes

	P	K	UF	UD	UU	SO
I	0.0002	0.0003	0.0002	0.0001	0.0002	0.0005
II	0.0005	0.0008	0.0004	0.0003	0.0005	0.0012
III	0.0021	0.0034	0.0016	0.0012	0.0020	0.0049
IV	0.0051	0.0084	0.0039	0.0031	0.0050	0.0122

$$\underset{e}{\forall}\,\widetilde{W}_e = 10.$$

The result can be seen in Table 5.

Table 5. The value of probability P_{tot} of a failure in a damming structure, by class division

Dam class	P_{tot}
I	0.0015
II	0.0037
III	0.0102
IV	0.0376

6. Discussion

As can be seen, the calculated probability of failure in a hydro-technical structure for each dam class exceeds the probability of the latter being destroyed by flood by one order of magnitude. It is, however, extremely difficult to say how correct and precise these results are. Intuitive feelings are rather misleading in this respect (Hartford 1998), and the literature on the topic is poor, which makes it difficult to discuss the problem. Most of the authors who have analysed hazards caused by dams, aim at an analysis of the event tree and the probability of occurrence of a failure, rather than the estimation of the global risk of the structure (Vick 1997). The analysis having been carried out globally to-date shows that the relation between the number of failures in dams of the selected type and the number of all failures is approximately equal to the relation between the number of dams of this type and the number of all dams (Dam failures 1995). This justifies the application of the results obtained in other countries to Polish dams. In recent works (Dam failures 1995), carried out for dams that are higher than 15 m, thus classified approximately into I and II dam classes, it has been said that the relation between the number of failures and the number of dams is less than 0.5%. Similar results have been obtained by Fell (1996), which is convergent with the result presented in this paper.

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