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APPLICATIONS FOR RELIABILITY IN DAMS AND RISK ANALYSIS IN SPILLWAYS

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Summary. Dams have a very important place in water resources projects. The high cost of construction and the long life spans of dams make careful and correct project development and optimum management imperative.

Many studies have been published on the shortcomings of dams. In particular, many of these studies have dwelt upon the inadequacy of spillways, and attempts have been made to determine the relevant risks. These studies indicate that if inadequacies are identified and appropriate rehabilitation measures are taken, it will be possible to increase the life spans of dams and to prepare for new risks.

At present, there are a number of methods in use for the determination of the risk of dams failing to function properly. The most developed of these are the mean value first order second moment method (MFOSM) and the advanced first order second moment method (AFOSM).

In the present study, the observed maximum flow values for the Kayacık and Surgu dams of Turkey which are part of the Southeastern Anatolia Project (GAP), were taken and it was attempted to determine the fitness of these values for normal distribution. The parameters obtained were subjected to risk analysis by MFOSM and AFOSM with the aid of a computer program prepared in the JAVA environment (which gives results according to normal distribution values only) and it was attempted to determine the reliability of the spillways of these dams.

The results of risk analysis carried out by these methods indicate that the spillways of both of these dams, against the observed overflow values, are all reliable in work mode, and that they can exceed these overflows.

Keywords: Spillway, flood, risk analysis, dam safety.

INTRODUCTION

The continuous observation of dam performance will help to identify any defect that might lead to damage. With studies to be performed on existing dams, important information can be obtained concerning the causes and effects of these deficiencies and what preventative measures need to be taken [1].

Deficiencies observed in large dams throughout the world, as reported in the literature, are shown in Table I.

Table I. Deficiencies observed in large dams throughout the world [2]

Year	The number of large dams deficiencies
Before 1900	38
1900 – 1909	15
1910 – 1919	25
1920 – 1929	33
1930 – 1939	15
1940 – 1949	11
1950 – 1959	30
1960 – 1965	25
Unknown dates	10
TOTAL	**202**

Various studies on the performance of dams have identified the risk factors generally affecting dams to be inadequate foundation, inadequate spillway, weak construction, irregular settlement, high vacuum pressure, effects of war, landslides, defective materials, incorrect operations and earthquakes [2-3].

Of all the reasons for failure, the second most common cause of dam breaks is spillway inadequacy, at 23%. (Table II) The malfunctioning of spillway valves alone has caused damage to a great number of dams. For examples: Euclides Da Cunha Dam, (Brazil, 1977), Machu II Dam, (India, 1979), Hirakuo Dam, (India, 1980), Tous Dam, (Spain, 1982), Noppikoski Dam, (Sweden, 1985), Lutufallet Dam, (Norway, 1986), Belci Dam, (Romania, 1991), Folsom Dam, (USA, 1995) [4].

Table II. The causes of failure of dams [2]

Causes of failure	Rates
Foundation problems	40
Inadequate spillway	23
Poor construction	12
Uneven settlement	10
High pore pressure	5
Acts of war	3
Embankment slips	2
Defective materials	2
Incorrect operation	2
Earthquakes	1

SPILLWAY PROJECT DEVELOPMENT AND THE EFFECTS OF OVERFLOW DISCHARGE

In recent years, dam breaks in various parts of the world have cost the lives of many people, as well as causing great material losses. For this reason, there is currently a trend to reevaluate spillways and the principal factors in dam breaks using a different approach. Old dams in particular are dealt with in this way. The reason for this is that the project criteria used in the past have since been found to be inadequate [5].

The principal factors in dam breaks are overflows caused by the inadequacy of flow discharge and by earthquakes. Old dams are found to be unreliable in these respects, and so breaks occur more frequently in them [6].

The potential human and material losses that would occur in the event of the collapse of a particular depot structure can be calculated. Both types of loss can be reduced with modifications in spillways. The material burden of these modifications must also be taken into consideration. After this, the calculation involves a method of comparison. The results will be recommended to the decision-makers and will help the decision-makers make sound decisions.

There are three steps to this new method, which is still being developed:

1. Risk Analysis

This analysis begins by defining the risk. In general, there are three types: hydraulic risk, risk stemming from an error made in determining the water level in the reservoir, and the risk of earthquake.

2. Solution-Dependent Risk Analysis

The approaches that need to be considered in this risk analysis are as follows:

a. The probability of loss of life and the numerical calculation of material loss based on the existing conditions.

b. The numerical values, based on the solutions found, of changes in risk dependent on solutions. These are decreasing values. Conversely, the expense of the solutions gradually increases.

3. The Decision

In order for the decision-makers to make the correct decision, the following issues must be addressed with thoroughness:

a. Potential loss of life,
b. Potential material losses,
c. The probability of dam break,
d. Damage to be suffered in the event of a collapse,
e. Alternatives arising from economic analysis,
f. Modification alternatives [7-8].

The size of the return interval of the chosen flood peak is dependent on the risk that can be taken in terms of the dams reliability. The value of this risk is related to the losses that would occur in the event of the exceeding of the flood peak. If loss of life or significant material losses are foreseeable, it is necessary to select a very small risk in order to achieve sufficient protection. Conversely, if the losses that will be incurred are not excessive, a greater risk is acceptable.

CALCULATION OF RISK AND DETERMINATION OF RELIABILITY IN SPILLWAYS

In order to determine the risk of structures being unable to function, researchers have proposed methods such as return interval, the safety factor, Monte Carlo simulation, reliability index, the mean value first order second moment method and the advanced first order second moment method [9-11].

If it is considered that the hydraulic data, which is sometimes inadequate, is used in the planning and project development stages, it is clear that if the risk calculation of spillways, the dimensions of which are determined according to overflow flood peaks calculated by probable maximum precipitation and frequency analysis, is done with one or more of the methods mentioned above, and the result value is determined, it can be determined which dams subject to which risks have what kind of reliability behavior, and the risk-security ratios with this behavior can be determined in a realistic manner [12-13].

Of these methods, the two that give the best results are MFOSM and AFOSM, and if we analyze them with short analysis logic, we obtain the data below:

First degree secondary moment methods are a group of very recently developed, powerful methods that can be used to determine total or resultant risks of structures. These methods require only the predicted average values of the factors affecting the structure, and the standard deviation. The necessary calculation amount is less than that of the Monte Carlo simulation and direct integration methods.

In engineering applications, the distributions of variables affecting the load and resistance capacity of structures fX1(X1), fX2(X2) .... fXn+1(Xn+1), ... fXm(Xm) are generally not well defined, and information about these variables is usually limited to averages and variances. Thus the approach used in these methods is consistent with the existing data on random variables [10].

Mean Value First Order Second Moment Method (MFOSM)

With this method, in the equation $z = g(x_i)$; $i = 1, 2, \ldots m$, the first degree Taylor series expansion of z is written in the x_i averages of x_i variables.

The derivatives here are obtained in

$$Z = g(\bar{x}_i) + \sum_{i=1}^{m} (x_i - \bar{x}_i) \frac{\partial g}{\partial x_i}$$

If we take the first and second moments of z in the above equation, ignoring terms higher than the second degree, we obtain the following:

$$E(z) = \bar{z} = g(\bar{x}_i)$$

$$Var(z) = \sum_{i=1}^{m} C_i^2 Var(X_i)$$

In these expressions, the C_i values are partial derivations of $\frac{\partial g}{\partial x_i}$ calculated

in $(\bar{x}_1, \bar{x}_2, \ldots\ldots, \bar{x}_m)$. The x_i variables are considered statistically independent. Thus, the following can be written:

$$\sigma = \left[\sum_{i=1}^{m} (C_i \sigma_i)^2 \right]^{1/2}$$

where σ_z and σ_i are the standard deviations of z and x_i, respectively.

Risk is found by the equation:

$P_f = P\,(Z<0)$

If z has normal distribution, then risk is

$$P_f = 1 - \phi\left[\frac{E(z)}{\sigma(z)}\right] = 1 - \phi(\beta)$$

and $\phi(\beta)$ is obtained from the cumulative standard normal distribution tables. In the MFOSM method, the reliability index for β is found as follows:

$$\beta = \frac{g\left(\bar{x}_i\right)}{\left[\sum_{i=1}^{m}\left(C_i\sigma_i\right)^2\right]^{1/2}}$$

The risk calculated in this way is approximate, and if the x_i variables fit normal distribution and the g(.) functions can be written as a linear combination of the base variables, the result will be complete and correct [14].

In civil engineering projects, the malfunctioning of structures occurs as a result of extreme events such as frequent floods and powerful earthquakes.

The risk assessed by this method may be significantly different from the real risk because the probability distributions of variables of this type vary considerably and have distortion coefficients, and the correction done in the MFOSM method and the g(.) function are determined in the average values of the x_i variables [10].

Advanced First Order Second Moment Method (AFOSM)

The basic assumption of this method

$z = g(x_1, x_2, \dots, x_m)$

calculates the performance function by linearizing it with the Taylor series expansion, not in the average values, as in the average value method, but in the

$x^* = (x_1^*, x_2^*, \dots, x_m^*)$

point on the dam break surface [15].

By writing the Taylor series expansion for the

$x^* = (x_1^*, x_2^*, \dots, x_m^*)$

point on the dam break surface, we get

$$z= g(x_1^*, x_2^*, \ldots, x_m^*)+\sum_{i=1}^{m} C_i\left(\bar{x}_i - x_i^*\right)$$

In these expressions,

$$C_i=\frac{\partial g}{\partial x_i}$$

x_i^* is the value at the point of break. Because z = 0 on the break surface, on the break point

$$g(x_1^*, x_2^*, \ldots, x_m^*)=0$$

and the predicted value and standard deviation of z

$$E(z) = \sum_{i=1}^{m} C_i\left(\bar{x}_i - x_i^*\right)$$

$$\sigma(z) = \left[\sum_{i=1}^{m} (C_i \sigma_i)^2\right]^{1/2}$$

the z variable's σ_z standard deviation can be written as follows:

$$\sigma_z= \sum_{i=1}^{m} \alpha_i C_i \sigma_i$$

$$\alpha_i=\frac{C_i \sigma_i}{\left[\sum_{j=1}^{m} (C_j \sigma_j)^2\right]^{1/2}}$$

After the α_i coefficient is found, because

$$x_i^* = \bar{x}_i - \alpha_i \sigma_i \beta$$

by placing the limit in the situation equation, β is calculated by trial and error. From this, the x*'s on the collapse surface are calculated. Then the

α_i's and x*'s are calculated. If β does not change with trials, then the risk is calculated [16]:

$P_f = 1 - \phi(\beta)$

If the random variables do not fit normal distribution, we can calculate the risk using equivalent normal distributions [15]. This leads us to try to make distortion distribution variables fit normal distribution with an appropriate transformation. The most frequently used transformation for this purpose is logarithmic transformation [14].

In order to find the equivalent normal distribution value of a variable that does not fit normal distribution, the cumulative probabilities of the equivalent normal distribution and the probability density ordinates are considered to be equal to the non-normal distribution values.

If we equalize the cumulative probabilities at the x_i break point,

$$\phi\left(\frac{x_i^* - x_{xi}^{-N}}{\sigma_{xi}^N}\right) = F_{xi}(x_i^*)$$

then

x_{xi}^{-N}, σ_{xi}^N = the average and standard deviation of the x_i variable's normal distribution

$F_{xi}(x_i^*)$ = the original cumulative probability calculated at the x_i^* point

$\phi(.)$ = the cumulative probability of the standard normal variable

$X_{xi}^{-N} = X_i^* - \sigma_{xi}^N \phi^{-1}(F_{xi}(X_i^*))$ is found.

$f_{xi}(x_i^*)$ = the original probability density ordinate at the point x_i^*

$\varphi(.)$ = the standard normal variable probability density ordinate

From the above equations, we find

$$\sigma_{xi}^N = \frac{\varphi\left\{\phi^{-1}\left[F_{xi}\left(x_i^*\right)\right]\right\}}{f_{xi}\left(x_i^*\right)}$$

The break surface coordinates are

$X_i^* = X_{xi}^{-N} - \alpha_i \beta \sigma_{xi}^N$

and we find

$$\alpha_i = \frac{C_i \, \sigma_i^{\,N}}{\left[\sum_{j=1}^{N} \left(C_j \, \sigma_j^{\,N} \right)^2 \right]^{1/2}}$$

The remaining procedures are carried out as in MFOSM [16].

APPLICATIONS FOR KAYACIK AND SURGU DAMS

In this study, the observed maximum flow values were obtained and an attempt was made to determine their fitness to normal distribution for Kayacik Dam (AGI pertaining to DSI no. 21 111 for 1967-84, a total of 13) and Surgu Dam (AGI pertaining to DSI no. 21014-21091 for 1960-69, a total of 9) [17-18].

The parameters obtained were subjected to risk analysis by MFOSM and AFOSM, with the aid of a program prepared in the JAVA environment, which gave results according to normal distribution values alone, and an attempt was made to determine the reliability of the spillways of these dams.

For normal distribution, the following parameters were obtained by risk analysis for Kayacık Dam, built on the River Aynifer-Oğuzeli in Gaziantep province: average, 17.6769; Standard deviation, 187.1645; Distortion coefficient: 1.64195; Kurtosis coefficient, 1.98952. This distribution was deemed normal, and the risk values for the two methods were found to be P(1)=0 for MFOSM, and P(2)=0 for AFOSM.

Name of the dam	**: Kayacık Dam**
Place	: Gaziantep, Turkey
Purpose	: Irrigation
Flood quantity of project(m^3/s)	: 612.0
Width of spillway(m)	: 17.6
Height of spillway(m)	: 6.7
Number of gates	: 4.0
Name and number of station	: Tuzel S. Ekinci Kop. (21 111), DSI
Number of observation	: 13.0
Observation values	: 10.5, 50.0, 43.0, 3.3, 7.9, 5.5, 20.0, 9.0, 21.0, 5.2, 2.3, 2.1, 50.0

Method of risk	Risk
MFOSM	P(1)=0.0
AFOSM	P(2)=0.0

For normal distribution, the following parameters were obtained by risk analysis for Surgu Dam, built on Surgu Stream in Malatya: average, 29.6111; standard deviation, 15.748; distortion coefficient, 0.967041; Kurtosis coefficient, 1.83941. This distribution was deemed normal, and the risk values for the two methods were P(1)=0 for MFOSM, and P(2)=0 for AFOSM.

Name of the dam	**: Surgu Dam.**
Place	: Malatya, Turkey
Purpose	: Irrigation
Flood quantity of project(m^3/s)	: 535.0
Width of spillway (m)	: 33.0
Height of spillway (m)	: 4.0
Number of gates	: 0.0
Name and number of station - DSI	: Surgu S., B. Out (21014), B. Aksis (21091)
Number of observation	: 9
Observation values	: 19.0, 37.0, 23.0, 58.0, 24.0, 23.0, 21.0, 51.0, 10.5,

Method of risk	Risk
MFOSM	P(1)=0.0
AFOSM	P(2)=0.0

RESULTS

By statistical evaluation carried out with use of the observed maximum flows of Kayacik and Surgu dams, parameters to be used in risk analysis were obtained. It was determined which distribution the values yielding these parameters fit, and they were transformed into ready data for MFOSM and AFOSM, which yield results for values that fit normal distribution only.

The results of risk analysis carried out by these methods indicate that the spillways of both of these dams, against the observed overflow values, are all reliable in work mode, and that they can exceed these overflows.

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