Water Resour Manage (2007) 21:747–760
DOI 10.1007/s11269-006-9063-x

ORIGINAL ARTICLE

Reliability in dams and the effects of spillway dimensions on risk levels

Kasim Yenigun · Cevat Erkek

Received: 26 July 2005 / Accepted: 9 June 2006

Abstract A general approach is presented for risk engineering and identification of the risk benefits analysis, goals and limits for risk evaluation in certain applications by considering the first-degree secondary moment methods. A computer program is developed in the Java language (DAM_RISK) with the aim to determine the safety levels of spillways in existing dams (or dams in the planning or construction phase). In consideration of a possible risk, observed overflow values are used, with the purpose of the rehabilitation values that need to be known, thus producing data ready for technical and financial analysis. This program is used to perform risk analysis for the Kürtün and Oymapınar dams in Turkey with the purpose dam rehabilitation at risk. Different spillway dimension and the change in risk for the reservoir damping factors are also presented. The most important conclusion for planners and risk evaluators is the graph that shows the riskless region in spillway dimensions. Various features of the computer program and areas in which it might be further developed are considered in detail. The results of the applications carried out are given in terms of risk evaluations.

Keywords Safety of dams · Risks of dams · Rehabilitation of spillways

1. Introduction

Throughout the world insufficiencies have been observed in dams designed with consideration given to meteorological and hydrological data, which are stochastic in nature, and with multiple purposes in mind. The general importance of safety evaluations in dam engineering is explained in addition to the risk analysis that needs to be performed with the purpose of

---

K. Yenigun (✉)
Department of Civil Engineering, Faculty of Engineering, Harran University, Osmanbey Campus, Şanlıurfa, Turkey
e-mail: kyenigun@hotmail.com, kyenigun@harran.edu.tr

C. Erkek
Department of Civil Engineering, Faculty of Civil Engineering, Istanbul Technical University, Ayazağa Campus, Istanbul, Turkey

Table 1 The causes of failure of dams (Uzel, 1991)

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

examining design of rehabilitation projects. Areas in which inadequacy may affect dams are identified and, of these, spillway safety and capacity are examined.

The continuous observation of dam performance helps to identify any defect that might lead to damage. As early as the very year of he construction, some of these dams have suffered accidents, collapse, or failure to function. 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 (Erkek and Ağıralioğlu, 1986). Thompson *et al.* (1997) presented risk analysis procedures for dam safety evaluation in their work as a complete table.

Various studies on the performance of dams have identified the different risk factors affecting dams, (Cheng, 1993; Vischer and Hager, 1998). Additionally, some human errors and possible sabotages may also endanger the safety of dams.

At times, feasible rehabilitation projects are undertaken. In addition to rehabilitating old dams, these projects can be used as a source of up-to-date information and experience for the planning of new dams, in order to reduce or completely eradicate similar risks.

Of all the reasons for failure, the second most common cause of dam breaks is spillway inadequacy at 23%. In places where large overflow discharges occur, spillway design is more important than the body of the dam. The cost of a large spillway makes up a significant part of the overall cost of the dam (Kite, 1976, Table 1).

The malfunctioning of spillway gates alone has caused damage to a great number of dams. For examples: Euclides Da Cunha Dam (Brasil, 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; Yıldız, 1998).

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 (Şentürk, 1994).

The principal factors in dam breaks are overflows caused by the inadequacy of design discharge and earthquakes. Old dams are found to be unreliable in these respects, and so breaks occur more frequently in them, (Cooper and Chapman, 1993).

The purpose of this study is to determine the factors that may pose a threat to dams and to establish the reliability levels of spillways, evaluating overflows, which are highly significant in terms of dam safety as the effective risk factor. The rehabilitation values are presented where necessary in situations with is a risk. According to Cheng (1993), risk is the probability of failure. Risk is defined in general as the probability of failure.

The following steps are the main points in the proposed method which is still under development:

- Risk Analysis: This analysis begins by defining the risk. In general, there are three types, namely, hydraulic risk, risk stemming from an error encountered in determining the water level in the reservoir.
- 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 found solutions of changes in risk dependent on cases. Although these have decreasing values but the expense of the solutions increases gradually.
- The Decision: In order for the decision-makers to make the correct decision, the following issues, potential loss of life, potential material losses, the probability of dam break, damage to be suffered in the event of a collapse, alternatives arising from economic analysis, modification alternatives must be addressed with thoroughnes (Sungur, 1993; Şentürk, 1988). It may be also helpful to consider the annualized risk for avoiding the isolated effects of risk as probability for a better approach to actual risk levels.

2. Risk analysis

The return period of a given design or a given flood discharge is a function of the risk level that accounts the dam's reliability. The value of this risk is related to the losses that would occur in the event of the exceeding the design flood. If loss of life or significant material damage is foreseeable, it is then necessary to select a small risk in order to achieve necessary protection. Conversely, if the losses that will be incurred are not excessive, a greater risk is acceptable.

Dam safety decisions normally involve many uncertainties, some of which may be large and significant. Such decisions can be made using risk analysis techniques which provide a structured basis for the use of engineering judgement in decision making under conditions of uncertainty.

The results of a risk analysis can be used to guide future investigations and studies, and to supplement conventional analyses in making decisions on dam safety improvements. Such a risk analysis currently provides the best answer available to the question "how safe is our dam?" Once an assessment has been made of the probability and consequences of failure (i.e. risk associated with the dam), standards of acceptable risk are needed to determine if safety improvements are required. With increasing confidence in the results of risk analyses, the level of risk could become the basis of safety decisions (Salmon and Hartford, 1995).

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 (MFOSM) and the advanced first order second moment method (AFOSM), (Yen *et al.*,1986; Tung and Yen, 1993).

For some examples only one reliability computation method is applied to each individual design. However, many problems can be solved by using more than one method. For instance, in designing a large dam, some components and parameters in the fault tree may be computed by using the MFOSM while other components and parameters by using the AFOSM, whereas some simple components and parameters could be solved by direct integration (Yen and Tung, 1993).

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 final design value is determined. One can determine which dams are subject to which type of risks and what kind of reliability behavior, and the risk-security ratios with this behavior can be determined in a realistic manner (Bulu, 1989; Cheng *et al.*, 1993). Of these methods, the two that yield better results are MFOSM and AFOSM, and if we analyze them with short logical analysis then he/she can observe that first degree secondary moment methods are a group of very recently developed, and powerful approaches 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.

3. Methodologies used

In engineering applications, the distributions of variables affecting the load and resistance capacity of structures $f_{X1(X1)}, f_{X2(X2)} \ldots f x_{n+1}(x_{n+1}), \ldots F x_m(x_m)$ 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 (Türkman, 1990).

(a) In the MFOSM, the first degree Taylor series expansion of $z = g(x_i), (i = 1, 2 \ldots m)$ can be is written in terms of averages, $\bar{x}_i$, as

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

The first and second moments of z by ignoring terms higher than the second degree lead to the expected value and the variance as,

$$E(z) = \bar{z} = g(\bar{x}_i) \tag{2}$$

and

$$\mathrm{Var}(z) = \sum_{i=1}^{m} C_i^2 \mathrm{Var}(x_i) \tag{3}$$

and the standard deviation as,

$$\sigma = \left[\sum_{i=1}^{m} (C_i \sigma_i)^2 \right]^{1/2} \tag{4}$$

where σ_z and σ_i are the standard deviations of z and x_i, respectively. In these expressions, the C_i values are partial derivations of $\frac{\partial g(x_i)}{\partial x_i}$ calculated in terms of means $(\bar{x}_1, \bar{x}_2, \ldots, \bar{x}_m)$. These derivations are based on the assumption that variables are statistically independent from each other. On the other hand, risk of failure is defined in probability terms as,

$$P_f = P(z < 0) \ldots P(z > 0) \tag{5}$$

If z has normal distribution, then it can be expressed as,

$$P_f = 1 - \phi\left[\frac{E(z)}{\sigma(z)}\right] = 1 - \phi(\beta) \tag{6}$$

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

$$\beta = \frac{g(\bar{x}_i)}{\left[\sum_{i=1}^{m}(C_i\sigma_i)^2\right]^{1/2}} \tag{7}$$

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, (Bayazıt and Oğuz, 1985). 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 skewness coefficients, and the correction done in the MFOSM method and the $g(.)$ function is determined in terms of the average values, (Türkman, 1990).

(b) The AFOSM, as defined

$$z = g(x_1, x_2 \ldots x_m) \tag{8}$$

gives the way to calculate the performance function by linearizing the z function with the Taylor series expansion, not in the average values, but in terms of a point $x^* = (x_1^*, x_2^*, \ldots, x_m^*)$ on the dam break surface, (Ang and Tang, 1984). The Taylor series expansion for such a point, on the dam break surface can be expressed as,

$$z = g(x_1^*, x_2^*, \ldots x_m^*) + \sum_{i=1}^{m} C_i(\bar{x}_i - x_i^*) \tag{9}$$

where

$$C_i = \frac{\partial g}{\partial x_i} \tag{10}$$

Here, since $z = 0$ is on the break surface, the break point will have the following condition,

$$g(x_1^*, x_2^*, \ldots x_m^*) = 0 \tag{11}$$

The expected and standart deviation values of z can be written as,

$$E(z) = \sum_{i=1}^{m} C_i(\bar{x}_i - x_i^*) \tag{12}$$

and

$$\sigma(z) = \left[\sum_{i=1}^{m} (C_i\sigma_i)^2\right]^{1/2} \tag{13}$$

Furthermore, the z variable's standard deviation σ_z can be expressed as follows,

$$\sigma_z = \sum_{i=1}^{m} \alpha_i C_i \sigma_i \tag{14}$$

where

$$\alpha_i = \frac{C_i\sigma_i}{\left[\sum_{j=1}^{m} (C_j\sigma_j)^2\right]^{1/2}} \tag{15}$$

After the determination of α_i coefficient, one can write,

$$x_i^* = \bar{x}_i - \alpha_i \sigma_i \beta, \tag{16}$$

by placing the limit in the situation equation, β is calculated by trial and error. Hence, the x^*'s on the collapse surface are calculated, after the calculation of α_i's and x^*'s. If β does not change with trials, then the risk is calculated (Bulu, 1989),

$$P_f = 1 - \phi(\beta) \tag{17}$$

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, (Ang and Tang, 1984). If one equalizes the cumulative probabilities at the x_i^* break point, then

$$\phi\left(\frac{x_i^* - \bar{x}_{xi}^N}{\sigma_{xi}^N}\right) = F_{xi}(x_i^*) \tag{18}$$

and hence $\bar{x}_{xi}^N, \sigma_{xi}^N$ are the average and standard deviation of the x_i variable's of the normal distribution. The explanations of different terms are as follows.

$F_{xi}(x_i^*) =$ the original cumulative probability calculated at the x_i^* point
$\phi(.) =$ the cumulative probability of the standard normal variable
$\bar{x}_{xi}^N = X_i^* - \sigma_{xi}^N \phi^{-1}(F_{xi}(X_i^*))$,
$f_{xi}(x_i^*) =$ the original probability density ordinate at the point x_i^*, and
$\phi(.) =$ the standart normal variable probability density ordinate.

From the above equations, one can write that

$$\sigma_{xi}^N = \frac{\varphi\{\phi^{-1}[F_{xi}(x_i^*)]\}}{f_{xi}(x_i^*)} \tag{19}$$

The break surface coordinates are,

$$X_i^* = \bar{x}_{xi}^N - \alpha_i \beta \sigma_{xi}^N$$

and hence,

$$\alpha_i = \frac{C_i \sigma_i^N}{\left[\sum_{j=1}^N \left(C_j \sigma_j^N\right)^2\right]^{1/2}} \tag{20}$$

The remaining procedures are carried out as in MFOSM. (Yen and Tung, 1993)

4. Software implementation

Research carried out to date comprises only individual studies and evaluations of flow observations, or the adaptation of the evaluated values to risk analysis. In contrast to these, the present work combines a number of methods and programs into a single computer program, (Davis, 1996).

The DAM_RISK computer program was developed by the first author in order to determine the following factors of spillways, and dams, in the face of hydraulic and hydrological loads of overflows of various return intervals (Davis, 1996; USBR, 1987)

- Performance
- risk values, and
- suitable dimension rehabilitation.

This program is unique in its structure and can be used as an important evaluation mechanism for dams still in the project phase, as well as those under construction and in operation. The flowchart of DAM_RISK program is given in Figure 1. Currently available programs only take into consideration statistical evaluations. In contrast, the statistical evaluation of observed data related to maximum flows forms only a small part of the planned DAM_RISK program.

In addition to the determination of distribution and alternative overflow parameterization based on the dimensions obtained, risk analysis is used to evaluate risk and reliability for all alternative dimensions. With this program, it is possible,

- to determine the dimensions used in risk analysis based on statistical evaluation, comparison and interpretation of the observed maximum flow data and the suitable statistical distribution; (Owen, 1962).
- to perform realistic risk analysis using methods such as MFOSM and AFOSM,
- to recalculate risk based on new dimensions that will lower the risk value when it is found to be at a certain level,

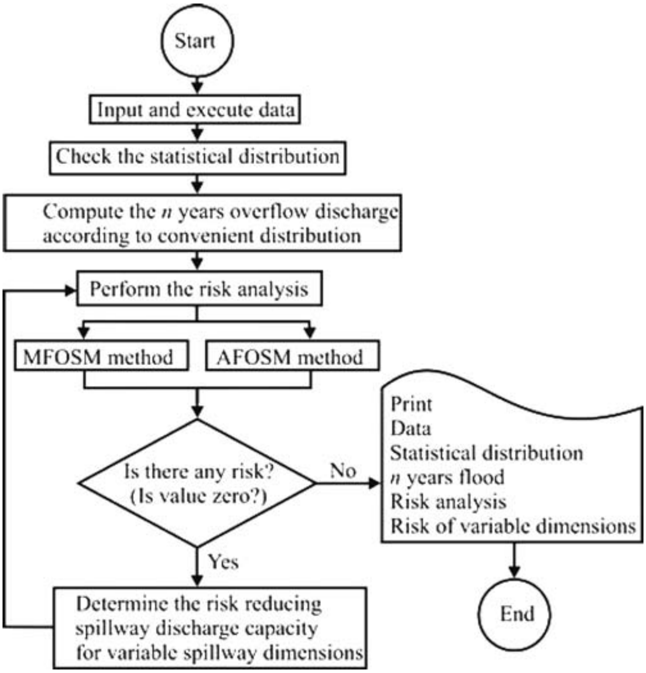


Fig. 1 Flowchart of DAM_RISK program

- to perform this rehabilitation for various dimensions, thus providing data for evaluating the new dimensions in terms of cost analysis and physical feasibility,
- to add new data easily and obtain new results quickly, because it is necessary to use new observation data to reevaluate the behaviors and risk levels of spillways in the event of overflow,
- to observe directly the values of the reservoir damping, which is significant in the determination of risk levels, and the effects of these values on the result, and
- to add new distribution control methods to the section concerned with statistical evaluation of data, which can be considered a subsection of the program, thus achieving more realistic results (Maidment, 1993; Ang and Tang, 1984).

The following information (from State Hydraulic Works – DSI) is entered in the program as input to be used in the output report. These are the name, location and purpose of the dam, the height of the crest, the maximum water elevation, the reservoir damping factor, and the standard deviation of the reservoir damping factor.

With regard to the spillway, the input information is the type of spillway, the threshold elevation, the height of the crest, the projected overflow discharge, the date of the beginning of construction, the date of the beginning of operation, the number of gates, the name and number of the observed station, the duration of evaluation in years, the maximum overflow discharges and the height of the spillway. The program has also the following features.

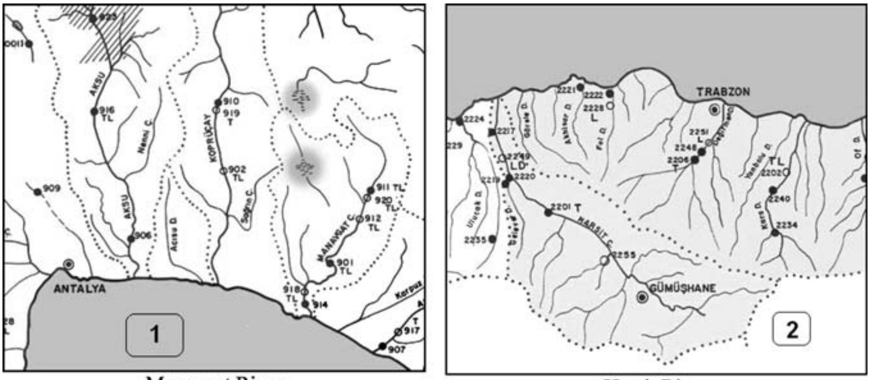
- In the program's output section, result values are recorded in the report file, and general information on the dam is processed in the first section,

- Afterwards, the suitability to statistical distribution of the overflow values given in the input section is checked,
- All statistical parameters found as a result of this checking are entered in the second section of the report,
- Afterwards, making use of the parameters determined based on the distributions found to be suitable, overflow discharges are calculated for 2, 5, 10, 25, 50, 100, 200, 500, 1000, 5000, 10000 and 15000 years, and these values are entered in the third section of the report, (Bayazıt, 1996; Helsel and Hirsch, 1992),
- Afterwards, the dam's risks are determined by MFOSM and AFOSM using the projected discharge. In order to determine the risk with all its parameters, for a situation in which m gates of the spillway do not open, the risks that might have occurred are calculated (if dimensioning had been done based on this discharge) according to the overflow discharge for N years for which risk values have been determined (which may vary as desired), and the results of these calculations are entered in the fourth section of the program. If the spillway is gateless, then calculations are made based solely on the projected discharge and the overflow discharge for n years for which risk values have been determined,
- At this stage, the conditions in which the risk values given in the fourth section of the report (the risks calculated based on the projected discharge and a situation in which the gates do not open) would be zero are evaluated, and if this is the case, a message recorded in the sixth section of the report appears stating that there is no need for rehabilitation of dimensions,
- In the dimension rehabilitation section, which forms the fifth section of the program, the effective spillway width (L) and spillway load (H), which make up the spillway's dimensions, are considered and three separate evaluations made,
- In one of these, width is kept constant, while spillway load is increased in increments of 10 cm and new spillway discharges are thus obtained, and risk is re-calculated based on these discharges. This procedure continues in 10 cm increments until the level at which all risks are zero. These procedures are stated in the first part of the fifth section of the report,
- In the second evaluation, the width is increased while the spillway load is kept constant, and the same cycle is tested for the new situation. The resulting values of this procedure are recorded in the second part of the fifth section of the report,
- In the third evaluation, L and H values are increased in equal proportion (10 cm) and risk is calculated based on the new discharge thus created, and the dimensions that reduce the risk to zero are determined,
- At the end of the rehabilitation procedures, the second part of the sixth section of the report appears on the screen, and the cost analysis is stated for the conditions in which the projected new dimensions are applied. In this cost analysis, physical feasibility is as important as evaluation of the dam's production input and life span, and the damage that will occur in the event of the specified risk.

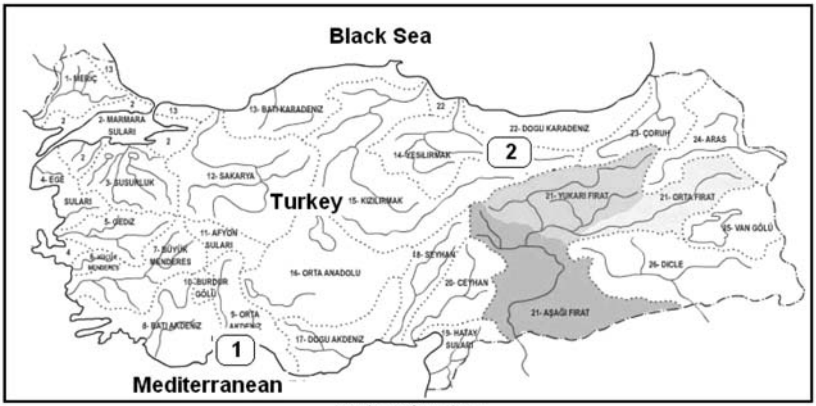
In this study, the observed maximum flow values were obtained and an attempt was made to determine their fitness to normal distribution for Kürtün and Oymapınar Dam.

The parameters obtained were subjected to risk analysis by MFOSM and AFOSM, with the aid of a program prepared in the JAVA programming language, and an attempt is made to determine the reliability of the spillways of these dams. The reason for adopting the JAVA language is due to its visual quality, fast running in web media, and the easiness in arranging various subroutines in an effective system.

By statistical evaluation carried out with use of the observed maximum flows of those two dams, parameters to be used in risk analysis are obtained. It is determined which distribution



Manavgat River Harşit River



Basins of Turkey

Fig. 2 Location map of study area

the values yielding these parameters fit, and they are transformed into ready data for MFOSM and AFOSM, which yield results for values that fit normal distribution only (DSİ, 1990; Kulga and Dizdar, 1994; Önöz and Bayazıt, 1995; Vogel, 1986; Vogel and Wilson, 1996).

5. Application to Kürtün and Oymapınar dams

The geographic location of Kürtün and Oymapınar Dams are shown in Figure 2. The Kürtün dam has risk values of zero in the event of an overflow based on the maximum observed flow values, both in risk analysis based on the projected overflow discharge and in a situation in which one or even two of the spillway gates are closed. Kürtün dam specifications are given in Table 2.

However, for the Oymapınar Dam, the results of MFOSM analysis indicate that if two of the spillway's four gates are closed, the risk value is 0.0001, and if three are closed then it is 0.3745. AFOSM risk analysis did not yield any risk value for this dam (DSİ, 1980). Oymapınar specifications are presented in Table 3.

As a result of dimension rehabilitation carried out for these dams, risk values are found. The risk becomes zero if dimensioning is performed according to the data determined by the program.

Table 2 Risk analysis results for Kürtün Dam

Name of dam	Kürtün Dam	
Place	Harşit River, Gümüşhane, Turkey	
Purpose	Hydroelectric power	
Flood quantity of project (m3/sn)	3775	
Width of spillway (m)	30	
Height of spillway (m)	11,6	
Number of Gates	3	
Name and number of station	Kürtün Stream, Ahırlı, 14014-DSİ	
Number of observation	27	
Statistics of observation values	Average	78,5185
	Standard deviation	71,3798
	Distortion coefficient	1,7838
	Kurtosis coefficient	6,11824
Method of risk	Value of risk	
Risk for MFOSM	0	
Risk for AFOSM	0	

Nonetheless, even when the risk is numerically determined to be zero, the risk never completely disappears. This point must be taken into consideration in every application carefully. It must not be forgotten that the data used in the calculation are stochastic in nature, particularly hydrologic and meteorological data, and thus the observed values may change over time.

The reservoir damping factor (S), which is a function of the reservoir volume at normal water level versus the reservoir volume at maximum water level, is extremely important in both MFOSM and AFOSM for determination of risk value. All input and output datas are given in Tables 2 and 3. Thus it is clear that the risk values will be affected significantly not only by dimension rehabilitation, but also by changes made in the reservoir damping factor, which is closely related to the operation mode of the dam and the type of spillway. This factor is important in obtaining preliminary information for use in future studies. The changes in risk value caused by the reservoir damping factor are shown in Figure 3 for the Oymapınar Dam.

For the same dam, a different graphic evaluation can easily be carried out for some of the risks obtained showing different dimensions that yield the same risks. Thus, it is clear that effective data can be obtained in cost analysis for any dimension rehabilitation project.

In the risk analysis carried out for the Oymapınar Dam, it is possible to see which of the different dimensions are effective in the decreasing risk values of 0.3745, which is found if three of the spillways are closed (see Figure 4).

The planned DAM_RISK program will process the observed maximum flow statistically, using these to calculate the reliability performance and risk value of dams in the face of the overflow value that may occur, and determining suitable dimension rehabilitation that may be proposed in situations where risk occurs, thus rendering the rehabilitation ready for technical and financial analysis.

This program can be used as an important evaluation mechanism for dams still in the project phase, just as it can determine risk values for dams under construction and in operation, based on observed flow values. Thus a dam can undergo revision as necessary while still in the planning stage.

Moreover, the fact that the rehabilitation is included in the same program provides rapidity and ease of use. In short, the program not only determines the dam safety level, but also indicates how the dam can be made safer.

Table 3 Risk analysis results for Oymapınar dam

Name of dam	Oymapınar	
Place	Manavgat Stream, Antalya, Turkey	
Purpose	Hydroelectric power	
Flood quantity of project (m3/sn)	3100	
Width of spillway (m)	28,2	
Height of spillway (m)	15	
Number of Gates	4	
Name and number of station	Manavgat I., Homa, 9901-EİEİ	
Number of observation	44	
Statistics of observation values	Average	704.418
	Standard deviation	211.348
	Distortion coefficient	1.88508
	Kurtosis coefficient	3.75862
Method of risk	Value of risk	
Risk for MFOSM	1 gate closed	0
	2 gates closed	0,0001
	3 gates closed	0,3745
Risk for AFOSM	1 gate closed	0
	2 gates closed	0
	3 gates closed	0

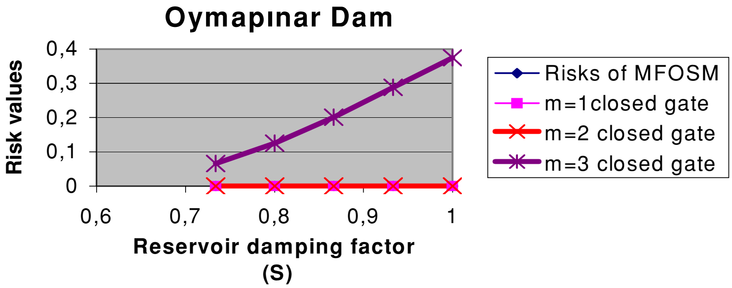


Fig. 3 The changes in risk value caused by the reservoir damping factor for the Oymapınar Dam with MFOSM

In order to demonstrate the practicability of this program, applications are carried out with the real observed values of certain dams and the results obtained from these are already shown above.

A diagram with the obtained dimensions shows the safety evaluator as the numerically riskless region, which comprises the most suitable dimension values based on the characteristics of the location of the dam and the technical and financial considerations of the precautions to be taken.

With developments such as distant perception techniques, which are currently gaining importance, the flow observations, which are a fundamental part of real-time operations, can be directly monitored and evaluated by computer, and with the current risk values obtained in this way, as well as with the early warning system, emergency intervention, risk and safety evaluation, it is possible to achieve a significant degree of personal safety and financial security. The DAM_RISK program is designed to be suitable for the entering of such data, and safety values can be constantly updated with ease and rapidity.

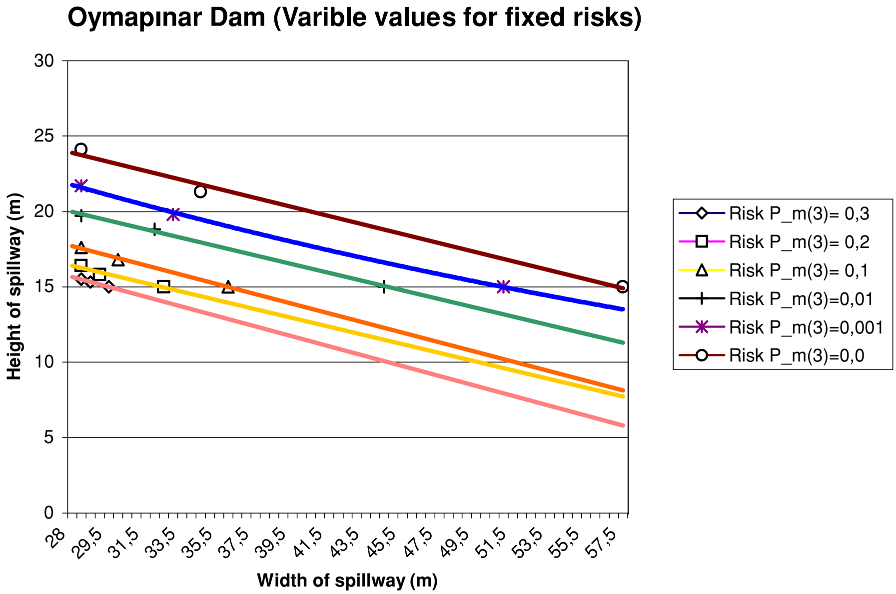


Fig. 4 Changing of the dimensions of Oymapınar Dam's spillway which are giving the same risk values with MFOSM

6. Conclusions

Convenient software, DAM_RISK, is developed for the assessment of dam risks, which is capable of providing fast and reliable service for specialists who are processing the maximum overflow values that will be observed throughout the life of the dam and who are performing the risk analysis. Such software is useful for the academician, persons responsible in research and planning studies, project designers, and for private and public groups managing the operations.

This program will process incoming data, will allow statistical analysis, and will be flexible with regard to risk methods used and the use of different versions of these methods (the risk when different numbers of spillways are in use, the risk of different spillway dimensions, etc.). Because of this ease of use, the program is flexible in structure, adapting easily to rehabilitation and modifications, and thus will provide long-term service.

With this program, the rehabilitation carried out with the purpose of reducing potential risk is based on changes in spillway dimensions and on the reservoir damping factor, which is determined by the reservoir operation level, and is open to researching the type and size of alternative factors to be used in a similar risk reduction projects.

References

Ang AHS, Tang WH (1984) Probability concepts in engineering planning and design, vol 2, decision, risk and reliability. John Wiley and Sons Inc, USA

Bayazıt M, Oğuz B (1985) Statistics for engineers, Birsen Publ, Istanbul, Turkey (in Turkish)

Bayazıt M (1996) Probability methods in civil engineering. Istanbul Technical University, Print of Civil Engineering Faculty, Istanbul, Turkey (in Turkish)

Bulu A (1989) Risk analysis of dams. Mediterranean University, Isparta, Turkey. J Isparta Eng Faculty 4:19–29 (in Turkish)

Cheng ST (1993) Statistics of dam failures, reliability and uncertainty analyses in hydraulic design. ASCE, New York, USA, p 97

Cheng ST, Yen BC, Tang WH (1993) Stochastic risk modeling of dam overtopping, reliability and uncertainty analyses in hydraulic design. ASCE, New York, USA, p 123

Cooper DF, Chapman CB (1993) Risk analysis for large projects. John Wiley and Sons, USA

Davis SR (1996) Learn JAVA now, Microsoft Press, USA

DSİ (1980) Report of Oymapinar dam. Publication of DSI, Ankara, Turkey (in Turkish)

DSİ (1990) Frequency atlas of maximum precipitation in Turkey. Publication of DSI, Ankara, Turkey (in Turkish)

Erkek C, Ağıralioğlu N (1986) Engineering of water resources. Technical Books Pub, Istanbul, Turkey (in Turkish)

Helsel DR, Hirsch RM (1992) Statistical methods in water resources. Elsevier Pub, USA

Kite GW (1976) Frequency and risk analyses in hydrology, Inland waters directorate. Water Resources Branch, Applied Hydrology Division, Network Planning and Forecasting Section, Ottawa, Canada

Kulga Z, Dizdar M (1994) Proceedings of frequency analysis of maximum discharges. Publication of DSI, Ankara, Turkey (in Turkish)

Maidment DR (1993) Handbook of hydrology. McGraw-Hill, Inc, USA

Önöz B, Bayazıt M (1995) Best-fit distributions of largest available flood samples. J Hydrol 167:195–208 (USA)

Owen DB (1962) Handbook of statistical tables. Addison-Wesley Publishing Company, USA

Salmon GM, Hartford DND (1995) Risk analysis for dam safety. International Water Power and Dam Safety 47(3) (UK)

Şentürk F (1988) Hydraulics criteria for design of dams. DSI Publ, Ankara, Turkey (in Turkish)

Şentürk F (1994) Hydraulics of dams and reservoirs. Water Resources Pub, USA

Thompson KD, Stedinger JR, Heath DC (1997) Evaluation and presentation of dam failure and flood risks. J Water Resour Plan Manag 123(4):216–227

Tung YK, Yen BC (1993) Some recent progress in uncertainty analysis for hydraulic design, reliability and uncertainty analyses in hydraulic design. ASCE, New York, USA, p 17

Türkman F (1990) Identification of risk and reliability of water structures. The Seminar of Water Engineering Problems, DSİ TAKK, Ankara, Turkey (in Turkish)

USACE (1990) Hydraulic design of spillways, engineer manual, no 1110-2-1603. Department of the Army, US Army Corps of Engineers, Washington, DC 20314-1000, USA

USBR (1987) Design of small dams. Water Resources Technical Pub, USA

Uzel T (1991) Barajların Güvenliği. Doğan Publ, Istanbul

Vischer DL, Hager WH (1998) Dam hydraulics. John Wiley and Sons Pub, USA

Vogel RM, Wilson I (1996) Probability distribution of annual maximum, mean, and minimum streamflows in the United States, ASCE. J Hydrol Eng 1(2) (USA)

Vogel RM (1986) The probability plot correlation test for the normal, lognormal and Gumbel distributional hypotheses. Water Resour Res 22(4):587–590 (USA)

Yen BC, Tung YK (1993) Some recent progress in reliability analysis for hydraulic design, reliability and uncertainty analyses in hydraulic design. ASCE, New York, USA, p 35

Yen BC, Cheng ST, Melching CS (1986) First order reliability analysis, stochastic and risk analysis in hydraulic engineering. Water Resources Pub Littleton, USA, p 1

Yıldız D (1998) Safety of dams and spillways. Journal of Turkey Engineering News N393, Istanbul, Turkey (in Turkish)