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ITJ

ISSN 1812-5638

# INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 12 (23): 7651-7655, 2013
ISSN 1812-5638 / DOI: 10.3923/itj.2013.7651.7655


# Reliability Optimization of Barrier Lake Disposal Based on Engineering and Cost

Wang Shaoyu, Li Qiang, Huang Xing, Bai Hua and Jia Jing
Department of Management of Technology, School of Architecture,
Harbin Institute of Technology, People Republic of China, Konkuk University, Korea, China

**Abstract:** To improve the ability of risk disposal of major barrier lakes, the research on reliability of barrier lake disposal was carried on. Through the analysis of basic characteristics on barrier lake disposal and the assessment on optimal reliability of disposal system, series-parallel logical structure was proposed to improve the reliability. And then the optimal reliability for series-parallel system of composition unit and disposal system was proposed in the progress of project and the constraint of economic cost. In comprehensive consideration of importance and complexity of the distribution unit, first optimized system unit which did not meet the expected reliability index was optimized again to improve the disposal system reliability and this provide a reference for disposal of major barrier lake in the future.

**Key words:** Barrier lake, risk disposal, system reliability, optimization

## INTRODUCTION

Dammed lake is a natural dam of horizontal obstruction valley causing the upstream segment backwater. And the natural dam is formed by volcanic eruption, landslide, debris flow, glacier debris and so on. Typically, due to rapid accumulation, the dam is relatively loose. It is prone to dam failure in the current rush which makes the downstream people's lives and property suffered heavy losses. The key of dammed lake disposal is security and rapid. Therefore, in order to reach the dammed lakes disposal optimization of the project progress and the time control, the barrier lake disposal system of high reliability and stable operation was needed to ensure the smooth progress of the major dammed lake disposal.

In the evaluation of dammed lake risk dispose, Mandrone *et al*. (2007) studied drainage danger and rescue effects For the landslide damming body and damming size of dammed lake disposal. Liu, 2008. thought that the dammed lake disposal should be based on a comparison of the costs and benefits principle and the lowest cost and shortest process, the benefits of security risk management program should be chosen. By analyzing the breach parameter selection dam break flood characteristics, including the sensitivity between flood propagation time,Chauhan *et al*. (2004) studied the key role of dam stability in the dammed lake disposal. Zhang (2009) focused on the economic and environmental benefits assessment of dammed lake risk management and disposal. These researches for barrier lake risk disposal evaluation to a large extent provided the basis of theory and practice but there was little study from the point of view to the reliability on project and cost control. Therefore, the introduction of reliability theory to the risk disposal of barrier lake, firstly demonstrated the series and parallel logic structure which will help improve the system reliability, on the basis of analysis of the operating characteristics of the major barrier lake disposal system and then studied the optimization problems of major barrier lake disposal system reliability in the project schedule and cost constraints and finally optimized again reliability and allocation for the unit does not meet the system requirements, to ensure the reliability of a major barrier lake disposal (Li *et al*., 2013).

## RELIABILITY LOGIC DIAGRAM

**Reliability diagram:** Defined on the system reliability, there are some certain differences among different majors. In general, these definitions are concentrated in the inspection system, which are under the specified conditions and within the prescribed period of time to complete the required function ability, which can be measured by the reliability. The disposal of barrier lake is composed of unit, according to the certain connection mode of organic composition, connected in different ways, the unit on the reliability of the whole system has different effects. Therefore, to study the reliability of the whole system, first need to identify the logic structure in

**Corresponding Author:** Li Qiang, Department of Management of Technology, School of Architecture, Harbin Institute of Technology, People Republic of China, Konkuk University, Korea, China Tel: 0086-451-86400206

reliability system of the disposal. According to the task analysis from the system, The barrier lake disposal mainly consists of three parts, which form two unit (subsystem) in the entire system, each with a unit is composed of several components (nodes), in practice, the system of units and components are in different ways to achieve the same task the system reliability is also different (Cai *et al*., 1991).

From the structure of barrier lake disposal, there are two kinds of system composition can achieve the relief supplies from raising money to eventually rescuing point distribution. One is associating some enterprises, which produce the similar production in enterprise production subsystem, with designated distribution center and aid station to consist of several integrated emergency supply chains. Then make the chains together in parallel and give a clear input and output interface to form an independent series-parallel structure of the system block diagram. (Singer, 1990)

The other is making the enterprise nodes which are in enterprise production subsystem, distribution center nodes which are in distribution system and salvage nodes respectively together in parallel, then gives a clear input and output interface, each subsystem are connected in series and forming a complete parallel-series structure block diagram of the system.

These two kinds of system structure, to a certain extent, can realize the relief material market acquisition. But two kinds of system reliability and component reliability will be different, this is the problem needs to be solved before the system optimization. Namely, to choose what kind of system structure diagram can ensure the reliability of barrier lake disposal (Dai and Da, 2000).

**Reliability of series parallel system reliability:** When all the parts in hybrid system are in the mutual independence and known each component's reliability, you can write series-parallel system reliability formula with the series system and parallel system only according to the parallel-series system reliability block diagram. If the disposal of barrier lake is the series-parallel system, given the system is connected in series with the independent working class n subsystem. Among them, the i level subsystem is consisted of $m_i$ independent components each other, components reliability is $R_{ij}(i = 1, 2,\ldots, n; j = 1, 2,\ldots, m_i)$ may have series-parallel system reliability:

$$R = \prod_{i=1}^{n}\left\{1-\prod_{j=1}^{m_i}\left[1-R_{ij}\right]\right\} \quad (1)$$

**Parallel-series system reliability:** It is supposed that the system is consisted of by i level subsystem of independent work each other. Among them, the i level subsystem is consisted of by $m_i$ string components, it is supposed that components reliability is $R_{ij}(i = 1, 2,\ldots, n; j = 1, 2,\ldots, m_i)$, may have Parallel-series system reliability:

$$R = 1\text{-}\prod_{i=1}^{n}\left[1-\prod_{j=1}^{m_i}R_{ij}\right] \quad (2)$$

**Determination of reliability logic structure:** To choose appropriate structure of barrier lake disposal, it needs to compare with series-parallel system and parallel-series system. Figure1 block diagram of system is a typical component redundancy system, while parallel-series system is a subsystem redundancy system; we need to make an overall reliability comparison with the two categories to select the series-parallel systems with component redundancy, or the parallel-serial system with subsystem redundancy, as market acquisition system structure of relief materials. From the point of view of emergency management, the disposal of barrier lake with every subsystem's efficient cooperation, can complete predetermined tasks, therefore, the entire system should possess the high reliability. It is supposed that $R_1(t)$, $R_2(t)$ represent the reliability of series-parallel system and parallel-series system. There is:

$$R_1(t) = \prod_{i=1}^{n}\left[1-(1-R_i(t))^2\right] = \prod_{i=1}^{n}\left[1-F_i^2(t)\right] = \prod_{i=1}^{n}[1-F_i(t)]\prod_{i=1}^{n}[1+F_i(t)] \quad (3)$$

$$R_2(t) = 1-\left[1-\prod_{i=1}^{n}R_i(t)\right]^2 = \prod_{i=1}^{n}R_i(t)\left[2-\prod_{i=1}^{n}R_i(t)\right] = \prod_{i=1}^{n}[1-F_i(t)]\left[2-\prod_{i=1}^{n}[1-F_i(t)]\right] \quad (4)$$

Take notice of:

$$\prod_{i=1}^{n}[1+F_i(t)] = 1+\sum_{i=1}^{n}F_i(t)+\sum_{1\le i\le j<n}F_i(t)F_j(t)+\ldots+\prod_{i=1}^{n}F_i(t) \quad (5)$$

$$\prod_{i=1}^{n}\left[1-F_i(t) = 1-\sum_{i=1}^{n}F_i(t)+\sum_{1\le i\le j<n}F_i(t)F_j(t)+\ldots+(-1)^v\prod_{i=1}^{n}F_i(t)\right] \quad (6)$$

So:

$$\prod_{i=1}^{n}[1+F_i(t)]-2+\prod_{i=1}^{n}[1-F_i(t)] > 0 \quad (7)$$

So, there is $R_1(t)\text{-}R_2(t)>0$, it is shown that redundant components better than subsystem redundancy, namely series-parallel system logic structure is superior to parallel-series system. Therefore, in the disposal of barrier lake, it is beneficial to improve overall system reliability in accordance with series-parallel structure (Cooman, 1996).

## UNDER CONSTRAINT CONDITIONS

**Constraint of progress:** The progress of project is the amount of unit time for completion, expressed by curve of the progress level. The curve reflects the level of fluctuations. In the process of disposal, time is the primary index in optimization of system reliability. However, it has no sense to separately assess it and the progress of project which can accurately measure the reliability must be combined. On the subsystem of risk disposal, it mainly studies the relationship between the reliability and unit time of project. The unit reliability refers to the various subsystems at set time or set conditions; it provides project volume that remains at an allowable deviation probability in a prescribed range. The curve is expressed as the actual project level (versus time curve) of the various subsystems; two dotted lines indicate the allowable deviation. Here the project level curve is on the basis of the various subsystems given statistical data in different time, different subsystems have different curves. Here for discussion, uniform rules $D_i(t)$ for a theoretical curve (Wang and Tan, 1990).

where, $q_1$, $q_3$ are looked as the upper limit of the lower limit of deviation, $q_2$ is the expected curve within the time, $D_i(t)$ is the actual curve, which is represented by the level cure, meanwhile the level cure would be change to follow the time. The point $B_1$ is the lowest deviation point in time $(t_1, t_2)$ and the point $B_2$ is the highest deviation point in time $(t_3, t_4)$. Although, the level fluctuation of two time sessions is beyond the prescribed scope, both have essential difference, the level curve of $(t_1, t_2)$ is less than the minimum fluctuation curves $q_3$, it indicates that the level of $q_3$ is insufficient and a low reliability performance of subsystem; The level cure of $(t_1, t_4)$ is beyond the fluctuation upper limit but it belongs to the level excess and it, belongs to the category of the subsystem high reliability, is also an expectation cure under certain conditions but it is not concerned by this study. The paper only concerns the $(t_1, t_2)$, which is regarded as the level shortage of subsystems. Now investigation the area B, which is formed by $D = q_3$ cure and $(t_1, t_2)$, calculating the area B, it is supposed that $D_i(t)$ is continuous and integral inside $(t_1, t_2)$, then:

$$B = \int_{t_1}^{t_2} D_i(t)dt \tag{8}$$

The subsystem reliability, which based on volume within the $(t_1, t_2)$ is:

$$R_m = 1 - \frac{\int_{t_1}^{t_2} D_i(t)dt}{2 \times q_3 \times (t_2 - t_1)} \tag{9}$$

Among them, the calculation method of :

$$\int_{t_1}^{t_2} D_i(t)dt$$

is split $(t_1, t_2)$ into several units time and then counts the integral sum of each component, which might exceed the minimum fluctuation range. Now improving Eq. 9 to become to a function equation between reliability $R_m$ of each subsystem and volume $Q_I$:

$$R_m(Q_i) = 1 - \frac{\int_{t_i}^{t_j} D_i(t)dt}{2 \times Q_i \times (t_j - t_i)} \tag{10}$$

Or:

$$Q_i(R_m) = \frac{2Q_i(t_j - t_i) - \int_{t_i}^{t_j} D_i(t)dt}{2R_m(t_j - t_i)} \tag{11}$$

So, reliability optimization problem, which based on constraint of the volume, can be expressed as a problem of mathematical programming to solve the value of $R_1$, $R_2$,..., $R_m$, under constraint of total volume Q and zade total reliability meet:

$$\begin{cases} \max \prod_{i=1}^{m} R_m = R^{\circledast} \\ s.t. \sum Q_i = Q \end{cases} \tag{12}$$

Then made Eq. 11 into the constraint conditions of Eq. 12 and took logarithm to the objective function:

$$\begin{cases} \sum_{j=1}^{J} \ln R_m = \ln R \to \max \\ s.t. \sum_{j=1}^{J} \frac{2Q_i(t_j - t_i) - \int_{t_i}^{t_j} D_i(t)dt}{2R_m(t_j - t_i)} = Q \end{cases} \tag{13}$$

Took Lagrange function:

$$L, R_1, R_2, ..., R_m, \lambda) = \sum_{j=1}^{J} \ln R_m + \lambda \left[ Q - \sum_{j=1}^{J} \frac{2Q_i(t_j - t_i) - \int_{t_i}^{t_j} D_i(t)dt}{2R_m(t_j - t_i)} \right] \tag{14}$$

From:

$$\frac{\partial L}{\partial R_m} = \frac{1}{R_m} + \frac{\lambda\left[2Q_i(t_j - t_i) - \int_{t_i}^{t_j} D_i(t)dt\right]}{2R_m^2(t_j - t_i)} = 0$$

Gets:

$$R_m = \frac{\lambda\left[\int_{t_i}^{t_j} D_i(t)dt - 2Q_i(t_j - t_i)\right]}{2(t_j - t_i)} \quad (15)$$

Made Eq. 15 into the constraint conditions of Eq. 13 and gets:

$$\lambda = -\frac{m}{Q} \quad (16)$$

In Eq. 16, m is expressed as the unit number, let Eq. 16 into Eq. 15 and gets:

$$R^{\otimes} = \prod_{i=1}^{m} R_1 R_2 ... R_m \quad (17)$$

Where:

- **$Q_i$:** Each subsystem expected minimum volume, which can be calculated to accord to emergency demand before collection
- **($t_j$, $t_i$):** Expressed as a difference from the starting time to finishing time of operation of each system unit
- **$D_i(t)$:** Fitting level curve of volume to accord to the actual value of volume at per unit time

According to Eq. 17 can get the value of $R_1, R_2, \ldots, R_m$ that is expressed as the optimum reliability:

$$\text{s.t.} \sum_{j=1}^{J} C_j(R_j) = C \quad (18)$$

**Constraint of cost:** Barrier lake disposal is an important content in emergency management, which has the advantages of timeliness and weak economy. But emphasizing timeliness is not ignored the importance to the economy, in the guarantee time priority premise, we must pay great attention to control the cost. Therefore, with the exception of volume to reflect the reliability the cost is the important index of reliability evaluation. Generally speaking, according to the emergency demand, it is prior to expect the way of various market total costs. After confirming the total cost, we can inspect the optimization reliability and system reliability of each subsystem to control of the cost of market collection and provide the evidence to improve the system reliability. And then it can achieve the purpose of promptly improving the system (Tanaka *et al*., 1983).

Now given the total costs and solved the reliability of each unit, made the total reliability:

$$R^* = \prod_{j=1}^{J} R_j \to \max$$

And met:

$$\text{s.t.} \sum_{j=1}^{J} C_j(R_j) = C \quad (19)$$

Among them, C for a given overall costs. Here the function equation, which is used to describe the reliability of engineering structure and mechanical devices, is introduced:

$$R_j(C_j) = 1 - e^{-\alpha_j/(c/\beta_j - 1)} \quad (20)$$

Or:

$$C_j(R_j) = \left[1 - \frac{1}{\alpha_j}\ln(1 - R_j)\right]\beta_j \quad (21)$$

where, parameters $\alpha_j$ is the dimensionless quantity and $\alpha_j$ decided to the trend of the function curve. When system units $R_j \to 0$, parameters $\beta_j$ is the system cost. Now makes Eq. 21 into the constraint function of Eq. 19 and gets the following mathematical programming problem:

Solving the reliability $R_1, R_2, \ldots, R_m$ of each unit and making the logarithm of the system total reliability:

$$\ln R = \sum_{j=1}^{J} \ln R_j \to \max$$

And meets:

$$\sum_{j=1}^{J}\left[1 - \frac{1}{\alpha_j}\ln(1 - R_j)\right]\beta_j = C \quad (22)$$

Also, took Lagrange function, solving partial derivative of and taking extreme value, tiding and gets:

$$R_j = \frac{\alpha_j}{\lambda\beta_j + \alpha_j}(j = 1, 2, \ldots, J) \quad (23)$$

Make Eq. 23 into the Eq. 19 and gets:

$$\sum_{j=1}^{J} \frac{\beta_j}{\alpha_j} \ln\left(\frac{1}{1 + \frac{\alpha_j}{\lambda\beta_j}}\right) = \sum_{j=1}^{J} \beta_j - C \quad (24)$$

According to Eq. 23, now references the method of literature [10] and gives directly simple the method:

$$\bar{R}_j = \frac{\bar{R}_j}{b_{ji} + (1 - b_{ji})\bar{R}_i} \qquad (25)$$

Where:

$$\bar{R}_j = 1 - R_j \qquad (26)$$

$$b_{ji} = \frac{1}{\alpha_{ji}} \qquad (27)$$

And then by Eq. 23:

$$\bar{R}_1 = \prod_{j=2}^{J} \left[ \frac{\bar{R}_i}{b_{ji} + (1 - b_{ji})\bar{R}_i} \right]^{\alpha_{j1}} = e^{-\frac{\alpha_1}{\beta_1}(C - \sum_{j=1}^{J} \beta_J)} \qquad (28)$$

At present, there are many existing mature numerical methods can be used to solve the nonlinear equations of Eq. 28 and gets the value of $\bar{R}^*_1$, then according to the Eq. 26 to work out $R^*_j (j = 1, 2,\dots, J)$. The following with the literature [10] of examples to explain the optimization process of system reliability under the costs given (Mirsa and Soman, 1995).

## CONCLUSION

The reliability research of barrier lake disposal is the important work to establish the emergency management system and information system; it is also a problem should be solved in improving China's disaster relief management system:

- Analyzed the logic structure of barrier lake disposal and got $R_1 > R_2$ by comparing parallel-series system reliability and series-parallel system reliability, it indicated that the reliability of barrier lake disposal could be improved by increasing Parts redundancy
- The disaster emergency characteristic determined the barrier lake disposal, its reliability index is mainly measured by level and cost control under the time restrained. To inspect the constraints of the reliability, this paper studies the system in engineering and total cost of the unit under the constraint of reliability allocation and overall system reliability optimization problem
- Under the constraint conditions to complete the initial optimization of the system unit, if the system reliability and unit reliability do not reach a predetermined task requirements, it also need to do further analysis. Combined with characteristics of barrier lake disposal, put forward the reliability optimization method basing on the unit importance and complexity of system, redistribute the low reliability units in system and provide a theoretical basis to ensure the whole system reliability stability and coordination

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