International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-8 Issue-10, August 2019

Confidence-Based Assessment of Safety of Irrigation Reservoir in Vietnam

Lan Huong Nguyen, Quang Hung Nguyen

***Abstract**: Recently, in Vietnam deterministic design method has been applying for assessment of dam safety which confidence for the works and the headworks are not quantified. Under this study audience are introduced to the number of existing dams in Vietnam and relevant studies on confidence in the field of irrigation. The authors have applied theories of irrigation works, the theory of statistical probability and the theory of system analysis in developing algorithms for assessment of confidence level II for irrigation reservoir headworks in conditions in Vietnam. Based on detailed algorithms and block diagrams, the authors have built program for design of safety probability for incident mechanisms for individual works and the entire system of Phu Ninh reservoir in Quang Nam province. Analysis of the influence of random variables on individual incident mechanisms, the impact of incident mechanisms on the confidence of the works and the level of effect caused by the works on the overall confidence of the system brought the authors about solutions that improve the confidence of the system in case of new design or system repair.*

***Keywords**: problem tree, random variable, function of confidence, confidence, safety probability.*

I. INTRODUCTION

Vietnam is a country with developed agriculture, and dams play an important role in the socio-economic development in the country, and provide good contributions to sustainable water resources development. As of the end of 2017, Vietnam has about 6886 irrigation reservoirs and hydropower plants, of which most dams for irrigation reservoirs are earth dams, built in the 70-80s of the last century, therefore the quality of the works are not equal, resulted in many problems during the construction and operation, threathened the safety of the works and damaged the downstream area. Therefore, it is necessary to reassess the safety of the reservoir headworks against applicable standards and find out appropriate solutions to improve their confidence of safety [1]. Recently, random design methods and confidence standards have been included in the design standards of advanced countries, such as: Russia, China, Japan and some European countries, while in Vietnam the deterministic design method are applicable. Since the 1960s, the theory of confidence has been known and studied in Vietnam, however, until early 2000s it has been applied in practice. There have been many scientific researches on confidence in the field of irrigation: dike systems and bank protection works, open sluices, canals and on-canal structures, researches on confidence of dam safety. However, studies on the confidence of reservoir system have been less mentioned. For those reasons, this article serves as good introduction on how to use the theory of confidence in establishment of design models of confidence for works and reservoir headworks system, thereby applying the theoretical results in assessment of confidence of Phu Ninh reservoir system in Quang Nam province and making recommendations to improve the confidence of the system.

Manuscript published on 30 August 2019.
***Correspondence Author(s)**
Lan Huong Nguyen, Thuyloi University, Hanoi, 100000 Ha noi, Vietnam.
Quang Hung Nguyen, Thuyloi University, Hanoi, 100000 Ha noi, Vietnam.

II. THEORY

A. Simulation of system problems in the form of problem tree

It's considered that failures are the cause of the works problem, a system problem is caused by many reasons and these reasons are listed in the shape of a tree, called a problem tree. Fig. 1 is an example of a problem tree of a reservoir system working on a coupling scheme. At the connecting points the words "or ", " and " show the linkage of problems in the same works, the word " or " represents the serial link, the word " and " represents a parallel link

B. Establishment of function of confidence of problem mechanism

Each problem mechanism as illustrated in Fig. 1 shall establish a function of confidence Z to represent relationship between load bearing capacity and load on the works [1-3].

$$Z = R(x_i) - N(y_j) \quad (1)$$

In which: $N(y_i) = N(y_1, y_2, ..., y_n)$ is the function of load; $R(x_i) = R(x_1, x_2, ..., x_n)$ is the function of load bearing capacity.

x_i : are the basic random variables, including: effects of water environment, soil and rock environment, works environment that create the resistance against the destruction of works.

y_i : are the basic random variables, including: impacts of water environment, effects of the ground environment through the properties of soil and rock as well as the loads arising from the works environment through the properties of building materials.

$x_i, y_i, R(x_i), N(y_i), Z$ are random variables and random functions which probability distribution law is defined in section 2.3.

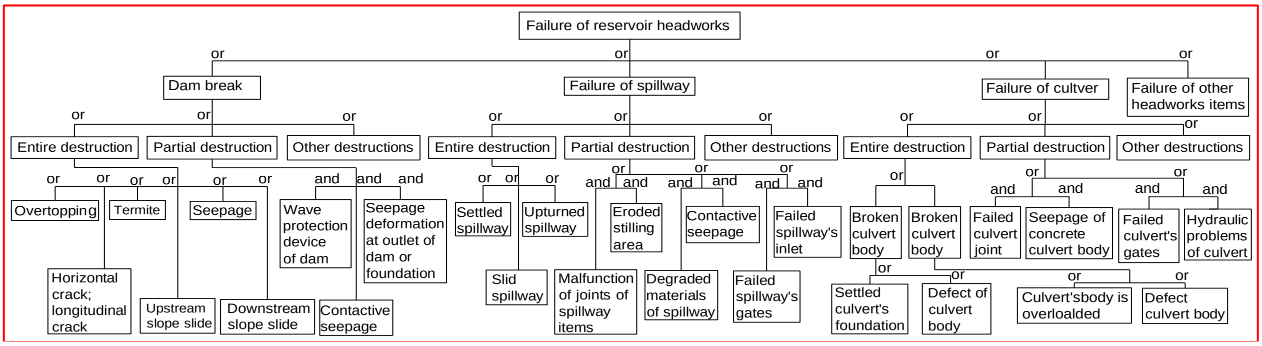

Fig. 1. Diagram of problem tree of reservoir headworks [3]

C. Confidence of problem mechanism of level II

1) Function of confidence Z is linear, random variablese $X_1, X_2, X_3, ..., X_n$ *follow the standard distribution law [4]:*

$$Z = a_1.X_1 + a_2.X_2 + a_3.X_3 + ... + a_n.X_n \qquad (2)$$

In which: a_i - Constant.

- Expectation of function Z: $\mu_Z = \sum_{i=1}^{n} a_i.\mu_{Xi}$ (3)

- Standard deviation of Z: $\sigma_Z = \sqrt{\sum_{i=1}^{n} \left(a_i.\sigma_{Xi}\right)^2}$ (4)

In which: μ_{Xi} - Expectation of random variables X_i:

$$\mu_{Xi} = \overline{X} = \frac{1}{n}.\sum_{i=1}^{n} X_i \qquad (5)$$

σ_{Xi} - Standard deviation of random variables X_i :

$$\sigma_{Xi} = \sqrt{\frac{1}{n-1}.\sum_{i=1}^{n}\left(X_i - \overline{X}\right)^2} \qquad (6)$$

n: observed number of random variables X_i

Confidence indicator: $\beta = \frac{\mu_Z}{\sigma_Z}$ (7); Probability of safe working (confidence): $P_{at} = P_{(Z>0)} = \phi(\beta)$ (8); which $\phi(\beta)$ is standard distribution function; probability of problem: $P_{sc} = (1 - P_{at})$ (9)

2) Function of confidence Z is linear, random variables follow standard distribution law

Taylor expansion for the Z function and use the first two numbers of this polynomial. Function Z is linearized at the original design point X_o [4]:

$$Z = Z\left(X_0\right) + \sum_{i=1}^{n} \frac{\partial Z\left(X_0\right)}{\partial X_i}.\left(X_i - X_0\right) \qquad (10)$$

Coordinates of the original design point:

$$X_o\left(X_1^o, X_2^o, X_3^o, ..., X_n^o\right) \qquad (11)$$

In which: $X_i^o = \mu_{Xi}$ (12); withi μ_{Xi} : expectation of random variables in function Z is calculated as in (5).

Original expectation of function Z:

$$\mu_Z = Z\left(X_0\right) + \sum_{i=1}^{n} \frac{\partial Z\left(X_0\right)}{\partial X_i}.\left(\mu_{Xi} - X_0\right) \qquad (13)$$

Original standard deviation of Z:

$$\sigma_Z = \sqrt{\sum_{i=1}^{n}\left(\frac{\partial Z\left(X_0\right)}{\partial X_i}.\sigma_{Xi}\right)^2} \qquad (14)$$

Confidence indicator (β), probability of safe working $P_{(Z>0)}$ and probability of problem $P_{(Z<0)}$ are calculated according to (7), (8), (9) [4].

Coefficient of impact: $\alpha_i = -\frac{\frac{\partial Z\left(X_0\right)}{\partial X_i}.\sigma_{Xi}}{\sigma_Z}$ (15)

coordinates of new design point: $X^*\left(X_1^*, X_2^*, X_3^*, ..., X_n^*\right)$ (16)

In which: $X_i^* = \mu_{Xi} + \alpha_i.\beta.\sigma_{Xi}$ (17)

Repeating the calculation to find the design point and statistical features of the Z function. The iteration process is described on block diagram in Fig. 2, the iteration only stops when the design point converges. Use the result of the final design point (converged) to calculate the statistical characteristics of the Z function and thereby determine the reliability $P_{(Z>0)}$.

3) Random variables with random probability distribution law

Changing variables to transform random variables with any probability distribution law to the ones with normal distribution law so that the values of the confidence function f_{Xi} and the original probability distribution function with different distribution law are equal corresponding values of a random variable with normal distribution at the design point [4].

$$f_{Xi}\left(X_i^*\right) = \frac{1}{\sigma'_{Xi}}.\varphi\left(\frac{X_i^* - \mu'_{Xi}}{\sigma'_{Xi}}\right) \qquad (18)$$

$$F_{Xi}\left(X_i^*\right) = \phi\left(\frac{X_i^* - \mu'_{Xi}}{\sigma'_{Xi}}\right) \qquad (19)$$

Calculating new statistic properties: $(\mu'_{Xi}, \sigma'_{Xi})$ according to (20), (21)

$$\mu'_{Xi} = X_i^* - \Phi^{-1}(F_{Xi}(X_i^*))\,\sigma_{Xi} \qquad (20)$$

$$\sigma'_{Xi} = \frac{\varphi\left(\Phi^{-1}(F_{Xi}(X_i^*))\right)}{f_{Xi}(X_i^*)} \qquad (21)$$

Retrieval Number: J96160881019/19©BEIESP
DOI: 10.35940/ijitee.J9616.0881019
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-8 Issue-10, August 2019

In which: Φ^{-1} : is an inverse of the standard normal distribution function.

- If Z is a linear: After changing the probability distribution law of random variables into the normal distribution law, perform the calculations to find the confidence of Z function.
- If Z is a nonlinear: Doing the calculation to find the confidence of the Z function, but for each iteration it is necessary to calculate the new statistical features: $(\mu'_{Xi};\sigma'_{Xi})$ according to (20), (21).

4) Probability of Safety of Works in a System

It is assumed that the system has n works and m mechanisms of problem would occur in each works, and the mechanism of problem is independent, let's develop a safety probability matrix of works as in Tabs 1 [2], [5].

Tab 1. Matrix of safety probability of works in headworks

Failure	Works 1	Works 2	Works 3	....	Works n
1	P_{11}	P_{21}	P_{31}	....	P_{n1}
2	P_{12}	P_{22}	P_{32}	....	P_{n2}
....	....	....	....	....	....
m				....	
Safety probability of works	P_{at}^{CT1}	P_{at}^{CT2}	P_{at}^{CT3}	....	P_{at}^{CTn}

Problems are linked each to other through port "or", safety probability of works number i [4]: $P_{at}^{CTi}=1-\sum_{j=1}^{m}\left(1-P_{ij}\right)$ (22)

Probability of problem [4]: $P_{sc}^{CTi}=1-P_{at}^{CTi}$ (22a)

Problems are linked each to other through port "and", safety probability of works number i [4]: $P_{at}^{CTi}=1-\prod_{j=1}^{m}\left(1-P_{ij}\right)$ (23)

In which: P_{ij} – Safety probability of individual problem as mentioned in 3).

5) Safety probability of reservoir headworks which works are arranged in sequential connection.

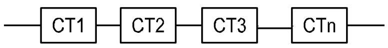

Fig. 2 Reservoir's headworks which works are arranged in sequential connection [7], [8].

In consideration of the correlation between the works in a system, the calculation model of the system will enter the critical state right after the occurrence of a problem of only one works, the safety probability of the system [5], [7], [8].

$$P_{at}^{HT}=r_S.P_{at\min}^{CTi}+\left(1-r_S\right).\prod_{i=1}^{n}P_{at}^{CTi} \quad (24)$$

In which: r_S - general correlation coefficient, valued from 0 to 1;

$P_{at\min}^{CTi}$ - safety probability is the smallest.

If r_S approaches to 1, P_{at}^{HT} increases due to the quantity called the structure's preserved correlation. In the current calculation of safety probability, $r_S=0$ as correlation problem in the calculation of any structure is a separate target of the research, therefore, safety probability and problem probability of reservoir headworks that comprises of n works (Fig. 2) is determined as in (25), (26) [2], [4].

$$P_{at}^{HT}=\prod_{i=1}^{n}P_{at}^{CTi} \quad (25); \quad P_{sc}^{HT}=\left(1-P_{at}^{HT}\right) \quad (26)$$

III. RESULTS AND DISCUSION

A. Introductions to Phu Ninh Irrigation Scheme

Phu Ninh reservoir is categorized at grade I, built on Tam Ky river in Quang Nam province. The reservoir was put into operation in 1986 and is the largest irrigation works in Quang Nam province, the headworks includes: 1 main dam, 5 auxiliary dams (Tu Yen, Long Son 1, Long Son 2, Long Son 3 and Duong Lam), 3 spillways, 3 intakes (South sluice, North sluice and Duong Lam sluice) and 1 hydropower plant; the canal system consists of 2 main canals: the South main canal, the North main canal and over 800 km of primary and secondary canals. The reservoir's capacity is $500.10^6\,m^3$, that provides water for irrigation of 23000ha agricultural lands in Quang Nam province; supplies water for industrial and domestic purposes at about $1.6m^3/s$; supplies water for hydropower plant at 2000kW; supplies water for aquaculture and ecological tourism. Particularly in flood season, the reservoir also involves in flood retention, it's approximately 34.5% flood volume, reducing significantly floods for Tam Ky city and downstream areas [6].

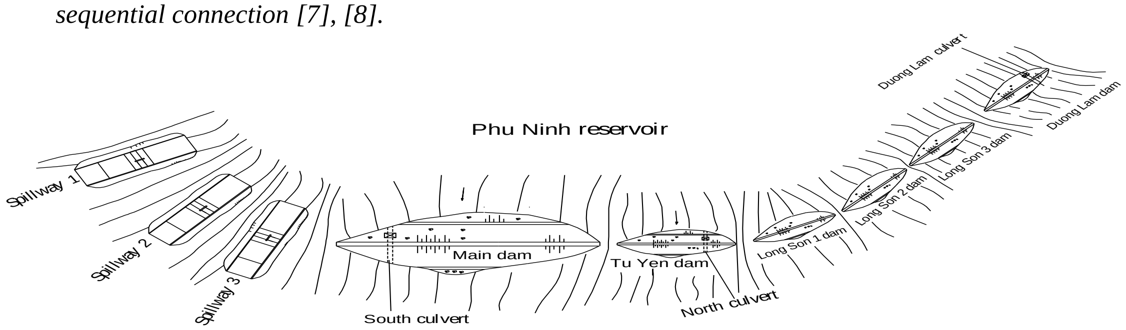

Fig. 3. Works arrangement of Phu Ninh Reservoir Headworks in Quang Nam [6]

B. Assessment of Confidence of Phu Ninh system

Calculations of stability and durability of Phu Ninh reservoir headworks aimed for maintaining safety for reservoir and downstream areas. The safety perspective in this study is: only one works in the system fails, the system will be in trouble so the reservoir will lose its working function, hence the dam and reservoir system's function is maintained if all works are in safe and sTab working conditions. Calculation content: determining the confidence of Phu Ninh reservoir (not including the canal system and on-canal structures) by reservoir water level during operation that ensure the working function of the reservoir [6].

1) System simulation

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

Based on the observations and surveys carried out at the site in combination with analysis and literature review of: design documents, construction documents, construction records, monitoring documents preliminary conclusions on the current status of Phu Ninh reservoir headworks have been made as follows [1], [6], [9]:

- The current flood control operation plan is appropriate with the reservoir system.
- For earth dams: The downstream slope of the main dam in the section near the riverbed, the saturation line is high, it potentially causes adverse impact on the dam slope; The upstream dam of the main dam in the middle of the river has some local landslides, and no other signs of damage has been observed.
- There was no sign of deterioration on masonry blocks and valve gates of the overflow concrete dam as well as the joint of the earth dam and banks. Monitoring records showed that the seepage flow in the foundation of the spillway increased abnormally, downstream relocation of the spillway's middle unit is larger than the two units that connected to the dam and the bank.
- Observations and monitoring results of permeability of the dam's cross section at different positions, the North, South and Duong Lam sluices did not show signs of damage. The valve and valve tower of the culvert are under normal operation, the body of the culvert has many places that have been seriously degraded, especially in the middle units of the culvert body.

According to the surveys and desk study of the reservoir system, a qualitative conclusion was made about the major failures of the system as illustrated in the problem tree in Fig. 4

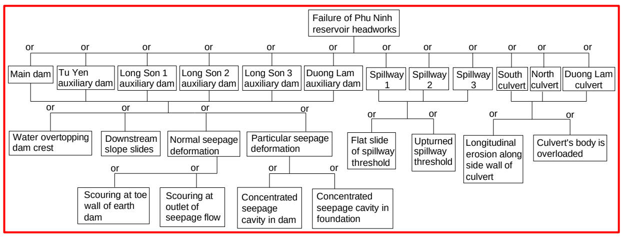

Fig. 4 Problem tree of Phu Ninh reservoir headworks in Quang Nam

2) Function of Confidence of Problems

(a) Function of Confidence of Earth Dam

Water overtopping the dam

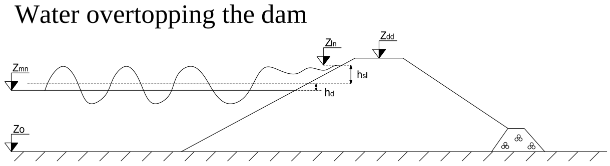

Fig. 5. Water overtopping the dam

Function of confidence of overtopping the dam Z_1 represents the relationship between dam crest and water level in the reservoir, including the height cased by waves and winds, according to (28) [8], [9]:

$$Z_1 = Z_{dd} - Z_{\ln} = Z_{dd} - \left(Z_{mn} + h_d + h_{sl}\right) \quad (28)$$

In which: Z_{dd} : Dam crest; Z_{mn} : Water level in the reservoir;

h_d: Height of backwater (caused by wind):

$$h_d = 2.10^{-6}.\frac{V^2.D}{g.(Z_{mn} - Z_o)}.\cos\alpha \quad (28a)$$

h_{sl}: Height of wave run-up:

$$h_{sl} = K_1.\,K_2.\,K_3.\,K_4.K_\alpha.h_{s1\%} = K.h_{s1\%} \quad (28b)$$

In which: V- Wind velocity; D – fetch; K- The coefficient of relative roughness, characterized by materials of dam slope, wind speed and coefficient of upstream slope. $_1$; $h_{s1\%}$ - Height of wave probability is 1%.

Downstream dam slope slides

Downstream dam slope stability is calculated by circular cylinder sliding method in order to find out the sliding surface with the smallest slip resistance. The safety of the dam is assessed against the calculated sliding surface. Bishop's formula is used to establish confidence function Z_2, where the sum of the slip-resistant moments is considered the load-bearing function, the gross moents causing slides is the load function [7], [9].

$$Z_2 = \left(\sum_{i=1}^{m}\left(c.b_n + \left(W_n - u_n.b_n\right).\tan\varphi\right).\frac{1}{m_\alpha}\right) - \left(\sum_{i=1}^{m} W_n.\sin\alpha_n\right) \quad (29)$$

In which: $m_\alpha = \left(1 + \frac{\tan\alpha_n.\tan\varphi}{K_{at}}\right).\cos\alpha_n$ (29a)

$K_{at}, W_n, u_n, c, \varphi, \alpha_n, b_n$: respectively are slope safety factors, weight of soils, pore water pressure, unit cohesion, internal friction angle, horizontal and sliding angle , width of soils.

Normal seepage deformation

At the special points of the dam body, such as toe wall, outlet of the seepage flow, and so on, there are potentially local scours caused by seepage gradients that excess the allowable ones.

Function of confidence of scour at toe wall [7], [9]: $Z_3 = [J]^{chânkhay} - J_{chânkhay}^{\max}$ (30); Function of confidence of scour at outlet gate [7], [9]: $Z_4 = [J]^{ra} - J_{ra}^{\max}$ (31)

In which: $J_{ra}^{\max}$, $J_{chankhay}^{\max}$ - Maximum seepage gradients are at outlet and toe wall, determined by seepage calculations. Water head is preliminary random variable, which through the seepage calculation program Seep/w (Geoslope 2007) help to find out the probability distribution law and statistic features of secondary random variables: $J_{ra}^{\max}$, $J_{chankhay}^{\max}$.

$[J]^{ra}$, $[J]^{chankhay}$: Allowable gradients at toe wall and outlet, determined by experimental data of embankment soils of outlet and toe wall.

Abnormal seepage deformation.

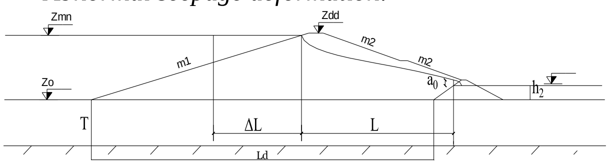

Fig. 6. Abnormal seepage deformation calculation

During embankment, compaction may not have been carried out evenly across the dam section or the quality of the soils has not been satisfactory in some places, or dam foundation treatments were not properly, there are latent "permeability caves" in dam and foundation, therefore, average permeability in the dam and foundation should be taken into account [7], [8].

Confidence of abnormal seepage for dam body:

Retrieval Number: J96160881019/19©BEIESP
DOI: 10.35940/ijitee.J9616.0881019
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

$$Z_5 = \left[J_{kcp}\right]^d - \frac{(Z_{mn}-Z_o-h_2-a_o)}{\left(L_d - m_1.(Z_{mn}-Z_o)+\frac{m_1.(Z_{mn}-Z_o)}{(2.m_1+1)}\right)} \quad (32)$$

Confidence of abnormal seepage for dam foundation:

$$Z_6 = \left[J_{kcp}\right]^n - \frac{(Z_{mn}-Z_o-h_2)}{(L_d+0{,}88.T)} \quad (33)$$

In which: $\left[J_{kcp}\right]^d, \left[J_{kcp}\right]^n$ **:** Permissible hydraulic slope of dam and foundation materials, depending on the grade of works and embankment materials of dam and foundation, considered as load bearing capacity of the works and determined through monitoring data analysis of the works that has encountered problem until the time of assessment.

h_2: Water head downstream and upstream dam; a_o: Height of water absorbtion; T: Thickness of seepage layer; m_1: Upstream slope; m_2: Downstream slope; L_d: Length of dam bed; Z_{mn}: Height of upstream water level; Z_o: Altitute of reservoir bed.

(b) Confidence Functions of Spillway

Flat spillway threshold slides

Spillway is built on rock foundation, confidence function Z_7 is developed upon the formula for calculation of slide stability at the contact face between gravity concrete dam and foundation [8], [9] .

$$Z_7 = \left(\sum G - W_t\right).f + C.A - \sum P \quad (34)$$

In which: Friction resistance $\left(\sum G - W_t\right).f$ and cohesion resistance C.A on destructive surface is the load bearing function, force causing slide $\sum P$ is load function.

Calculation indicators: weight of works $\left(\sum G\right)$, permeability force $\left(W_t\right)$, friction coefficient (f), adhesive force unit (C) are random variables, determined with monitoring and survey data.

Overturned Spillway Threshold

Spillway may be overturned around an axle of downstream dam toe if gross overturning resistant moment $\sum M_{cl}$ is smaller than overturning moment $\sum M_{gl}$. Confidence function Z_8 [8], [9]:

$$Z_8 = \sum M_{cl} - \sum M_{gl} \quad (35)$$

In which: $\sum M_{cl}$ is load bearing function, $\sum M_{gl}$ load variable. Random variables for calculation of moments are: water level in reservoir, concrete density, size of spillway, physical-mechanical properties of foundation, and so on are determined by monitoring data of the works in serveral years, surveys, assessments of existing works at the time of research.

Confidence functions of culvert

(1) Longitudinal seepage along culvert side wall

Confidence function of longitudinal seepage along culvert side wall Z_9 [7], [9]:

$$Z_9 = [J]_{cp} - \frac{Z_{mn}-Z_2}{L_c} \quad (36)$$

In which: $[J]_{cp}$: Seepage gradient applicable for clay soils of culvert body is considered as function of load bearing, determined by the drills for experiment at the time of assessment of seepage; random variables are determined by observations and measurements carried out in many years: Z_2 - Ground water Level at tail of culvert; Z_{mn}- Upstream water level; L_c - Length of culvert body.

(2) Durability of culvert body structure

The culvert body is of a degraded space structure, the confidence function is Z_{10} [9]

$$Z_{10} = M_{gh} - M_{tt} \quad (37)$$

In which: M_{tt}: load function is experimental, established upon the analysis of culvert body moments that are changed by random variables: seepage head, reservoir water head, physical-mechanical properties of embankment soils, reinforced concrete indicators.

- M_{gh}: durability function is experimental of critical bending moments of culvert body, M_{gh} is determined with test carried out at the site at the time of assessment of random variables: reinforncement materials (tensile strength, area of reinforcement), concrete (compressive strength), culvert wall thickness and size of cross section.

3) *Calculation data*

Tab 2. Calculation water levels in the reservoir Z_{mn} [6]

No	Expectation μ	Deviation σ	Probability distribution law
1	28.17	1.929	Weibull
2	28.41	2.056	Standard
3	29.39	1.838	Loga standard
4	30.17	1.617	Loga standard
5	31.65	1.63	Weibull
6	31.85	1.287	Standard
7	32.00	1.119	Standard
8	32.38	1.173	Standard
9	32.50	1.899	Standard
10	33.00	1.145	Weibull
11	33.86	1.318	Weibull
12	34.44	1.086	Weibull

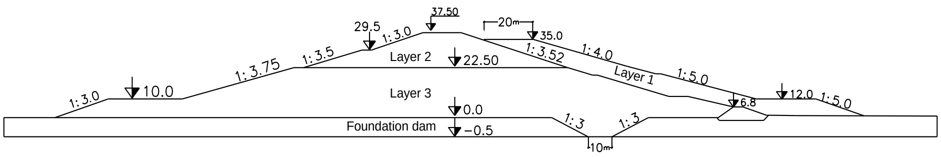

Fig. 7. Cross section of Phu Ninh main dam

Tab 3. Physical – mechanical properties of soil materials of main dam and foundation

Name of random variables	Main dam			Auxiliary dam			
	Symbol of random variable	μ	σ	Symbol of random variable	μ	σ	Probability distribution law
Density	γ_1 (KN/m^3)	19,78	1,978	$\gamma_đ$ (KN/m^3)	19,78	1,978	Standard
	γ_2 (KN/m^3)	18,515	18,515				
	γ_3 (KN/m^3)	18,63	1,863				
	γ_n (KN/m^3)	19,205	19,205	γ_n(KN/m^3)	19,205	19,205	Standard
Internal friction angle	φ_1 (degree)	20	6	$\varphi_đ$ (degree)	21	6,3	Standard
	φ_2 (degree)	15	4,5				
	φ_3 (degree)	12	3,6				
	φ_n (degree)	22	6,6	φ_n(degree)	22	6,6	Standard
Unit adhesive force	C_1 (KN/m^2)	23	6,9	$C_đ$ (KN/m^2)	23	6,9	Standard
	C_2 (KN/m^2)	22	6,6				
	C_3 (KN/m^2)	22	6,6				
	C_n (KN/m^2)	0	-	C_n (KN/m^2)	0	-	Deterministic
Weight, internal friction angle and unit cohesion force of the drain	$\gamma_đ$ (KN/m^3)	21	2,1	γ_{lt} (KN/m^3)	21	2,1	Standard
	$\varphi_đ$ (độ)	35	8,5	φ_{lt} (degree)	35	8,5	Standard
	$C_đ$ (KN/m^2)	0	-	C_{lt} (KN/m^2)	0	-	
Permeability coefficient	K_1(m/s)	1.10^{-6}	-	$K_đ$(m/s)	1.10^{-6}	-	
	K_2(m/s)	$1,4.10^{-6}$	-				
	K_3(m/s)	4.10^{-6}	-				
	K_n(m/s)	2.10^{-5}	-	K_n(m/s)	2.10^{-5}	-	Deterministic
	K_{lt}(m/s)	1.10^{-2}	-	K_{lt}(m/s)	1.10^{-2}	-	Deterministic

Tab 4. Statistic characteristics of sizes of earth dam, wave, wind of Phu Ninh reservoir [6], [9]

No	Name of random variables	Symbol of random variable	Main dam		Tu Yen dam		Long Son dams 1, 2, 3		Duong Lam dam		Probability distribution law
			μ	σ	μ	σ	μ	σ	μ	σ	
1	Dam crest	Z_{dd} (m)	37,5	0,2	37,5	0,2	36,9	0,2	36,65	0,2	Standard
2	Wind velocity	V (m/s)	13,86	1,36	13,86	1,36	13,86	1,36	13,86	1,36	Logarithm
3	Average upstream slope	m	3,53	-	3,0	-	2,5	-	2,5	-	Deterministic
4	Roughness Δ of rocks of upstream slope	(m)	0,05	-	0,06	-	0,06	-	0,06	-	Deterministic
5	Average wave	D (m)	3120	50	3120	20	3120	20	3120	20	Standard
6	The angle of the wind direction is perpendicular to the dam alignment.	α (°)	0	-	0	-	0	-	0	-	Deterministic
7	Dam bed elevation	Z_o (m)	0,2	0,02	21,5	0,1	22,9	0,1	25,15	0,1	Standard
8	Height of wave	h_{sl} (m)	0,95	0,15	0,77	0,1	0,77	0,1	0,77	0,1	Logarithm

Retrieval Number: J96160881019/19©BEIESP
DOI: 10.35940/ijitee.J9616.0881019
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

Tab 5. Gradients at various places on main dam and auxiliary dams with normal distribution law

No	Z_{mn}	Variable	Main dam		Tu Yen dam		Long Son and Duong Lam dams	
			μ	σ (10^{-2})	μ	σ (10^{-2})	μ	σ (10^{-2})
1	28.17	J^{max}	0.23	3.45	0.265	3.98	0.21	3.15
		J^{max}_{out}	0.41	6.15	0.371	5.57	0.18	2.70
2	28.41	J^{max}	0.24	3.53	0.286	4.29	0.220	3.30
		J^{max}_{out}	0.42	6.23	0.381	5.72	0.185	2.78
3	29.39	J^{max}	0.24	3.60	0.328	4.92	0.230	3.45
		J^{max}_{out}	0.42	6.30	0.398	5.97	0.19	2.85
4	30.17	J^{max}	0.25	3.75	0.37	5.55	0.235	3.53
		J^{max}_{out}	0.43	6.45	0.424	6.36	0.197	2.96
5	31.65	J^{max}	0.26	3.83	0.39	5.85	0.250	3.75
		J^{max}_{out}	0.44	6.60	0.435	6.53	0.22	3.30
6	31.85	J^{max}	0.26	3.90	0.41	6.15	0.257	3.86
		J^{max}_{out}	0.45	6.75	0.445	6.68	0.226	3.39
7	32.00	J^{max}	0.27	3.98	0.43	6.45	0.260	3.90
		J^{max}_{out}	0.46	6.86	0.456	6.84	0.23	3.45
8	32.38	J^{max}	0.28	4.20	0.44	6.60	0.265	3.98
		J^{max}_{out}	0.46	6.90	0.477	7.16	0.234	3.51
9	32.50	J^{max}	0.29	4.35	0.449	6.74	0.270	4.05
		J^{max}_{out}	0.47	7.02	0.489	7.34	0.24	3.60
10	33.00	J^{max}	0.30	4.50	0.459	6.89	0.275	4.13
		J^{max}_{out}	0.47	7.05	0.505	7.58	0.25	3.75
11	33.86	J^{max}	0.32	4.80	0.468	7.02	0.280	4.20
		J^{max}_{out}	0.48	7.17	0.521	7.82	0.26	3.90
12	34.44	J^{max}	0.35	5.25	0.515	7.73	0.290	4.35
		J^{max}_{out}	0.50	7.50	0.525	7.88	0.28	4.20

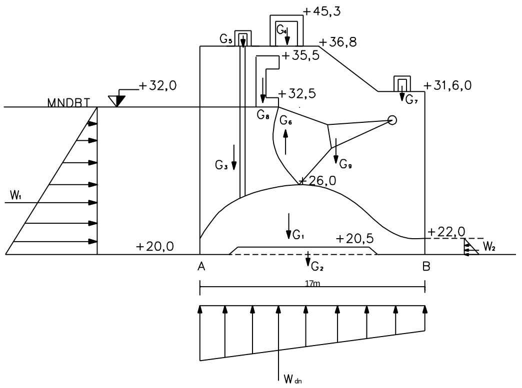

Fig. 8. Calculation of stability of threshold of spillway 2

Tab 6: Allowable Seepage Gradients of Dam and Foundation [6], [9]

No	Name	Symbol	Value
1	Allowable permeability gradients for checking abnormal permeation resistance of the dam body	$\left[J_{kcp}\right]_{dap}$	1,25
2	Allowable permeability gradients for checking abnormal permeation resistance of the dam foundation	$\left[J_{kcp}\right]_{nen}$	0,28
3	Allowable permeability gradients for checking normal permeation resistance of the dam body	$[J]_{ra}$	0,85
4	Allowable permeability gradients for checking normal permeation resistance of the dam foundation	$[J]_{chânkhay}$	0,6

Tab 7. The statistical characteristics of random variables with normal distribution for calculation of stability of threshold of spillways 1, 2, 3 [6], [9]

No	Variable	Symbol	μ	σ
1	Concrete density	γ_{bt} (KN/m^3)	24	1,2
2	Length of threshold of spillway 1	L_1 (m)	30	0,1
2	Length of threshold of spillway 2	L_2 (m)	17	0,05
3	Length of threshold of spillway 3	L_3 (m)	20	0,05
4	Friction coefficient between spillway and foundation	f	0,65	0,065
5	Unit cohesion force	c (KN/m^2)	166,7	25,14

Tab 8. Statistic characteristics of random variables in calculation of safety probability of South, North and Duong Lam sluices [6], [9]

No	Name of variable	Symbol of variable	μ	σ	Probability distribution law
1	Allowable seepage gradient for clay soils of sluice body	$[J]_{cp}$	4	-	Deterministic
2	Length of body of South sluice	L_n (m)	173	0,5	Standard
3	Elevation of inlet of South sluice	Z^n_{cv} (m)	15	0,01	Standard
4	Elevation of outlet of South sluice	Z^n_{cr} (m)	14,68	0,01	Standard
5	Thickness of wall of South sluice	t (m)	0,5	-	Deterministic
6	Height of South sluice	h (m)	1,6	-	Deterministic
7	Width of South sluice	b (m)	1,2	-	Deterministic

8	Length of body of North sluice	L_b (m)	96	0,1	Standard
9	Elevation of inlet of North sluice	Z^b_{cv}	13	0,02	Standard
10	Elevation of outlet of North sluice	Z^b_{cr}	12,67	0,02	Standard
11	Thickness of wall of North sluice	t (m)	0,5	-	Deterministic
12	Height of North sluice	h (m)	3	-	Deterministic
13	Width of North sluice	b (m)	3	-	Deterministic
14	Length of body of Duong Lam sluice	L_{DL} (m)	60	0,1	Standard
15	Elevation of inlet of Duong Lam sluice	Z^{DL}_{cv}	26	0,02	Standard
16	Elevation of outlet of Duong Lam sluice	Z^{DL}_{cr}	25,7	0,02	Standard
17	Thickness of wall of Duong Lam sluice	t (m)	0,5	-	Deterministic
18	Height of Duong Lam sluice	h (m)	3	-	Deterministic
19	Width of Duong Lam sluice	b (m)	3	-	Deterministic
20	Density of concete of sluice body	γ_{bt} (KN/m^3)	24	1,2	Standard
21	Area of shear bearing reinforcement	F_a (cm^2)	5,65	0,10735	Standard
22	Area of compression bearing reinforcement	$F_a^{'}$ (cm^2)	3,93	0,07467	Standard
23	Calculated shear strength of reinforcement	R_a (daN/cm^2)	2700	224,1	Standard
24	Calculated compression strength of reinforcement	$R_a^{'}$ (daN/cm^2)	2700	184	Standard
25	Calculated compression strength of concrete	R_n (daN/cm^2)	90	11,25	Standard

4) Confidence ofsystem

Calculated confidences of system

Tab 9. Safety Probability of Main Dam

Z	Overtopping	Downstream slope slide	Formed seepage cavity in dam body	Formed seepage cavity in dam foundation	Toe wall scourse	Sourse at toe wall outlet	$P^{maindam}_{at}$
28,17	9,9944E-01	9,9950E-01	9,9988E-01	9,9999E-01	9,9999E-01	9,9999E-01	9,9882E-01
28,41	9,9877E-01	9,9948E-01	9,9986E-01	9,9999E-01	9,9999E-01	9,9999E-01	9,9811E-01
29,39	9,9848E-01	9,9890E-01	9,9982E-01	9,9999E-01	9,9999E-01	9,9999E-01	9,9720E-01
30,17	9,9799E-01	9,9810E-01	9,9976E-01	9,9999E-01	9,9998E-01	9,9999E-01	9,9584E-01
31,65	9,9762E-01	9,9709E-01	9,9974E-01	9,9999E-01	9,9997E-01	9,9999E-01	9,9443E-01
31,85	9,9735E-01	9,9705E-01	9,9970E-01	9,9999E-01	9,9997E-01	9,9999E-01	9,9407E-01
32,00	9,9731E-01	9,9675E-01	9,9966E-01	9,9999E-01	9,9996E-01	9,9999E-01	9,9368E-01
32,38	9,9684E-01	9,9650E-01	9,9962E-01	9,9999E-01	9,9995E-01	9,9998E-01	9,9291E-01
32,50	9,9673E-01	9,9618E-01	9,9959E-01	9,9999E-01	9,9994E-01	9,9993E-01	9,9238E-01
33,00	9,9514E-01	9,9542E-01	9,9955E-01	9,9999E-01	9,9993E-01	9,9993E-01	9,8999E-01
33,86	9,6790E-01	9,9299E-01	9,9951E-01	9,9998E-01	9,9992E-01	9,9986E-01	9,6042E-01
34,44	9,5420E-01	9,9030E-01	9,9947E-01	9,9990E-01	9,9991E-01	9,9983E-01	9,4411E-01

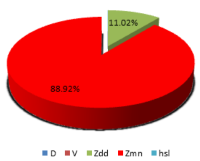

Fig. 9. Random variable's impact on overtopping main dam

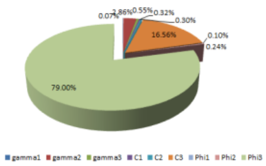

Fig. 10. Random variable's impact on downstream main damslope slide

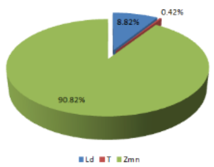

Fig. 11. Random variables' impact on formation of seepage cavity in dam body

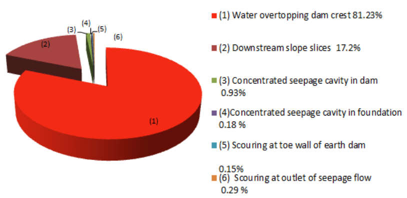

Fig. 12: Impacts of problems on confidence of main dam

Retrieval Number: J96160881019/19©BEIESP
DOI: 10.35940/ijitee.J9616.0881019
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-8 Issue-10, August 2019

Tab 10. Safety Probability of Tu Yen Dam

Z	Overtopping	Downstream slope slide	Formed seepage cavity in dam body and foundation	Toe wall scourse	Sourse at toe wall outlet	P_{at}^{TuYen}
28,17	9,9920E-01	9,9962E-01	1,0000E+00	1,0000E+00	1,0000E+00	9,9882E-01
28,41	9,9900E-01	9,9961E-01	1,0000E+00	1,0000E+00	1,0000E+00	9,9861E-01
29,39	9,9846E-01	9,9960E-01	1,0000E+00	1,0000E+00	1,0000E+00	9,9806E-01
30,17	9,9798E-01	9,9959E-01	1,0000E+00	9,9997E-01	1,0000E+00	9,9754E-01
31,65	9,9761E-01	9,9958E-01	1,0000E+00	9,9988E-01	1,0000E+00	9,9707E-01
31,85	9,9732E-01	9,9957E-01	1,0000E+00	9,9982E-01	1,0000E+00	9,9671E-01
32,00	9,9729E-01	9,9955E-01	1,0000E+00	9,9976E-01	1,0000E+00	9,9660E-01
32,38	9,9710E-01	9,9953E-01	1,0000E+00	9,9970E-01	1,0000E+00	9,9633E-01
32,50	9,9650E-01	9,9951E-01	1,0000E+00	9,9964E-01	9,9999E-01	9,9565E-01
33,00	9,9200E-01	9,9950E-01	1,0000E+00	9,9958E-01	9,9999E-01	9,9107E-01
33,86	9,6770E-01	9,9943E-01	1,0000E+00	9,9951E-01	9,9997E-01	9,6665E-01
34,44	9,5390E-01	9,9938E-01	1,0000E+00	9,9945E-01	9,9997E-01	9,5275E-01

Tab 11. Safety Probability of Long Son Dams 1, 2, 3

Z	Overtopping	Downstream slope slide	Formed seepage cavity in dam body	Formed seepage cavity in dam foundation	$P_{at}^{LongSon1,2,3}$
28,17	9,9987E-01	9,9992E-01	1,0000E+00	1,0000E+00	9,9979E-01
28,41	9,9978E-01	9,9991E-01	1,0000E+00	1,0000E+00	9,9969E-01
29,39	9,9969E-01	9,9990E-01	1,0000E+00	1,0000E+00	9,9959E-01
30,17	9,9960E-01	9,9989E-01	1,0000E+00	1,0000E+00	9,9949E-01
31,65	9,9945E-01	9,9987E-01	1,0000E+00	1,0000E+00	9,9932E-01
31,85	9,9942E-01	9,9986E-01	1,0000E+00	1,0000E+00	9,9928E-01
32,00	9,9939E-01	9,9985E-01	1,0000E+00	1,0000E+00	9,9924E-01
32,38	9,9924E-01	9,9984E-01	1,0000E+00	1,0000E+00	9,9908E-01
32,50	9,9920E-01	9,9983E-01	1,0000E+00	1,0000E+00	9,9903E-01
33,00	9,9906E-01	9,9982E-01	1,0000E+00	1,0000E+00	9,9888E-01
33,86	9,9897E-01	9,9981E-01	1,0000E+00	1,0000E+00	9,9878E-01
34,44	9,9888E-01	9,9980E-01	1,0000E+00	1,0000E+00	9,9868E-01

Tab 12 Safety Probability of Duong Lam dam

Z	Overtopping	Downstream slope slide	Formed seepage cavity in dam body	Formed seepage cavity in dam foundation	$P_{at}^{DuongLam}$
28,17	1,300E-04	1,200E-05	4,170E-15	5,580E-19	0,99986
28,41	2,442E-04	2,100E-05	1,410E-13	2,680E-18	0,99973
29,39	3,584E-04	3,000E-05	2,778E-13	4,802E-18	0,99961
30,17	4,726E-04	3,900E-05	4,147E-13	6,924E-18	0,99949
31,65	5,868E-04	4,800E-05	5,515E-13	9,046E-17	0,99937
31,85	7,010E-04	5,700E-05	6,883E-13	1,117E-16	0,99924
32,00	8,152E-04	6,600E-05	8,252E-13	2,575E-16	0,99912
32,38	9,294E-04	7,500E-05	9,620E-13	3,411E-16	0,99900
32,50	1,044E-03	8,400E-05	1,099E-12	4,246E-16	0,99887
33,00	1,158E-03	9,300E-05	1,236E-12	5,081E-16	0,99875
33,86	1,272E-03	1,020E-04	1,372E-12	5,917E-16	0,99863
34,44	1,386E-03	1,110E-04	1,509E-11	6,752E-16	0,99850

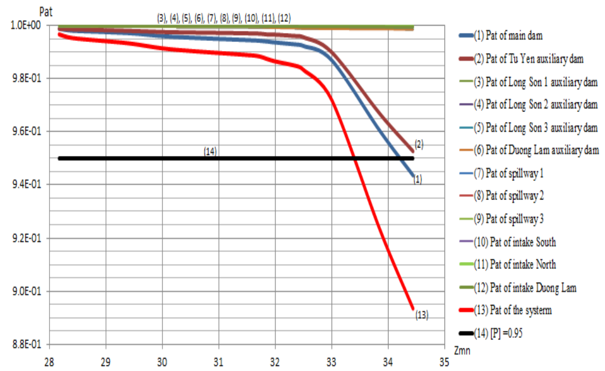

Fig. 13. Safety probability of Phu Ninh headworks

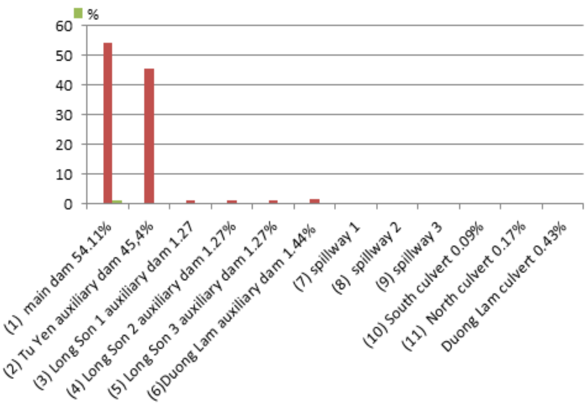

Fig. 14. Impacts of individual works on Phu Ninh reservoir headworks

Analysis of calculated confidences of Phu Ninh system

Standard confidence $[P]$ is referred to the Russian standard confidence, standard confidence of headworks is refered to the principle of equal confidence of works, i.e., $[P_{at}]$ of individual works = 9.8E-01; $[P_{at}]$ system = 9.5E-01 [5]. The system's confidence is satisfactory if $P_{at}^{HT} \geq \left[P_{at}^{HT}\right]$

Impacts of random variables on confidence of individual problems (Fig 9-11)

Retrieval Number: J96160881019/19©BEIESP
DOI: 10.35940/ijitee.J9616.0881019
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

- Water level in reservoir Z_{mn} and dam crest Z_{dd} are random variables that cause the most significant impact on overtopping, 88.92% and 11.02%, respectively, other variables: D, V, h_{sl} cause insignificant impact. It's noted for monitoring of water level variables and vertical movements of dam crest as they are the two variables that cause main impact on main dam's safety.
- Internal friction angle (φ_3) (acounting for 79%), and unit cohesion force (C_3) (accounting for 16.56%) of soil layer 3 (close to the foundation) shall be the decisive factors on downstream slope slide (Fig. 3-9), physical-mechanical properties of other soil layers' impacts are insignificant. Therefore, quality assessment of main dam shall take into account physical – mechanical properties of soil layers that are close to the ground.
- Water level and length of dam bed are random variables which impacts are the most significant to the formation of seepage cavity in dam body, others are insignificant.

Impact of problems on confidence of individual works of the system (Fig. 12)

- Overtopping and downstream slope slides cause the most significant impact on the earth dam (main dam and Tu Yen dam) and the impact is constant if water level fluctuates between Z_{mn} = +28.17 and Z_{mn} = +33.30. If Z_{mn} > +33.00 overtopping shall be the main cause of main dam problem (81.23%), when safety probability of overtopping reduces quickly and to be much lower than that of downstream slope slide.
- Formation of cavity in dam body (5.35%) and scour at dam toe wall (0.68%) causes less significant impact than that caused by overtopping and downstream slope slides; the two kinds of problems; forming seepage cavity in the foundation and scour at dam's outlet are of small probability then cause less impact on confidence of main dam.

Impacts of works elements on general confidence of system (Fig. 13, 14)

- When water level in the reservoir rises up from Z_{mn} = +28.17 to Z_{mn}= +34.44 safety probability of Phu Ninh headworks reduces quickly, from $P_{at}^{HT} = 0,99714$ down $P_{at}^{HT} = 0,89581$
- If $Z_{mn} \le +33,30$ $\;P_{at}^{HT} \ge \left[P_{at}^{HT}\right] = 0,95$, the system is safe under the allowable confidence
- If $Z_{mn} > +33,30$ system's confidence is small and smaller than the standard confidence $P_{at}^{HT} < \left[P_{at}^{HT}\right] = 0,95$, Phu Ninh system is vulnerable to problem which cause would be one of works is of low confidence such as: main dam, Tu yen dam, Long Son dams 1, 2, 3 and Duong Lam dam. Culverts and spillways' confidence is high then their impact on safetey of headworks is insignificant.
- The analysis as illustrated in Fig. 12 shows that Safety of Phu Ninh system may be categorized in 3 levels:
+ Significant impact (81.87%) caused by main dam and Tu Yen dam;
+ Insignificant impact (16.13%) caused by Long Son dams 1, 2, 3 and Duong lam dam;
+ Minor impact (2%) caused by sluices (North, South and Duong Lam) and spillways (1, 2, 3).

Research of confidence of headworks presented that earth dam (main dam and Tu Yen dam) are elements which confidence is lower than that of other elements of the system therefore they are the most vulnerable elements of the system. In case of system operation, those elements are at the risk of problem, therefore, appropriate confidence distribution and weight are required for those works in new design, upgrades or repairs of headworks

IV. CONCLUSION

Under the research algorithsms have been developed for calculation of safety probability for individual works and reservoir headworsk system with reference to the Theory of Confidence. The analysis of causes of problems of the system, authors have developed confidence function for various problems for different works of the system: earth dam, spillway and culvert. SYPRO2016 is applied in calculation of safety probability of problems, of individual works and the entire system of Phu Ninh reservoir in Quang Nam. The comparison against Russian standard confidence helped to come up with conclusions on various levels of confidence of individual works and the system as good suggestions of structural measures in case of the system or individual works at risk. Quantified random variables (water level, physical-mechanical properties of soils, size of works), problems that cause significant impacts on the safetey of works to be downstream slope slides, overtopping. They are grounds for recommended frequency of monitoring, measurement of random variables to come up with satisfactory confidences. The research also determined the importance of individual works so that appropriate order of priority for maintenance and upgrade would be established: earth dams, particularly main dam and Tu Yen dam's impact is the most significant on the system's safety; while, culverts and spillways' impacts are less significant. The article would be good references for dam safety design and management in Vietnam.

REFERENCES

1. Phan Si Ky, *Problems in some irrigation works in Vietnam and measures*. Agricultural Press, Hanoi, 2000.
2. Nguyen Vi, *Method of modeling of statistics in calculation of confidence of port works*. Transportation Press, Hanoi, 2009.
3. Nguyen Van Mao, Nguyen Huu Bao, Nguyen Lan Huong, *Dam safety probability calculation grounds, Construction Press*, 2014
4. Probabilistic design and risk assessment of large dams, 1996, J,K Virijling/ M, Hauer/ R,E, Jorissen.
5. "Основные положения расчета причальных сооружений на надежность," М. В/О "Мортехинформреклама", РД 31-31-35-85, 1986.
6. "Main report of Phu Ninh irrigation system in Quang Nam" HEC1, Phu Ninh reservoir rehabilitation and safety improvement project, 2001
7. Nguyen Quang Hung, Nguyen Van Mao . *Reliability analysis of revetment using interlocking concrete blocks*. Jurnal of water resources and environmental engineering. Vol 44. 37-42. 2014.
8. Pham Hong Cuong, Quang Hung Nguyen. *Applying reliability theory to appraise quality of irrigation system in Vietnam*. International Journal of Innovative Technology and Exploring Engineering (IJITEE), Volume-8 Issue-8. 1277-1281. 2019
9. Lan Huong Nguyen, Quang Hung Nguyen, *Application of reliability theory in calculation of safety reservoir*. International Journal of Recent Technology and Engineering (IJRTE)Volume-8,Issue-2, July, 2019.

Retrieval Number: J96160881019/19©BEIESP
DOI: 10.35940/ijitee.J9616.0881019
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)