International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-8 Issue-2, July 2019

# Application of Reliability Theory in Calculation of Safety Reservoir

**Lan Huong Nguyen, Quang Hung Nguyen**

***Abstract*: The design of confidence of safety for irrigation reservoirs has been developed upon theory of hydraulic works, theory of systems and theory of confidence levels II and III, algorithms of SYPRO2016. They are two of several practical problems for design of irrigation reservoirs built under marginal conditions of Vietnam such as: problem for assessement of confidence of irrigation headworks under single flood regulation option and prolem for design of dam under allowable confidence. Upon the design of confidence for individual components of the wroks, it's possible to evaluate effects of random variables and individual emergency mechanisms of the reservoir.**

***Keywords*: Confidence of works, Function of confidence, Random variables, SYPRO2016.**

## I. INTRODUCTION

Vietnam is a country with a large number of dams with about 6886 irrigation and hydropower reservoirs and dams, of which a majority (about 96.5%) are small and medium-sized [1]. Those reservoirs and dams were built in many different periods with different technical standards, and evidential inadequecies in term of quality, the design and the management arrangement would be observed in any of existing reservoirs and dams. This determined the level of safety for individual works. The existing reservoirs and dams in the country have been built under definite design model and their safety factor design followed reservoir and dam design standards and regulations. However, during the operation, there are many failures and incidents incurred for the reservoirs and dams that could not be explained by the designer, and this was considered as shortcoming of the definite design model. That's why designers are increasingly inclined to random designs and analysis of confidence in assessing the safety of dams, and this is a modern design method that has been applied in the countries where many reservoirs and dams are built such as Netherlands, Switzerland, Russia, China, and so on. For those reasons, research and development of statistical probability applications in combination with the theory of hydraulic works and theory of systems in dam safety analysis and assessment of the current quality of existing headworks shall be the new contribution to quality improvement of current dam safety operations in Vietnam. Under this study, the authors look forward to using the SYPRO2016 to solve two of the many problems under theory of confidence to be applicable to hydraulic works in Vietnam: the problem of assessement of dam quality under a signle flood operation plan and problem of dam design under the theory of confidence.

## II. EXPERIMENTAL AND MODELLING CONFIGURATION

Safety calculation and assessment of irrigation and hydropower reservoirs is based on problem of confidence levels II and III. Selected problem depends the level and importance as well as determined input parameters, which is a very difficult task for a hydraulic works that depend heavily on objective factors.

### A. *Problem of confidence level 2.*

With the conception that the works is unsafe (in case of emergency) because load and impact (S) on the works exceed the capacity of the design load (R), or the load and impact are within the design limits but the load capacity of the works has been reduced, function of confidence (Z) is established as follow:

$$Z = R - S \qquad (1)$$

Where load capacity R and applied load S are functions of random quantities which distribution laws are defined. According to the expression (1), the function Z is read as follows: Z <0 the works does not meet safety conditions; Z> 0, the works satisfies safety conditions; Z = 0 is the boundary between the safety and unsafe zones. The function of confidence Z can be a linear function with random variables with a standard distribution law; or Z is a nonlinear function with random variables with a standard distribution law; or Z: is a nonlinear function with random variables having any distribution rules.

Probability designs, in which the nonlinear functions of confidence are linearized at the design point, the random variables of the function are transformed or assumed to be the normal (standard) distribution form called computation of probability at level II. Calculations by level II are made according to the diagram in **Fig.** 1.

**Revised Manuscript Received on 30 July 2019.**
* Correspondence Author

**Lan Huong Nguyen,** Thuyloi University, Hanoi, 100000 Ha noi, Vietnam.

**Quang Hung Nguyen**, Thuyloi University, Hanoi, 100000 Ha noi, Vietnam.

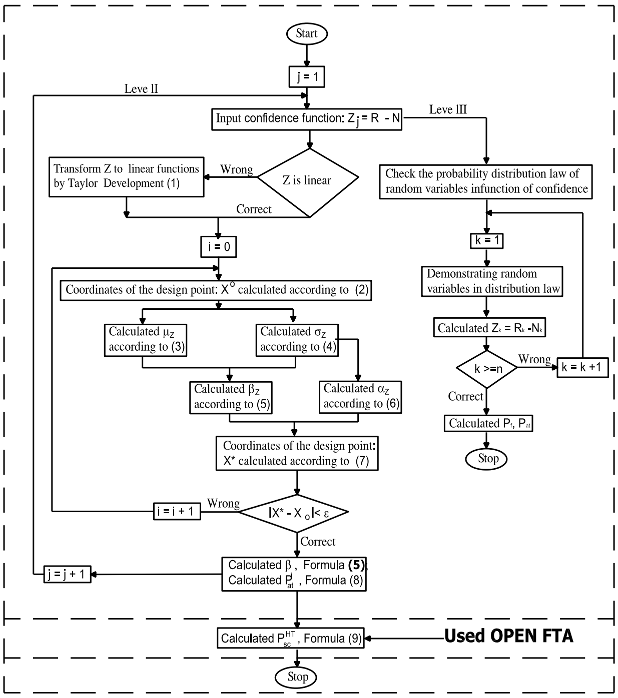


**Fig. 1: Diagram of confidence design of works and system of works under theory of confidence.**

Note the formulas in the diagram in **Fig.** 1:

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

$$X_o\left(\mu_1, \mu_2, \mu_3, ...\right) \quad (2)$$

$$(\mu_Z)_o = Z\left(X_0\right) + \sum_{i=1}^{n} \frac{\partial Z\left(X_0\right)}{\partial X_i}.\left(\mu_{Xi} - X_i^o\right) \quad (3)$$

$$(\sigma_Z)_o = \sqrt{\sum_{i=1}^{n} \left(\frac{\partial Z\left(X_0\right)}{\partial X_i}.\sigma_{Xi}\right)^2} \quad (4)$$

$$\beta_Z = \frac{\mu_Z}{\sigma_Z} \ (5); \ \alpha_i = -\frac{\frac{\partial Z\left(X_0\right)}{\partial X_i}\sigma_{Xi}}{\sigma_Z} \quad (6)$$

$$X_i^* = \mu_{Xi} + \alpha_i.\beta.\sigma_{Xi} \quad (7)$$

$$P_{at(Z_i>0)}^i = \phi\left(\beta\right) \ (8); \ P_{sc}^{HT} = 1 - \prod_{i=1}^{n} P_{at}^i \quad (9$$

## B. *Problem of Theory of Confidence Level 3.*

The problems of confidence of safety of works and works systems in theory of confidence level II used the formula of central limit theorem of probability problem. The prerequisite for applying this law is: the destructive mechanism function must be linear, the component random variables must be independent and the random variables are considered of the same distribution laws (In this study, random variables are considered of the same normal distribution law). Many of dam safety calculations are not consistent with this assumption. Among the functions describing the destructive mechanism in **Tab.** 6, random variables cannot be considered independent and their distribution is not normal, and some Z functions are nonlinear, so it is difficult to find the probability distribution law of function Z and it is also impossible to consider Z as a random function with a normal distribution. In this study, the authors used Monte carlo method to calculate the safety probability for the works grade III, the calculations are illustrated in diagram in **Fig.** 1.

## C. *Introductions to SYPRO2016*

SYPRO2016 is written in $C^{++}$ language (the calculation of confidence of levels II and III for works) and Java (calculation of confidence for the system) on Windows in order to model the system of works according to theory of confidence, the program operation algorithms are illustrated in **Fig.** 1.

For the confidence of the system according to formula (9), OPEN FTA program has been prepared for general cases. However, in this study, the authors used the code of OPEN FTA software for a separate case.

In terms of structure, the program is classified into 3 main blocks: Input block, calculation analysis block according to theory of confidence and output block. SYPRO2016 program is applied in the design and repair of irrigation reservoir system according to the required confidence.

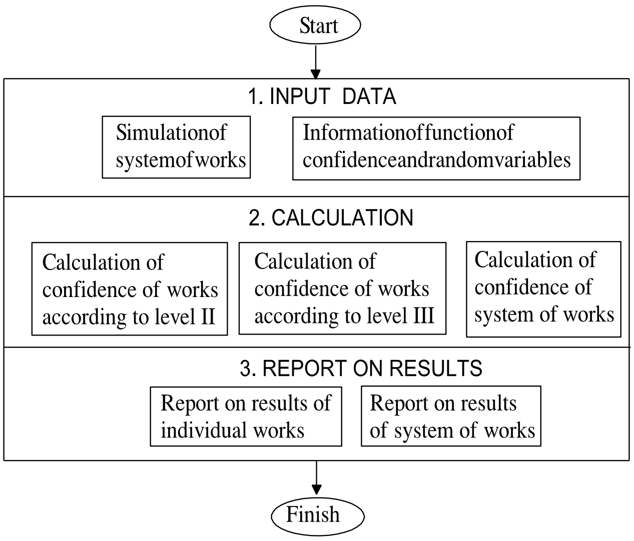


**Fig. 2: Diagram of main modules of *SYPRO2016***

Besides, the program also helps to assess dam quality according to reservoir operation plans as the basis for proposed structural or non-structural measures to improve dam safety. The program calculates the confidence of works and system of works by level II, this is the accepted level and is included in the standards of reliability of many countries around the world such as: Russia, Netheland, China, ... [2]. The program has been tested and reached the required accuracy. SYPRO2016 is used for calculating the confidence of the works when data on random variables do not follow standard (normal) distribution laws and functions of confidence for emergency cases are nonlinear. The program's results are probability of failures of the works, this calculation is of level III. However, when calculating the confidence of a works of level II, the data used as the input parameters of SYPRO2016 are still considered to be approximated that have a normal distribution, so the calculation results of confidence would be wrong if converted into standard distribution law. Besides, considering the mechanism of incident occurrence with each works is independent or not considering the correlation of incident mechanisms. When calculating the confidence of a system of works, interdependent interactions of works are skipped. Assessing the confidence of a works at level III under Monte carlo method is implemented for individual components of the works.

## III. RESULTS AND DISCUSION

### *A. Assessment of confidence of irrigation headworks under single flood operation plan*

The irrigation reservoir headworks considered under this study includes many works items: earth dam, spillway, culvert, hydropower plant. However, to illustrate the ability to calculate the confidence of the works with SYPRO2016 program, the authors calculated the confidence for two works elements: the main earth dam and the spillway no.2 of Phu Ninh reservoir in Quang Nam province which the layout as shown in the **Fig.** 3.

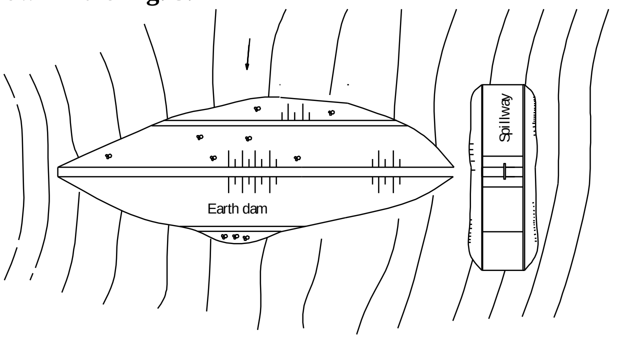


**Fig. 3: General layout of irrigation reservoir headworks.**

In which, the dam is made of homogenous soils. Spillway No.2's spillway is of practical type, including two gated chambers. Both works are of grade II. Under the layout as showed in **Fig.** 3, the works are connected each to other under consecutive link [2].

*1) Diagram of Problem Tree of the System*

The analysis of destructive mechanism that leads to the dam failure of the structural system in the reservoir cluster as arranged in **Fig.** 3 shows that: once the incident occurs independently for the spillway, or for any position of the dam it's considered as a dambreak of system failure. The relationship between the incident of the spillway with the dam break in the headwork system is shown in the diagram of problem tree in **Fig.** 4. [7-9]

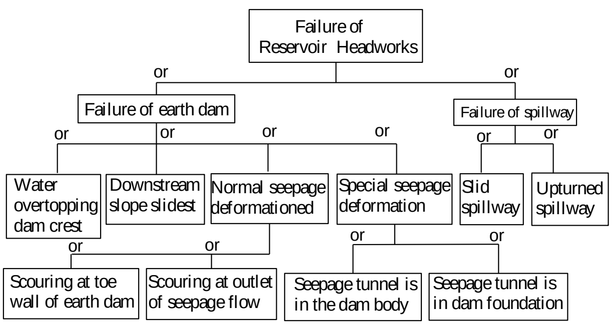


**Fig. 4: Failure tree of Phu Ninh reservoir headworks in Quang**

The analysis of destructive mechanism that leads to the dam failure of the structural system in the reservoir cluster as

arranged in **Fig.** 3 shows that: once the incident occurs independently for the spillway, or for any position of the dam it's considered as a dambreak of system failure. The relationship between the incident of the spillway with the dam break in the headwork system is shown in the diagram of problem tree in **Fig.** 4.

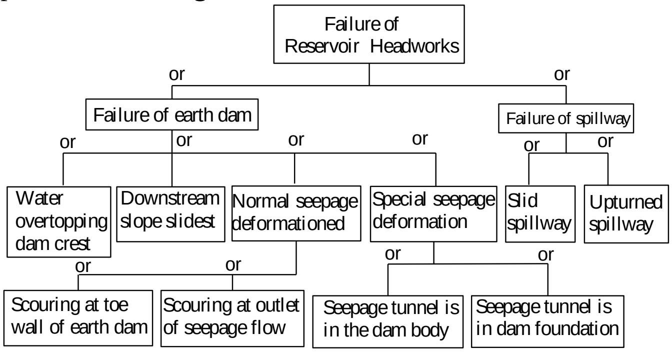

**Fig. 4: Failure tree of Phu Ninh reservoir headworks in Quang**

### *3.1.2 Design of Confidence of System of Works at Level II*

*a) Design data*

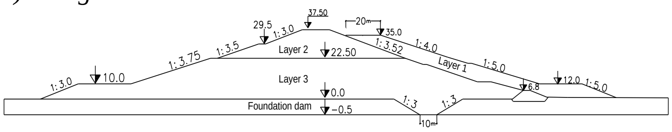


**Fig. 5: Cross section of Phu Ninh earth dam in Quang Nam province.**

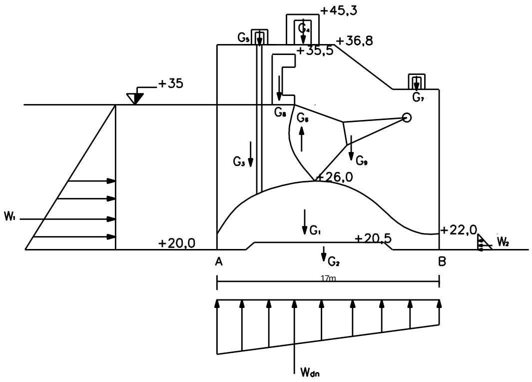


**Fig. 6: Design of stability of spillway No.2 of Phu Ninh dam in Quang Nam province.**

**Tab. 1: Physico-mechanical properties for design of confidence of downstream slope slide mechanism.**

| Name | Symbol of random variables | Mathematical expectation : $\mu$ | Standard deviation: $\sigma$ |
|---|---|---|---|
| Internal friction angle of soils | $t_1$ | 0.335 | 0.049 |
| | $t_2$ | 0.256 | 0.022 |
| | $t_3$ | 0.206 | 0.0209 |
| Density of soils | $\gamma_1$ (KN/m$^3$) | 19.7 | 1.78 |
| | $\gamma_2$ (KN/m$^3$) | 18.515 | 1.8515 |
| | $\gamma_3$ (KN/m$^3$) | 18.3 | 1.863 |
| Unit | $C_1$ (KN/m$^2$ | 23 | 2.3 |

| | | | |
|---|---|---|---|
| cohesion force of soils | $C_2$ (KN/m$^2$) | 22 | 2.2 |
| | $C_3$ (KN/m$^2$) | 22 | 2.2 |

**Tab. 2: Random variables of normal distribution law of overflow mechanism.**

| Name of variables | Symbol | Expectation: $\mu$ | Standard deviation: $\sigma$ |
|---|---|---|---|
| Elevation of dam crest | $Y_{dd}$ (m) | 37.5 | 0.8 |
| Water level in reservoir | $Y_{mn}$ (m) | 35 | 0.5 |
| Velocity of wind | V (m/s) | 13.86 | 1.36 |
| Average wave momentum | D (m | 3120 | 50 |
| Elevation of dam bed | Yo(m) | 0. | 0.2 |
| Height of climbing wave | $h_{sl}$ (m) | 0.95 | 0.15 |

**Tab. 3: Random variables with normal distribution law of scour at toe wall and outlet.**

| Name of variables | Symbol | Expectation: $\mu$ | Standard deviation $\sigma$ |
|---|---|---|---|
| Gradient at toe wall | $J_{chânkhay}^{max}$ | 0.554 | 0.051 |
| Gradien at outlet | $J_{ra}^{max}$ | 0.3 | 0.105 |
| Gradien of seepage at toe wall | $[J]^{chânkhay}$ | 0.75 | - |
| Gradien of seepage at outlet | $[J]^{ra}$ | 0.55 | - |

**Tab. 4: Random variables of standard distribution law of formation of seepage caves in dam body and foundation.**

| Name of variables | Symbol | Expectation : $\mu$ | Standard deviation: $\sigma$ |
|---|---|---|---|
| Water level in the reservoir | $Y_{mn}$ (m) | 35 | 0.5 |
| Elevation of dam's bed | $Y_o$ (m) | 0.2 | 0.2 |
| Length of dam's bed | $L_d$ (m) | 281 | 2.81 |
| Average factor of upstream slope | $m_1$ | 3.53 | 0.25 |
| Thickness of seepage layer | T (m) | 5 | 0.5 |

**Tab. 5: Random variables of standard distribution law for calculation of confidence of spillway**

.

| No | Name of variables | Symbol | Expectation: $\mu$ | Standard deviation: $\sigma$ |
|---|---|---|---|---|
| 1 | Density of concrete | $\gamma_{bt}$ (KN/m$^3$) | 24 | 0.24 |
| 2 | Length of spillway's threshold | L (m) | 17 | 0.5 |
| 3 | Water level in reservoir | $Y_{mn}$ (m) | 35 | 0.5 |
| 4 | Friction coefficient between dam and ground | f | 0.65 | 0.1 |
| 5 | Unit cohesion force of stone foundation | c (KN/m$^2$) | 166.7 | 16.67 |

*2) Function of Confidence and Probability of Problem*

With the problem tree diagram as shown in **Fig.** 4, the establishment of functions of confidence is presented in detail in the monograph "Dam safety confidence design basis" [2]. **Tab.** 6 presents the functions of confidence corresponding to the problem mechanisms that can happen to the two works of the system and the designed confidences for each of those problems by SYPRO2016.

**Tab 6. Reliable function**

| No | Problem mechanism | Function of confidence | Probability of problem | Level of effect on problem of system |
|---|---|---|---|---|
| 1 | Downstream slope slide | $Z_1 = t_2.(25,9.\gamma_1 + 22,771.\gamma_2) + t_3.(128,687.\gamma_1 + 55,806.\gamma_2 + 138,019.\gamma_3) + t_3.(454,007.\gamma_1 + 662,763.\gamma_3) - 7378,168.t_3 + 12,414.C_1 + 12,653.C_2 + 93,079.C_3 - (\gamma_1.112,231 + \gamma_2.58,870 + 146,639.\gamma_3) + 23,433.\gamma_1.t_1$ | $P_1 = 0,0104$ | 16.12% |
| 2 | Water overtopping the crest | $Z_2 = Y_{dd} - (Y_{mn} + H_g + H_{sl}) = Y_{dd} - \left(Y_{mn} + 2.10^{-6}.\frac{V^2.D}{g.(Y_{mn} - Y_o)}.\cos\alpha + H_{sl}\right)$ | $P_2 = 0,0454$ | 70.41% |
| 3 | Scour at toe wall | $Z_3 = [J]^{ra} - J_{ra}^{max}$ | $P_3 = 6,07e-05$ | 0.09% |
| 4 | Scour at outlet | $Z_4 = [J]^{chânkhay} - J_{chânkhay}^{max}$ | $P_4 = 0,009641$ | 14.94% |
| 5 | Formation of seepage cave in the dam body | $Z_5 = 1.15 - (Y_{mn} - Y_o)/(L_d - m_1.(Y_{mn} - Y_o) + m_1.(Y_{mn} - Y_o)/(2m_1 + 1))$ | $P_5 = 2,1E-8$ | 0.0% |
| 6 | Formation of seepage cave in the dam foundation | $Z_6 = 0.2 - (Y_{mn} - Y_o)/(L + 0.88T)$ | $P_6 = 1,05E-6$ | 0.0% |

Retrieval Number B3090078219/19©BEIESP
DOI: 10.35940/ijrteB3090.078219
Journal Website: www.ijrte.org



Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

| | | | | |
|---|---|---|---|---|
| 7 | Slid spillway | $Z_7 = \left[\gamma_{bt}.(6.L-39,5)+7,155.L+Y_{nm}.(5-0,5.L)+47,75\right].f$ $+10.L.c-(6.Y_{mn}-147,38)$ | $P_7 = 2,95E-15$ | 0.0% |
| 8 | Upturned spillway | $Z_8 = 85.\gamma_{bt}.(6.L-39,5)+10250.Y_{mn}-62418,043+5000.3,19$ $-L^2.(16,67.3,19+33,33.Y_{mn}-633,26)$ | $P_8 = 1,4E-17$ | 0.0% |

Probability of problem of the system: $P_{sc}^{HT} = 0,0645$ or probability of safe operation of the system: $P_{at}^{HT} = 0,9355$, confidence of system: $\beta_{HT} = 1,52$.

*3) Design of confidence of safety for earth dam at level III*

Using SYPRO2016 at level 3 for design of confidence for problem of water overtopping dam crest. If input data in **Tab.** 7 and function of confidence is $Z_2$ (**Tab.** 6) probability of problem $P_{sc}^{nuoctran} = 0,038$.

**Tab. 7: Input data for design of confidence of dam at level III**

| No | Name of variables | Symbol of variable | Unit | Expectation: $\mu$ | Standard deviation: $\sigma$ | Probability distribution law |
|---|---|---|---|---|---|---|
| 1 | Elevation of dam crest | $Y_d$ | m | 37.5 | 0.8 | Standard |
| 2 | Level of water in reservoir | $Y_{mn}$ | m | 35 | 0.5 | Weibull |
| 3 | Height of wave | $H_{sl}$ | m | 2.5674 | 0.2021 | Standard Logarithm |
| 4 | Height of tailwater by wind | $H_g$ | m | 0.0161 | 0.020 | Exponential |

*4) Analysis of Results*

Probability of safe operation of the system $P_{at}^{HT} = 0,9355$ or indicator of confidence of the system $\beta_{HT} = 1,52$ are below the probability allowed by design standards [3], [4]. This is indicator of low confidence, if assessed against those standards, it can be concluded that the system's proble is probable due to one of 4 reasons: water overtopping the dam crest; downstream slope slide; scour at toe wall and scour at outlet. The design of confidence of system with various programs such as: Vap, Open FTA give similar results.

Water overtopping dam crest's probability is $P_{(Z<0)} = 0,0454$ or probability of water overtopping dam crest is $P_{at} = 0,9546$, the confidence of safety: $\beta = 1,69$, it's indicator of low confidence. The analysis of effect of random variables on probability of water overtopping dam crest as shown in **Fig.** 7 shows that: elevation of dam crest $Y_{dd}$ and water level in reservoir $Y_{mn}$ cause significant impacts on the probability of overtopping.

The design of confidence of overtopping at level III, random variables are fixed at probability distribution law, the probability of problem : $P_{sc}^{nuoctran} = 0,038$ smaller than approximate calculation at level II. Thus, for a case calculated at level III: error of probability of problem is 16.3%.

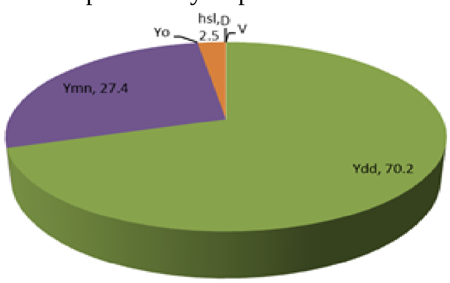


**Fig. 7: Level of effect of random variables on overtopping problem**

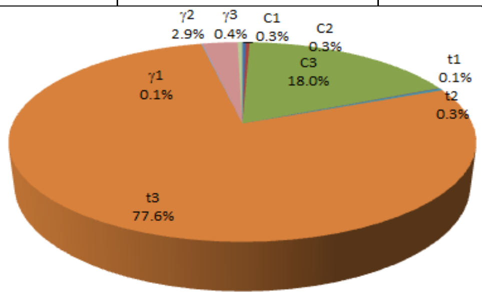


**Fig. 8: Level of effect of random variables on**

Probability of dam slope slide is $P_{(Z<0)} = 0,0104$, $\beta = 2,31$, those values are smaller than the indicator of allowable standard confidences [4], [5]. Transforming confidence $\beta$ into factor of safety K helps to determine: $K = 1,183$ [1]. According to Design Standard for Earth Dam: TCVN 8216-2012, earth dam is classified as works of grade III (with basic loads ), allowed stability factor that help to avoid dam slope slide [K] = 1.3, comparing: $K = 1,183 < \left[K\right] = 1,3$, dam slope is uns**Tab.**. The calculation shows that there is a similarity between the two methods, value of safety factor K and indicator of confidence $\beta$ are smaller than the allowed ones. Analysis of effect of random variables on probability of slope slide as in **Fig.** 8 shows that internal friction $tg\varphi_3$ takes 77.6%, unit cohesion force

$C_3$ takes 18.0%. This proves soil layer 3 causes the most significant impact on the stability of downstream slope of the dam. This is very important data collected to be the basis for development of measures for improving the confidence of safety for the dam.

*B. Design of dam at the allowed confidence*

When calculating the confidence of downstream slope failure mechanism with the size of earth dam as shown in **Fig.** 5 and the physico-mechanical properties as shown in **Tab.** 1, the confidence of the dam is relatively low, so in this study group of authors redesigned the basic section of the dam according to the allowable confidence.

The irrigation reservoir headworks's layout as shown in **Fig.** 3 is a works of grade II, according to Vietnamese standards, the lifespan of the works is 75 years, according to the design experiences, the allowable probability of problem of the dam $\left[P_{sc}^{dap}\right] = 0,001333$, [6], [7]. Based on the analysis of the problem tree of the headworks as shown in **Fig.** 4 and the level of effect of the problem mechanisms on the headworks, the level of effect of random variables on each problem, it's able to distribute the allowed probability of problem for each problem mechanism as shown in **Tab.** 7.

In order to determine the size of dam upon the confidence of various problem mechanisms:

- Overtopping: determining crest of dam $Z_{dd.}$
- Upstream slope slide: determining upstream slope coefficient $m_{1.}$
- Downstream slope slide: determining downstream slope coefficient $m_2$.
- Formation of seepage cave in the dam foundation: determining length of dam bed $L_{d.}$

Developing functions of confidence for 4 problem mechanisms [1], using SYPRO2016, repeating to determine the size of dam as shown in **Tab.** 8.

**Tab. 8: Main parameters of earth dam calculated by allowed probability of problem**

| Mechanism of problem | Overtopping | Upstream slope slide | Downstream slope slide | Formation of seepage dam in dam foundation |
|---|---|---|---|---|
| Level of effect on system's problem % | 70,41 | 1 | 16,12 | 1,0 |
| Probability of problem | 8,168E-04 | 1,333E-05 | 1,871E-04 | 1,333E-05 |
| Size of dam | Dam crest: $Z_{dd}$ (m) | Upstream slope cofficient: $m_1$ | Downstream slope coefficient: $m_2$ | Length of dam bed: $L_d$ (m) |
| Design values | 38.5 | 4.75 | 4.45 | 318.6 |

Comment: If the dam's dimensions are as shown in **Tab.** 7, the safety of the dam will be guaranteed or the probability of a dam problem will be less than the allowed probability of the problem.

## IV. CONCLUSION

Based on the theory of probability - statistics, the theory of hydraulic works and the theory of system, the authors have presented how to develop algorithms and flowcharts for calculating the confidence of safety of irrigation work according to the theory of confidence levels II and III. SYPRO2016 is written on the basis of algorithms as shown in diagram in **Fig.** 1 and used to calculate the confidence of safety of irrigation works. In this study, the authors used SYPRO2016 software to assess the confidence of safety of an irrigation reservoir headwork and then draw conclusions about the safety of individual items of the headworks after compared with the allowed confidence standards of other countries and the safety factor standards of Vietnam. Through the calculation of confidence, it is possible to analyze and predict the influence of random variables on safety of works in order to have appropriate measures to improve the safety of items of headworks. Indicating different levels of impact on safety of a works facilitating the redesign of the works by the allowed confidence of safety. The content of the article is a practical reference for dam safety design and management in Vietnam today.

## REFERENCES


1. Ministry of Agriculture and Rural Development, Dam safety program in 2015,
2. Nguyen Van Mao, Nguyen Huu Bao, Nguyen Lan Huong, Basis for design of confidence of dam safety, Construction Publishing House, 2014,
3. Nguyen Lan Huong, Calculating the confidence and safety of reservoir headwork, Journal of Water Resources Science and Technology and Environment No. 44, Year 3-2014,
4. ISO 2394, International Standars, General principles reliability structures,
5. Uniform standard for designing structural reliability, state standards, People's Republic of China JB 50153 - 92, [6] Probabilistic design and risk assessment of large dams, 1996, J,K Virijling/ M, Hauer/ R,E, Jorissen,
6. Mai Van Cong, Probabilistic design of coastal flood defences in Vietnam, Doctoral thesis, Netherlands (2010),
7. Nguyen Quang Hung. The effect of waves on the reliability of Embankment structure. Vietnam Hydraulic mechanics conference. . 96-99. 2001.
8. 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.
9. 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