Influence of random variability of soil parameters and seismic acceleration on a homogeneous earth dam stability.

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ABSTRACT: The reliability approach is carried out in this study to take into account the uncertainties linked to the calculating parameters of a dam stability. Three random variables are considered; namely the seismic acceleration (A), cohesion (C') and friction angle (ϕ') of the dam backfill. These variables are generated with log-normal distribution law. The state function, dictated by limit state of slops sliding, is taken from Fellenius mechanical model. The failure probability P_f is obtained by Monte Carlo simulation method, depending on the variation coefficient Cv. The results of the reliability analysis showed that the failure probability is more sensitive to random variability of the ground parameters (C', ϕ') than to the random variability of seismic acceleration (A), for the two slopes.

Keyword: Dam, Slope stability, Fellenius, Monte Carlo, Failure probability

1 INTRODUCTION

Usually, the stability analysis of dam with respect to the sliding risk is based on deterministic limit equilibrium approaches (Fellenius and Bishop) or numerical methods (MEF and MDF) (Mouyeaux,2015). An overall safety coefficient of the structure is determined from the characteristic values of the calculation parameters (USAC,2003). In these methodologies, the uncertainties associated to each parameter, involved in dam stability calculation, are not rigorously taken into consideration. Recent advances in the uncertainties quantification associated to the dams behavior have paved the way for the use of reliability methods (Guo,2020). These approaches, which are based on a probabilistic calculation, allow a better consideration of random variability inherent to each parameter, and proceed to quantitative analysis of failure risk dam, knowing the limit state criterion (Favre,1990).

In this research we propose a mechano-reliability approach for the sliding stability analysis of an homogeneous earth dam, taking into account the random variability of the seismic action and the effective ground parameters, namely the cohesion C' and the friction angle φ' in long term. Monte Carlo simulation method is adopted to calculate the failure probability of these upstream and downstream slopes.

2 MECHANICAL MODEL

The sability calculation dam is carried out in this section by modified Fellenius method, taking into account seismic acceleration, hydrostatic force Uβ and pore pressures Uα (Figure 1).

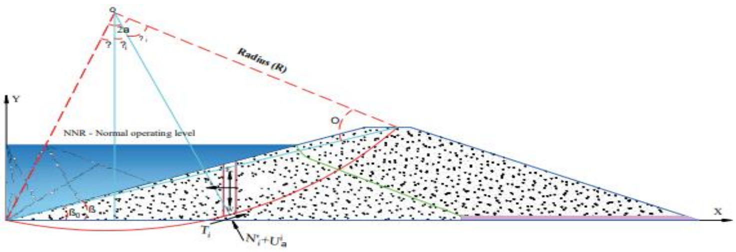

Figure 1. The sliding circle of upstream slope of an earth dam (Belazouz and *al*., 2023).

The inventory of forces, acting along the perpendicular direction to the sliding surface (figure 2), allows to deduce the resulting stabilizing normal component of the slice (i), such as:

$$N'_i = -U_\alpha^i - (W_i - F_v\ )cos\alpha_i - F_h sin\alpha_i - U_{i\beta}\cos(\beta - \alpha_i) \tag{1}$$

The tangential driving forces acting on the sliding surface are written as:

$$T_i = [(W_i - F_v\ ) + U_{i\beta}\ cos\beta]sin\alpha_i - U_{i\beta} sin\beta + F_h \tag{2}$$

where:
N'_i: effective normal force;
W_i: slice weight (i);
F_h, F_v: horizontal and vertical component of seismic loading;
$U_{\beta i}$: hydrostatic load on the slice upper surface;
$U_{\alpha i}$: component of the interstitial force;
αi: Inclination of the base of the slice (i);
βi: Inclination of the top of the slice (i).

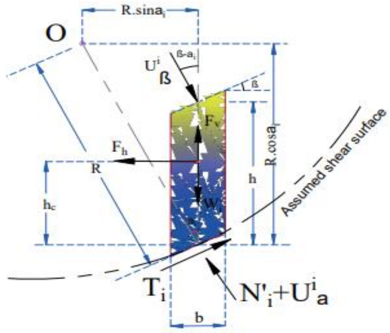

Figure 2. Forces Inventory acting on slice (i).

Moment of the stabilizing forces at base of section (i), is given by relation (3):

$$Ms = \sum_{i=1}^{n} R.\ \{C'.b\ + [\ (Wi\ - Fv).\cos\alpha_i - Fh.\sin\alpha_i\ -\ U_\alpha^i\ +\ U_\beta^i.\cos\ (\beta - \alpha_i)].\ \tan\varphi'\} \tag{3}$$

Driving moment relating to the center of the circle (o) is given by relation (5):

$$Mm = \sum_{i=1}^{n}\ [(Wi - Fv)\ +\ U_\beta^i\ \cos\beta]\ Rsin\alpha_i\ U_\beta^i sin\beta(Rcos\alpha_i - h)\ +\ Fh(Rcos\alpha_i\ -\ hc)\} \tag{4}$$

3 RELIABILITY MODEL

To quantify failure risk of earth dam we define the limit state function G({X}) for the failure mode by sliding of these upstream and downstream slopes, such us :

$$G(\{X\}) = R(\{X\}) - S(\{X\}) \tag{5}$$

R({X}): Resistance of dam with respect to failure mode , representing the stabilizing moment,
S({X}): Applied stress, representing the driving moment,
{(X)}: Vector of random variables xi.
The failure of dam is directly linked to exceeding the limit state G({X}),

$$P_f = (G(\{X\}) \leq 0 \tag{6}$$

The analytical evaluation of the probability failure P_f is carried out using the Monte Carlo simulations method (Lemaire, 2007) which is based on generation of large random draws number, noted N. A failure indicator I_d is used to define the failure state system for function G({X}), such that:

$$I_d = \begin{cases} 1\ si\ G \leq 0 \\ 0\ si\ G > 0 \end{cases} \tag{7}$$

The probability failure P_f is evaluated by: $$P_f = \frac{\sum_i^N I_d}{N} \tag{8}$$

4 CASE STUDY

The practical application concerns the stability analysis of an homogeneous earth dam of Châabet Thrid located in Medea (Algeria). This region is classified as a zone of medium seismicity (zone IIa), in accordance with RPA(2023). The geometric and physical characteristics are illustrated in Table 1. A Log-normal distribution law is adopted to generate the cohesion (C') and the friction angle (φ') in accordance with the literature (Metya, 2015). For seismic acceleration a log-normal law is defined on basis of a Kolmogorov-Smirnov test, carried out on a sample of 45 accelerograms recorded following Boumerdes the earthquake in 2003.

Table 1. Dam geometrical characteristics (PNUD, 2015)

Designation of parameter	Value	Unit
Height of the Dam	18	m
width of the Crest	7	m
Slope of the upstream dam	(1:3)	-
Slope of the downstream dam	(1:.2.5)	-

Table2. Statistics of dam constituting material

Désignation	Mean value	Coefficient of variation	Unit
Effective cohesion (C')	20.36	20%	KN/m²
Effective friction angle (φ')	26.55	10%	(°)
Saturated density (γ_{sa}t)	21	5%	KN/m^3
Wet density (γ_h)	19	5	KN/m^3

5 RESULTS AND INTERPRETATIONS

The failure probability P_f is analyzed taking into account the random variability of the ground parameters (C',φ'), and the seismic acceleration (A). The results show that in a normal operating situation (A=0) the dam is stable, P_f=0 for both slops (table 3). Furthermore, in medium seismicity zone, the value of P_f exceeds the admissible failure probability admitted for the civil engineering structures ($P_{fadm}= 10^{-3}$) (Lemaire, 2007), for the upstream and downstream slope.

Table2: Failure probability results.

Designation of parameter	Value
Probability P_f of the upstream slope (SNE)	0
Probability P_f of the downstream slope (SNE)	0
Probability P_f of the upstream slope (SS)	0.0217
Probability P_f of the downstream slope (SS)	0.0078

To study the seismic zone influence we vary the dam location from low seismicity zone (zone I) to high seismicity (zone III). The results show that P_f evolves in the same way as a function of seismic acceleration intensity for the upstream and downstream slopes (figure 5).

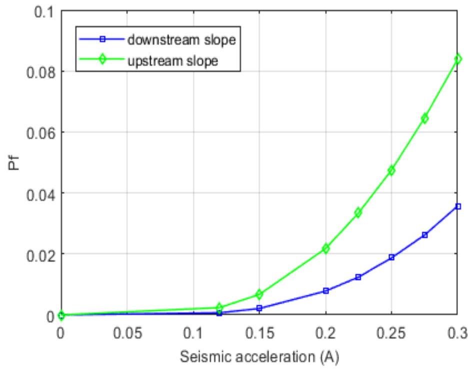

Figure 5. P_f in function of seismic acceleration (random A, C', and φ').

However, the upstream slope is more sensitive to seismic acceleration (P_{famont}> P_{faval}). We note that apart the low seismicity zone (A<0.12), the failure probability exceeds the admissible probability, whatever the zone considered for the two slopes.

The influence of the random variability of seismic action, and soil parameters is analyzed separately, considering a coefficient of variation of Cv=0.2, for the different seismic zones (figure 6). The results illustrate that P_f is more sensitive to soil parameters random variability, for both slopes. The results also reveal that the upstream slope is more sensitive to seismic acceleration random variability.

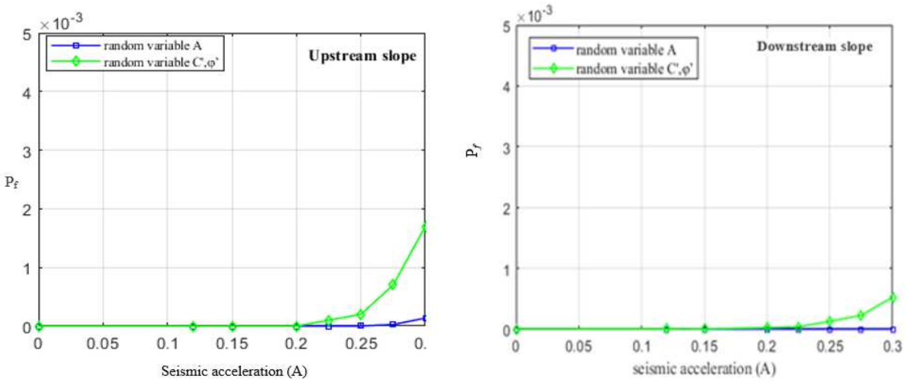

Figure 6 : Influence of random variability A, and (C', φ') on P*f* (upstream and downstream slope).

6 CONCLUSION

The reliability analysis of dam stability is carried out in this research taking into account the uncertainties linked to the seismic acceleration (A) and the soil parameters (C', φ '). The limit state function is dictated by the sliding of its upstream and downstream slopes. The failure probability results showed that the dam is stable in normal operating situation (A=0). In a seismic situation, the results showed that the upstream slope is more sensitive to seismic action, whatever the seismic area considered. The results also revealed that the failure probability is more sensitive to the random variability of the soil parameters, for the two slopes. We conclude that a spatial variability analysis of the soil parameters would be interesting.

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