A PARAMETRIC STUDY OF SLOPE STABILITY ANALYSIS IN COHESIVE SOILS USING A PROBABILISTIC METHOD

AHMED J. HAJI*, and MOHAMMED S. HUSSAIN**
*Civil Engineering Department, College of Engineering, University of Duhok, 1006 AJ Duhok, Kurdistan Region-Iraq
**Civil Engineering Department, College of Engineering, University of Duhok, 1006 AJ Duhok, Kurdistan Region-Iraq

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ABSTRACT

The probabilistic analysis of slope stability, accounting for the heterogeneity of the soil medium, was attempted in this study using an advanced approach called the Random Finite Element Method (RFEM). The method was used to investigate the effects of two statistical parameters, namely the coefficient of variation (CoV) and the isotropic spatial correlation length ($\theta = \theta_x = \theta_y$) of different soil parameters on the probability of failure (P_f) of a cohesive soil slope. The statistical effects of cohesion (C), angle of internal friction (Φ), modulus of elasticity (E), and unit weight (ɣ) of the 5V:6H soil slope were examined. The investigated values of θ were 1, 5, 10, 20, 30, and 50 m. The considered CoV values of cohesion (CoV_C) were 0, 0.1, 0.2, 0.3, 0.4, 0.5, and 0.7 and the CoV values of Φ (CoV_Φ) were 0, 0.05, 0.10, 0.15, 0.20, and 0.30. It is highlighted that the correlation length was directly proportional to the P_f for all the implemented parameters. Moreover, the results show that higher values of CoV of all the parameters corresponded to higher P_fs. Notably, changes in the CoV_C and CoV_Φ had a more significant impact on failure probability compared to variations in the modulus of elasticity or unit weight. For the cases with high correlation length and large CoV_C, a measured failure probability of about 45% was noted. In terms of uncertainty of Φ, the slope with large CoV_Φ experienced the P_f varying from 20% to 40% at the larger values of θ. Finally, the study brought attention to the significance of considering the spatial variability of soil properties for conservative evaluation of the stability of soil slopes.

***KEYWORDS*:** Isotropic soils, Probabilistic analysis, Random finite element method, Slope stability, Spatially varying soil.

1. INTRODUCTION

Slope stability is a significant aspect of geotechnical engineering, and is frequently encountered in various civil engineering projects, including the construction of highways, railways, and earth dams. Therefore, it is important to examine the available methods for analyzing slope stability and be aware of their limitations. This knowledge enables geotechnical engineers to make informed decisions when designing slopes, ensuring both safety and cost-effectiveness.

Traditionally, the stability of slopes has been analyzed using deterministic values of the soil strength, i.e., the soil mass has been assumed to be uniform, which is not the case. Soil is a complex and spatially variable material. This spatial variability stems from different geologic, physical, chemical, and environmental processes (Phoon & Kulhawy, 1999; Pramanik et al., 2017). Therefore, the uncertainty and randomness typically found in soil characteristics might be major influencers of the reliability of the safety factor (Malkawi et al., 2000). To investigate the uncertainty analysis of soil properties and its impact on soil slope stability, one must employ probabilistic methods. Simple probabilistic methods were first introduced in the literature to account for the inherent uncertainty in soil. In these methods, many realizations are analyzed, and each of them is given a single random variable for the strength parameters where no variation occurs within the soil slope; the strength parameters only vary from one realization to another. One shortcoming of the simple probabilistic methods is that they do not take into account spatial variability. To solve this problem, in the early 1990s, a new method called the Random Finite Element Method (RFEM) was introduced by a group of researchers (Griffiths & Fenton, 1993; Griffiths et al., 1994).

Procedures for probabilistic slope stability analysis differ in assumptions, limitations, ability to tackle complicated problems, and mathematical complexity. However, most of them belong to one of the two categories: approximate methods, such as the First Order Second Moment method, the Point Estimate Method (PEM), and event tree method; and Monte Carlo methods such as the Stochastic Finite Element Method (SFEM), and the Random Finite Element Method (RFEM) (El-Ramly et al., 2002).

In comparison to the RFEM, the main drawbacks of other probabilistic methods are accuracy, subjectivity and computational time. In terms of accuracy, the point estimate method results suffer from weak calculations for modeling nonlinear soil properties, and for cases with large soil variability (Baecher & Christian, 2003). Also, subjectivity is reported as a disadvantage for the event tree method, wherein each variable is assigned a probability and distribution based on the opinion of the person performing the analysis (Sheykhloo, 2015). The RFEM benefits from using the Local Average Subdivision (LAS) algorithm. Fenton and Vanmarcke (1990) highlighted the efficiency of a LAS algorithm in terms of computational time consumed compared to the other approaches in the literature. The LAS approach has a good compatibility with the FE analysis because the local average values can be mapped onto the finite elements with ease (Fenton & Griffiths, 1996). These advantages enable the RFEM to be potent in simulating complex geotechnical problems.

The more advanced method (RFEM) uses a random field generation algorithm (e.g., Local Average Subdivision (LAS)) in tandem with a nonlinear elasto-plastic finite element method. Then it analyzes the stability of the soil slope (in this study) in the framework of Monte Carlo Simulations (MCS).The method has then been applied by the same group of researchers and their colleagues to analyze numerous geotechnical problems.

Griffiths et al. (2009) study the effect of slope inclination, factor of safety based on mean values, and the cross correlation between strength parameters on the critical coefficient of variation. It is argued that the results of the estimation of the P_f are unconservative for cases in which the spatial variability of soil parameters is ignored and the CoV of the shear strength parameters exceeds a certain critical value. Similarly, a positive relation between slope inclination and P_f is observed by Allahverdizadeh et al. (2015b), conforming with traditional methods of analysis. They demonstrate the existence of a critical correlation length in their results. Wherein the P_f increases with bigger correlation lengths for slopes that have a small CoV. Chok et al. (2015) investigate many aspects of stochastic slope stability analysis. It is observed that the P_f increases as the CoV or θ increases. The authors also conclude that in the case where θ approaches infinity, P_f could be overestimated. The P_f is compared to the factor of safety (FS), drawing many conclusions; the most notable one is that the FS is a poor measure of the true safety of the slope and that it is only reliable at very small CoVs. Recently, the effect of spatial correlation length on the P_f considering anisotropy has been focused on by groups of researchers such as (Akbas & Huvaj, 2015; Liu et al., 2018; Nguyen et al., 2023; Zhu et al., 2019) using the RFEM approach.

In the present study, the RFEM approach is utilized to investigate the effects of the variability of different soil properties (C, Φ, E, and γ) on the probability of failure of a cohesive soil slope. In the framework of this probabilistic parametric study, the influence of isotropic correlation length ($\theta_x = \theta_y$) is studied in two different scenarios. The simulations are conducted by incorporating a diverse set of coefficients of variation (CoV) for soil properties. In the first scenario, all the parameters are set to have a (CoV = 0) except the one being studied. In the second scenario of the study, CoVs are set to a typical nonzero constant, and only the parameter of the study has its CoV varied.

2. PROBLEM STATEMENT AND METHODOLOGY

A hypothetical slope (5V:6H) of cohesive soil is examined. The geometry of the model is illustrated in Fig. (1). The slope has a height of 12m; the thickness of the layer on the left is 22m and on the right is 10m; the distance from the crest of the slope to the left side is 33m and from the toe of the slope to the right side is 20m. Both sides of the slope are restricted in the horizontal direction but free in the vertical direction. The bottom of the slope is restrained both horizontally and vertically. A nonlinear elasto-plastic finite element with a Mohr-Coulomb failure criterion is performed to analyze the problem. It uses 8-noded quadrilateral elements. Smith and Griffiths (1998, 2004) explain the theory behind the adopted finite element method, and Griffiths and Lane (1999) discuss how this method is used in analyzing slope stability. The generated FE mesh has 65 elements in the x direction and 22 elements in the y direction, with each element having a size of 1m by 1m. The measured deterministic factor of safety of the slope is 1.09 for the soil properties listed in Table (1). This is comparable to the results obtained using different approaches of the limit equilibrium (FS =1.24 by Bishop; 1.14 by Janbu; 1.24 by Morgenstern-Price; 1.32 by Spencer; 1.15 by Ordinary Method of Slices, 1.23 by Sarma) and also Optum G2 software (Krabbenhoft et al., 2015) (FS=1.18).

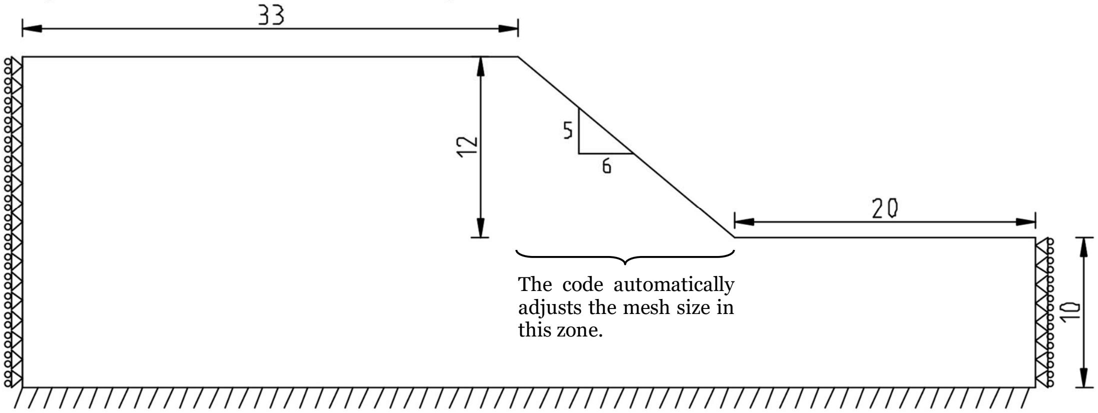

Fig.(1):- Geometry of the slope analyzed in the study (all dimensions are in meters).

The model is used to conduct the probabilistic parametric study approach to study the effect of spatial variability of different soil properties on the probability of failure of the slope. This is utilized using the RFEM method. The key input parameters for the random field include the mean (μ), coefficient of variation (CoV), and correlation length (θ). The corresponding statistical parameters of the mentioned soil properties that are studied using this probabilistic approach are listed in Table (1). These values are based on the typical range suggested in literature. The mean values of the studied soft clay soil properties are 10 kPa for cohesion strength (μ_C = 10 kPa), 25° for angle of internal friction (μ_Φ = 25°), 10 MPa for modulus of elasticity (μ_E = 10 MPa), and finally 18 kN/m^3 for unit weight (μ_Y = 18 kN/m^3). Due to minimal spatial variability observed in Poisson's ratio, as evidenced by previous studies (Paice et al., 1994; Fenton & Griffiths, 2002; Jimenez & Sitar, 2009), it is maintained at a constant value of $\nu = 0.3$ throughout the entirety of this study.

The correlation length (θ), also known as the scale of fluctuation, represents a distance over which points exhibit significant interrelation (Fenton & Griffiths, 2003). A smaller scale of fluctuation suggests that the soil property fluctuates rapidly in the spatial domain, which results in a ragged random field. On the other hand, a larger scale indicates a substantial relationship over an extensive spatial range, displaying a smoothly varying field (Griffiths et al., 2002; Fenton et al., 2011). When the correlation lengths in both horizontal and vertical directions are equal, the model is characterized as isotropic ($\theta_x = \theta_y$). Herein, different values of isotropic correlation lengths are examined ($\theta_x = \theta_y$ = 1, 5, 10, 20, 30, and 50 meters).

Table (1):- The input parameters used for the RFEM simulations.

Parameters	Values	References
μ_C	10 kPa	(Chai & Carter, 2011; Reeves et al., 2006)
μ_Φ	25°	(Das, 2011)
μ_E	10 MPa	(Bowles, 1996; Gunaratne, 2014)
μ_γ	18 kN/m^3	(Carter & Bentley, 2016)
CoV_C	0.1, 0.2, 0.3, 0.4, 0.5, 0.7	(Duncan, 2000; Baecher & Christian, 2003; Duncan et al., 2014; Rao & Sivakumar Babu, 2016)
CoV_Φ	0.05, 0.1, 0.15, 0.2, 0.3	(Duncan, 2000; Baecher & Christian, 2003; Duncan et al., 2014; Rao & Sivakumar Babu, 2016)
CoV_E	0.1, 0.3, 0.5, 0.7, 1, 3	(Baecher & Christian, 2003)
CoV_γ	0.01, 0.05, 0.1, 0.2, 0.5	(Duncan, 2000; Baecher & Christian, 2003; Duncan et al., 2014)

The Monte Carlo and the 2-D Local Average Subdivision (Fenton & Vanmarcke, 1990) techniques are employed to simulate realizations of the random field, and then the mapped slopes are subsequently passed to the Finite Element Method (FEM) for analyzing their failure conditions. The slope is labeled as failed if the calculations do not converge within a set number of iterations, 500 in this case, as the code suggests using this value as the recommended setting. Fig. (2) illustrates the typical flow chart of the RFEM procedure used in this study. The process of mapping the soil properties to the specified geometry of the slope and its numerical analysis are repeatedly performed again and again until the set number of realizations is reached. The number of realizations is set to 1000 in this study, which was deemed enough to produce stable and repeatable results by (Griffiths & Fenton, 2004; Griffiths et al., 2007; Zhu et al., 2017); then the P_f of the slope is measured.

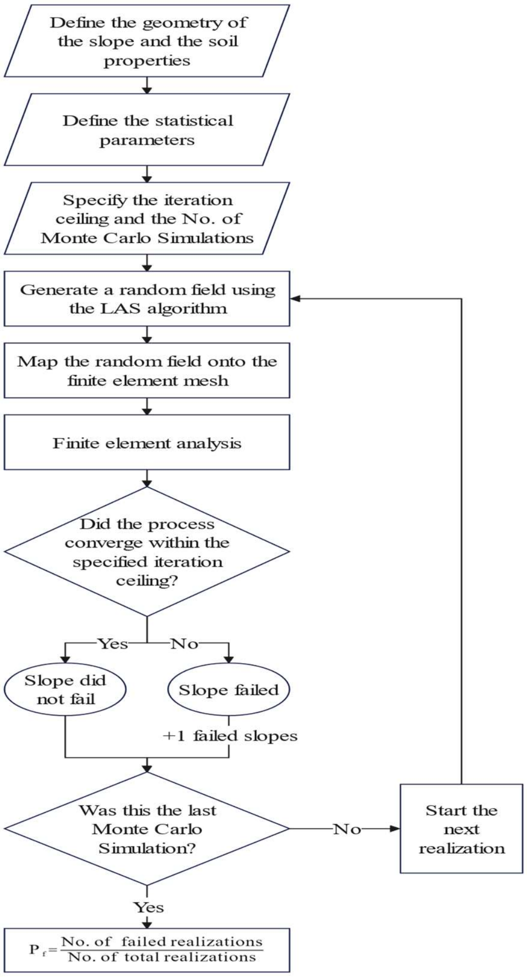

Fig.(2):- Flow chart of the RFEM process used in this study.

3. Parametric study

The study attempts to examine the effects of isotropic spatial variability on various soil properties in two different scenarios. In the first scenario, all the parameters are set to have a CoV = 0 except one. This helps to isolate the effect of the CoV of one parameter at a time. The parameters that are studied using this approach are the cohesion strength, angle of internal friction, modulus of elasticity, and unit weight. And each parameter whose CoV is studied is given lognormal distribution. This distribution is recommended for its simplicity and to avoid negative values of the parameters (Fenton & Griffiths, 2003, 2008; Huang et al., 2015). So, in the first scenario, CoVs are set to zero for any parameter that is not being studied. In the second scenario of the study, a different approach is used, where CoVs are set to a nonzero constant and only the parameter of the study has its CoV varied. This model is more realistic than the former because, in reality, all the parameters exhibit uncertainty, not just one.

The isotropic properties of soil are manipulated by considering the same scale of fluctuation (correlation length, θ) in both directions ($\theta = \theta_x = \theta_y$). For this purpose, the isotropic correlation length is set to ($\theta_x = \theta_y = 1$, 5, 10, 20, 30, and 50 meters). It was desired to test a wide range of correlation lengths, starting at a correlation length equal to the element size and ending at a correlation length that is close to the horizontal dimension of the slope model. Similar ranges have been explored in the literature (Griffiths & Fenton, 2004; Griffiths et al., 2009).

4. RESULTS AND DISCUSSION

4.1. Scenario 1: Zero CoV of Parameters

For this scenario, the CoV of every parameter except the one whose effect is being examined is set to zero. The parameters studied in this section are the cohesive strength, angle of internal friction, modulus of elasticity, and unit weight. The probabilistic analysis of the slope is conducted using isotropic values of correlation lengths from 1 to 50 meters ($\theta = \theta_x = \theta_y = 1$, 5, 10, 20, 30, and 50 m).

4.1.1. Cohesion strength

In order to highlight the effect of randomness in cohesion strength on the safety of the slope, the CoV_C spans from 0.10 to 0.70 (0.10, 0.20, 0.30, 0.40, 0.50, and 0.70). However, the CoVs of angle of internal friction, modulus of elasticity, and unit weight are all set to zero. The P_f ranges from 0% to 45% by combining various CoV_C and correlation lengths, as shown in Fig. (3). Higher failure probabilities are associated with high CoV_C values, which suggest greater uncertainty in the value of μ_C. Comparable trends are observed by Griffiths et al. (2009) and Zhu et al. (2019). For the case with $CoV_C = 0.7$, the P_f value at a small θ of 1m is approximately 25%. This value increases when θ increases and reaches 45% for the case with θ of 50 m. For the case of $CoV_C = 0.1$, the P_f value increases from 0% when θ is small to about 1% at a θ of 50 m. This illustrates that soils characterized by a higher coefficient of variation are more likely to experience slope failure. In addition, as the isotropic correlation length increases, the P_f also increases, with the biggest increase being observed at shorter correlation lengths. Similar conclusions have been reached by Griffiths & Fenton (2004) and Allahverdizadeh et al. (2015a) Fig. (4) depicts samples of realizations of cohesion random fields for the cases with CoV_C = 0.1, 0.2, 0.3, 0.4, 0.5, and 0.7 that are analyzed when the correlation length θ = 10m. The meshing and a thus typical failure mechanism are clearly visible in the majority of these realizations. In these figures, the darker zones have larger cohesion values. Fig. (5) shows samples of the random realizations generated for each correlation length θ = 1, 5, 10, 20, 30, and 50m for the cases where $CoV_C = 0.30$. This figure illustrates, the general influence of θ in RFEM analysis.

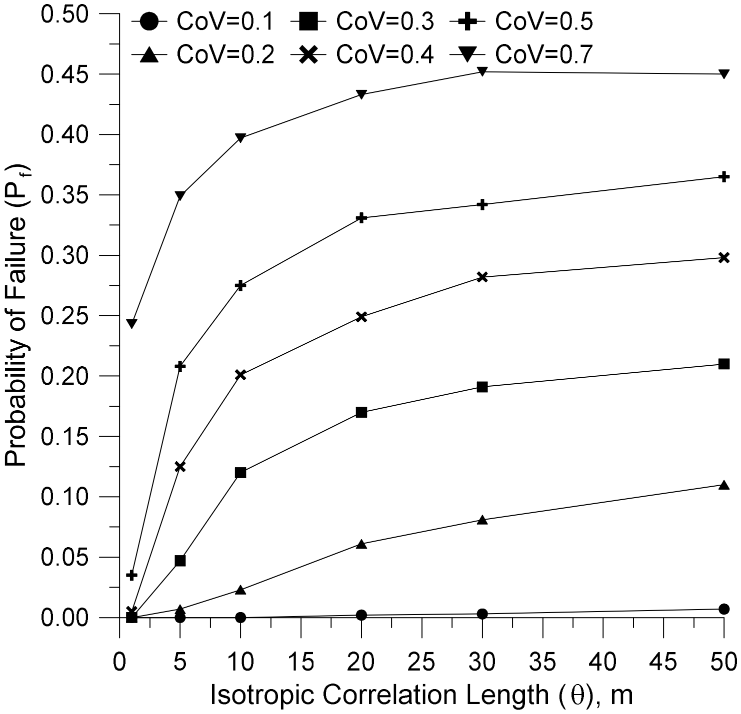

Fig.(1):- Variation of P_f with isotropic correlation length (θ) and CoV_C examined in scenario 1.

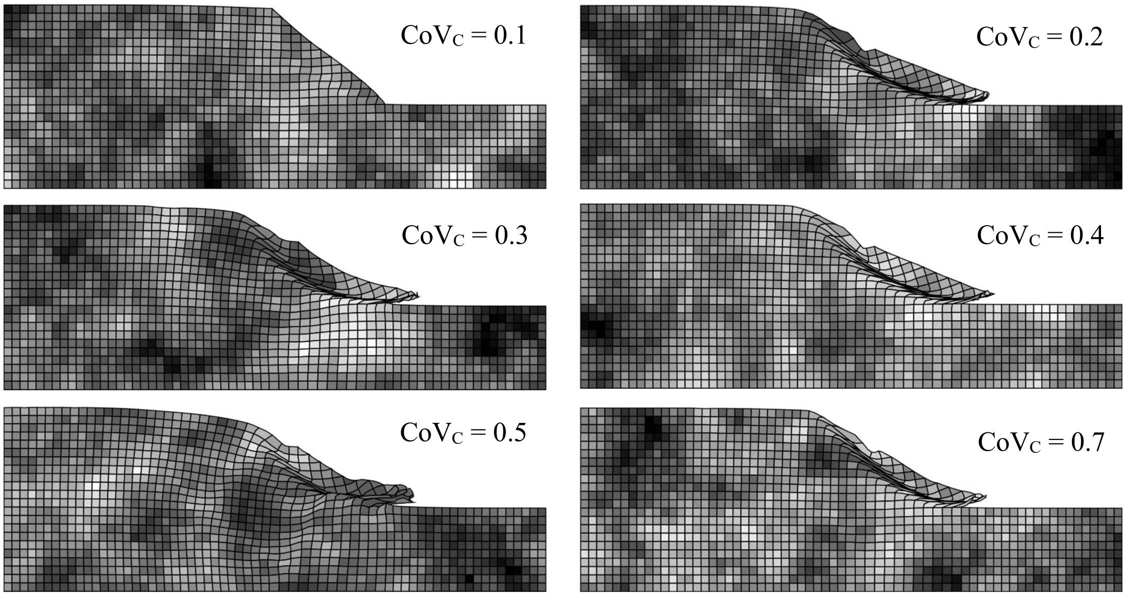

Fig.(4):- Several cohesion-random field realizations (and failure mechanisms) for the case with θ=10m.

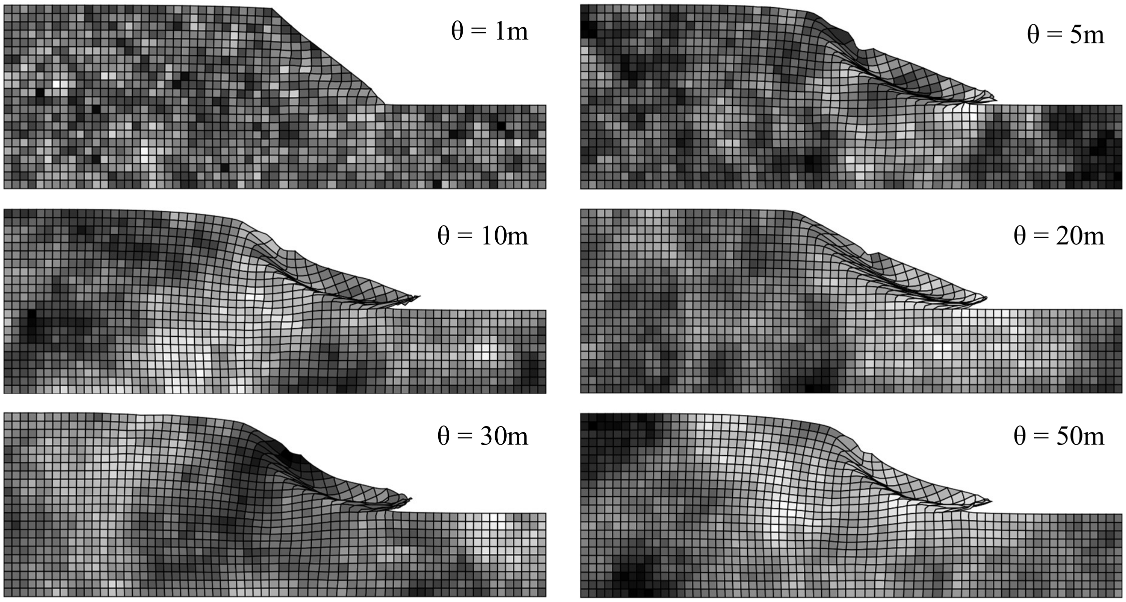

Fig.(5):- Selected realizations of the developed cohesion-random fields for different isotropic correlation lengths.

4.1.2. Angle of internal friction

The stochastic effects of Φ are measured by assuming the CoV_{Φ} values in the range of 0.05 to 0.30 (i.e., 0.05, 0.10, 0.15, 0.20, and 0.30). The probabilities of failure for various combinations of CoV and correlation lengths are shown in Fig. (6) and their values fall between 0% and 40%. This shows that an increase in CoV_{Φ} results in larger values of the P_f. Similarly, a rise in correlation length results in a higher P_f; The data collected by Szynakiewicz et al. (2002) showcase these relations. The findings underscore the significance of taking into account the impact of spatial variability on the safety of soil slopes. In other words, a traditional or deterministic approach, wherein, the spatial variability of soil is disregarded, tends to underestimate the failure probability and thus produce unconservative estimates of the quantitative assessment of soil slope stability.

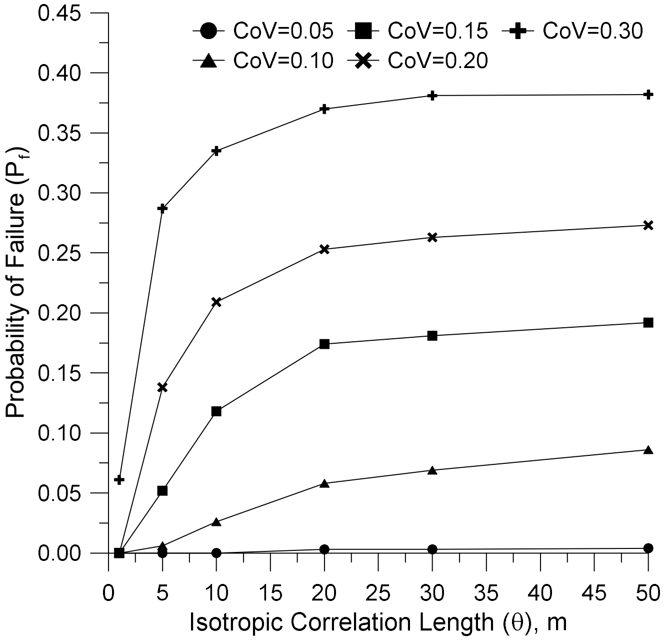

Fig.(6):- P_f versus isotropic correlation length (θ) for various values of CoV_Φ analyzed within Scenario 1

4.1.3. Modulus of elasticity and unit weight

Tables (2) and (3) show the effect of CoV of modulus of elasticity (CoV_E) and unit weight ($CoV_ɣ$) on P_f respectively. The ranges of values used are 0.10 to 1.00 for CoV_E and 0.01 to 0.50 for $CoV_ɣ$. In comparison to the effects of the strength characteristics outlined in the preceding sections, the effects of CoV_E and $CoV_ɣ$ are negligible. Alonso (1976) also observes that the effect of variation in ɣ on P_f is small; Chok et al. (2015) argue that this is due to the fact that uncertainty in ɣ is usually small as reported in the literature (Duncan, 2000; Baecher & Christian, 2003). Therefore, the primary emphasis of the second phase of the study will revolve around the effect of coefficients of variation of the strength parameters only, and those of modulus of elasticity and unit weight will not be considered.

Table(1):- Variations of P_f with various values of isotropic θ (m) and CoV_E

Isotropic correlation length (m)	**CoV_E**				
	0.10	**0.30**	**0.50**	**0.70**	**1.00**
1	0.000	0.000	0.000	0.000	0.000
5	0.000	0.000	0.000	0.003	0.043
10	0.000	0.000	0.001	0.017	0.064
20	0.000	0.000	0.001	0.012	0.042
30	0.000	0.000	0.000	0.010	0.026
50	0.000	0.000	0.000	0.002	0.016

Table (2):- Variations of P_f with various values of isotropic θ (m) and $CoV_ɣ$.

Isotropic correlation length (m)	$CoV_ɣ$				
	0.01	**0.05**	**0.10**	**0.20**	**0.50**
1	0.000	0.000	0.000	0.000	0.001
5	0.000	0.000	0.000	0.020	0.201
10	0.000	0.000	0.002	0.058	0.234
20	0.000	0.000	0.005	0.081	0.224
30	0.000	0.000	0.007	0.083	0.229
50	0.000	0.000	0.009	0.103	0.224

4.2. Scenario 2: Non-zero CoV of parameters

In the first scenario, the coefficients of variation (CoVs) associated with independent variables are constrained to zero, ensuring their complete independence from stochastic fluctuations. However, in this phase of the study, and in order to be more realistic, the CoVs of all independent variables are maintained at non-zero magnitudes except for the parameter whose effect is being investigated. Hence, the correlation lengths of strength parameters (C and Φ) are only examined under isotropic conditions. Similar to the first scenario, the considered isotropic correlation length ranges from 1 to 50 meters.

The effect of uncertainty in cohesion is evaluated for different CoV_C values ranging from 0.10 to 0.70 while the CoV values of other parameters $CoV_Φ$, CoV_E, and $CoV_ɣ$ are fixed at 0.2, 0.3, and 0.05 respectively. At small correlation lengths, the measured values of the P_f spanned from 0% to 45% as shown in Fig. (7), which eventually reduced to a narrower range of 25% to 45% at longer correlation lengths. Here, the number of failed slopes rises as the CoV and/or isotropic correlation lengths rise, continuing the same trend found in the results of the first scenario of this study.

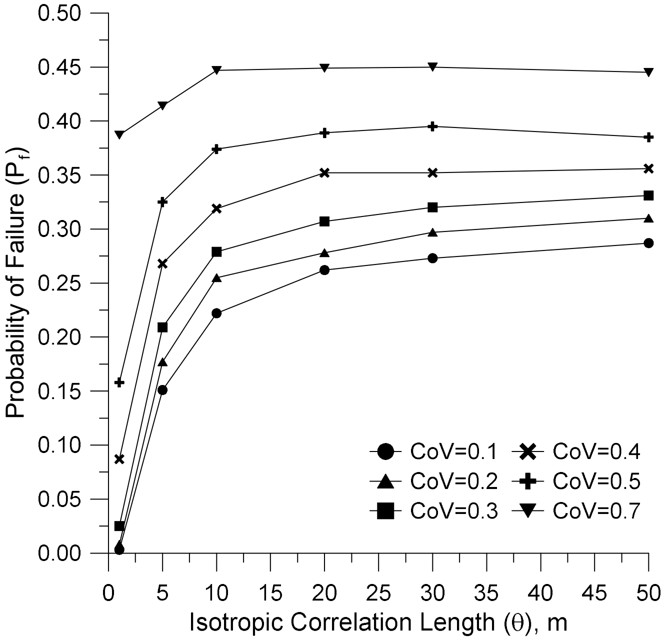

Fig.(7):- Variation of P_f with different values of isotropic correlation length (θ) and CoV_C measured in Scenario 2.

The two cohesion studies of scenario 1 (Fig. (3)) and scenario 2 (Fig. (7)) yield comparable results at higher degrees of CoV but vastly different results at lower values. Table (4) summarizes the results of this comparison in connection with cohesion parameter studies. It is evident that the calculated probabilities of failure exhibit a consistent pattern. Specifically, at lower values of CoVC (i.e., CoVC 0.1,0.2 and 0.3) tests resulted in an increase by at least 50% in the Pf when compared to the tests in which they were set to zero. In general, when considering nonzero constant CoVs (the CoVΦ, CoVE and CoVɣ were fixed but nonzero), the derived probabilities of failure surpass those corresponding to cases where CoVs are set to zero.

Table(3):- Comparison of probabilities of failure driven from both scenarios in terms of cohesion.

Correlation Length, θ (m) →		**1**	**5**	**10**	**20**	**30**	**50**
CoV_C =0.1	Scenario 1*	0.000	0.000	0.000	0.002	0.003	0.007
	Scenario 2**	0.003	0.151	0.222	0.262	0.273	0.287
CoV_C =0.2	Scenario 1	0.000	0.007	0.023	0.061	0.081	0.110
	Scenario 2	0.008	0.177	0.255	0.278	0.297	0.310
CoV_C =0.3	Scenario 1	0.000	0.047	0.120	0.170	0.191	0.210
	Scenario 2	0.025	0.209	0.279	0.307	0.320	0.331
CoV_C =0.4	Scenario 1	0.005	0.125	0.201	0.249	0.282	0.298
	Scenario 2	0.087	0.268	0.319	0.352	0.352	0.356
CoV_C =0.5	Scenario 1	0.035	0.208	0.275	0.331	0.342	0.365
	Scenario 2	0.158	0.325	0.374	0.389	0.395	0.385
CoV_C =0.7	Scenario 1	0.243	0.349	0.397	0.433	0.452	0.450
	Scenario 2	0.387	0.414	0.447	0.449	0.450	0.445

* Scenario 1 with $CoV_{\Phi, E, \gamma}$ = 0; ** Scenario 2 with $CoV_{\Phi, E, \gamma}$ = nonzero constant

In addition, within the same scenario of the study, the effects of angle of internal friction are evaluated as CoV_Φ ranges from 0.05 to 0.30, while CoV_C, CoV_E, and CoV_γ are fixed at 0.3, 0.3, and 0.05 respectively. The same pattern seen in the previous study of angle of internal friction in Scenario 1 (section 4.1.2) persists in this study as well; consequently, increasing the CoV_Φ results in a higher P_f of the slope Fig. (2).

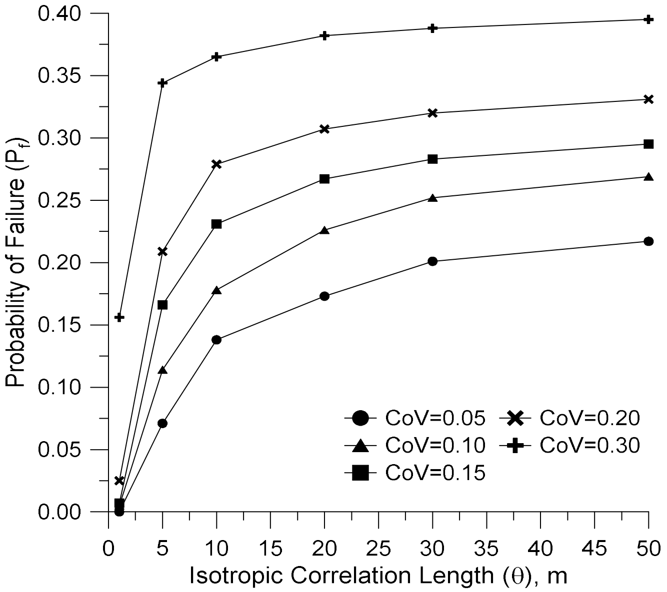

Fig.(2):- Effects of isotropic correlation length (θ) on the P_f of slopes evaluated for different CoV_{Φ} values of Scenario 2.

Table (5) provides an equivalent presentation for studies involving friction angles. This comparison manifests an increased trend in the P_f of the soil slope from scenario 1 (in which CoVs of independent variables are set to zero) to scenario 2 (in which CoVs are fixed at a constant value).

All these outcomes of both scenarios in terms of shear strength parameters are intuitively rational, as the introduction of uncertainties through nonzero CoVs inherently amplifies the chance of encountering failure scenarios within the studied system. Hence, this warrants the use of probabilistic methods to analyze a soil slope.

Table (4):- Comparison of probabilities of failure between Scenarios 1 and 2 in terms of angle of internal friction.

Correlation Length, θ (m) →		**1**	**5**	**10**	**20**	**30**	**50**
CoV_{Φ} = 0.05	Scenario 1*	0.000	0.000	0.000	0.003	0.003	0.004
	Scenario 2**	0.000	0.071	0.138	0.173	0.201	0.217
CoV_{Φ} = 0.10	Scenario 1	0.000	0.006	0.026	0.058	0.069	0.086
	Scenario 2	0.005	0.114	0.178	0.226	0.252	0.269
CoV_{Φ} = 0.15	Scenario 1	0.000	0.052	0.118	0.174	0.181	0.192
	Scenario 2	0.007	0.166	0.231	0.267	0.283	0.295
CoV_{Φ} = 0.20	Scenario 1	0.000	0.138	0.209	0.253	0.263	0.273
	Scenario 2	0.025	0.209	0.279	0.307	0.320	0.331
CoV_{Φ} = 0.30	Scenario 1	0.061	0.287	0.335	0.370	0.381	0.382
	Scenario 2	0.156	0.344	0.365	0.382	0.388	0.395

*Scenario 1 with $CoV_{C, E, \gamma}$ = 0; ** Scenario 2 with $CoV_{C, E, \gamma}$ = nonzero constant

5. CONCLUSIONS

The main conclusion points of this study are as follows:

- Increasing CoV of the investigated parameters (C, Φ, E, and γ) caused a rise in the failure probability of the soil slope. However, the effect of changing the CoV of cohesion and/or friction angle was much more pronounced than the

- uncertainty due to modulus of elasticity or unit weight parameters. Furthermore, the effect of CoV_E and CoV_γ on P_f is negligible when compared to the effect of CoV of strength parameters.
- Generally, a rise in the CoV of cohesion (CoV_C) is associated with a higher chance of failure, approaching 45% failure probability for soil slope when compared to cases with low correlation length. For the soil slope with a large CoV_Φ and large θ, the P_f ranges from 20% to 40%.
- In both scenarios of the study, increasing isotropic correlation length (θ) resulted in an increase in the P_f.
- In scenario 2, where a more realistic representation of soil behavior is considered, there was a discernible rise (at least 50%) in the P_f values at low CoVs.
- The results of the study emphasize the need to incorporate the spatial variability of soil properties in slope stability analyses. Introducing uncertainties in soil parameters increases the chances of slope failure. Therefore, it is crucial to use probabilistic methods for the assessment of soil slope stability.

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NOMENCLATURE

C	Cohesion strength, kPa
CoV	Coefficient of variation
E	Modulus of elasticity, MPa
FEM	Finite Element Method
FS	Factor of Safety
LAS	Local Average Subdivision
MCS	Monte Carlo Simulations
P_f	Probability of failure
RFEM	Random Finite Element Method
Greek symbols	
θ	Correlation length, m
Φ	Angle of internal friction, °
γ	Unit weight, kN/m^3
μ	Mean
v	Poisson's ratio

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