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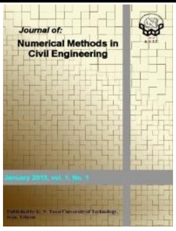

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Seismic Reliability-Based Design Versus Safety-Factor Based Design of Shallow Foundations Near a slope

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Abstract:

In this study, the stability of a foundation near a slope is investigated through a typical example of designing a shallow foundation. Foundation stability is typically evaluated through the bearing capacity's factor of safety and the reliability of the design, which depicts a more realistic perspective of design safety. Although an increase in the bearing capacity of the foundation leads to a subsequent increase in the safety factor and reliability index, a monotonically increasing functional relationship between the safety factor and reliability does not exist. This study investigates the effects of the foundation and slope properties on the reliability-based design (RBD) and safety factor-based design (SBD). Also, some valuable hints for practicing engineers unfamiliar with reliability concepts are presented to achieve a more reliable SBD. The results show that it is vital to consider how to increase the bearing capacity in the SBD methods. For example, in cohesive-frictional soils, by changing the embedment depth of the foundation (df) and the distance between the foundation and slope crest (x) to reach the target safety factor, we can obtain a more reliable SBD.

1. Introduction

One of the most crucial factors for foundation design is the stability of the foundation, which is typically assessed by the safety factor of bearing capacity. The foundation's safety factor can be defined as a ratio between the ultimate bearing capacity and the actual load on the foundation soil system. Traditionally, civil engineers have been practicing deterministic design approaches based on safety factors to account for uncertainties due to their simplicity [1]. It is essential to mention that the safety factor only investigates whether the system is safe or not. The effect of variability in soil properties cannot be adequately addressed in such analyses. The deterministic method may not always be conservative due to the considerable uncertainties resulting from in-situ soil variability [2-3].

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More recently, the reliability-based design (RBD) approaches have emerged as a more reasonable and rigorous way to quantify the uncertainties [4]. In RBD, the distributions of the variables are assigned to parameters instead of particular values; hence, the distribution of the safety factor can be obtained, which can undoubtedly present a realistic perspective of the design safety. Several recent studies have used reliability methods in strip foundation design and slope stability analyses [5-14].

There are also investigations on the relationship and differences between the reliability index and the safety factor. Elishakoff and Chamis [15] investigated the interrelation between the safety factors and reliability by presenting four probabilistic definitions of the safety factor. A framework with stochastic simulations was proposed by Ching [4] to investigate the relationship between the reliability and safety factors under a set of sufficient conditions. The concept of the ratio of safety margin (RSM) and the relationship between the factor of safety and reliability index was studied by Chen et al. [16]. Meanwhile, in another study, Griffiths [17] analyzed the sensitivity of the safety factors for footing problems.

Limit state methods, consisting of the limit analysis and limit equilibrium methods, are the leading solutions for the stability problems in foundation engineering [18-22]. As the first solution with a long utilization history, the limit equilibrium method assumes that the stresses on the failure planes are limited by traditional strength parameters c and φ [23]. On the other side, the limit analysis method uses the plastic flow rule to investigate the collapse load by equating the energy dissipated internally to the energy expended by the external loads [24]. The differences between these two methods undoubtedly lead to various RBD results. In seismic design, the limit analysis method can provide a more realistic effect of earthquake forces and calculate the bearing capacity more accurately [25-26].

By default, reliability increases with the increase of the factor of safety. This issue implies that a monotonically increasing functional relationship might exist between these parameters. However, such a connection does not exist in general. Nevertheless, there are some investigations in the literature on the probable relationship between the reliability index and safety factor. In this study, the importance and role of the reliability and safety factor in foundation design are investigated, and the effects of the foundation and slope properties on RBD and the safety factor are studied through a typical example of designing a near slope shallow foundation. As discussed above, the upper-bound limit analysis method and practical probabilistic approach are employed to evaluate foundation design bearing capacity and reliability index. This study's novelty is the investigation of the interrelation between the safety factor and reliability of shallow foundations near slopes. Moreover, some helpful hints for practicing engineers unfamiliar with the reliability concept who prefer to design foundations using the safety factor-based design (SBD) are presented to achieve a more reliable design. Besides, three different soil types that would be good representatives of cohesive to granular soils are selected to be comprehensive.

2. Upper-Bound Limit Analysis Method

The mechanism shown in Figure 1 is nonsymmetrical, allowing the bearing capacity calculation in the presence of seismic loading. As it is well known, an earthquake has two potential impacts on a soil-foundation system. The first is increasing the driving forces, and the second is decreasing the soil shearing resistance. Only the reduction of the bearing capacity due to the increase in driving forces is considered in the seismic design in this study. Hence, the soil shear strength is supposed to remain unaffected by the earthquake loading. On the other hand, the earthquake acceleration for the soil and the foundation is assumed to be identical, and only the horizontal seismic coefficient K_h is applied.

As displayed in Figure 1, the wedge ABC has a rigid shape with a downward velocity tilted at an angle φ to the AC's discontinuity line. The foundation is expected to move with equal velocity as the wedge ABC. The radial shear zone BCD is formed of n rigid triangular blocks which move in directions that make an angle φ with the discontinuity lines d_i (i = 1, . . . , n). Consequently, the state determines the velocity of each triangle. The velocity hodograph presented in Figure 1 constituted a kinematically admissible velocity field. The external forces contribute to the incremental external work consisting of the foundation load, the rigid block soil mass weight, and the foundation level's surcharge q [27].

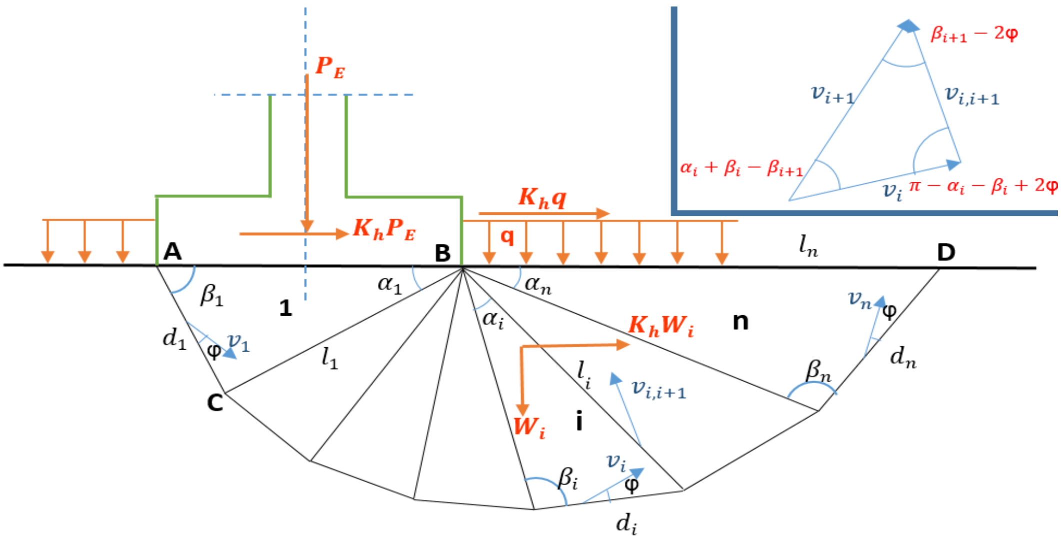


Fig. 1: The nonsymmetrical multiblock failure mechanism [2, 6].

Equations 1 and 2 represent the parametric velocity related to the rigid block *i*, and Equation 3 shows the relative velocity between the adjacent blocks (*i* and *i*+1).

$$V_1 = \frac{1}{\sin(\beta_1 - \varphi)} \quad (1)$$

$$V_{i+1} = V_i \frac{\sin(\pi - \alpha_i - \beta_i + 2\varphi)}{\sin(\beta_{i+1} - 2\varphi)} \quad (2)$$

$$V_{i.i+1} = V_i \frac{\sin(\alpha_i - \beta_i - \beta_{i+1})}{\sin(\beta_{i+1} - 2\varphi)} \quad (3)$$

Equations 4, 5, and 6 show the geometry parameters of the triangular block *i*.

$$l_i = B_0 \frac{\sin\beta_1}{\sin(\alpha_1 + \beta_1)} \prod_{j=2}^{i} \frac{\sin\beta_j}{\sin(\alpha_j + \beta_j)} \quad (4)$$

$$d_i = B_0 \frac{\sin\beta_1}{\sin(\alpha_1 + \beta_1)} \frac{\sin\alpha_i}{\sin\beta_i} \prod_{j=2}^{i} \frac{\sin\beta_j}{\sin(\alpha_j + \beta_j)} \quad (5)$$

$$S_i = \frac{{B_0}^2}{2} \frac{\sin^2\beta_1}{\sin^2(\alpha_1 + \beta_1)} \frac{\sin\alpha_i \sin(\alpha_i + \beta_i)}{\sin\beta_i} \times \prod_{j=2}^{i} \frac{\sin^2\beta_j}{\sin^2(\alpha_j + \beta_j)} \quad (6)$$

According to the energy survival principle, the amount of the bearing capacity is determined by the equalization of the internal and external works (Equations 11, 12, and 13) introduced in Equations 7 to 10. The external work consists of the force acting on the footing, weight of soil in motion, surcharge loading, and different inertia forces. Internal work, including the work of cohesion forces at the levels of di and li, energy is dissipated along the lines $\boldsymbol{l_i}$ (i = 1, . . . , n-1) and $\boldsymbol{d_i}$ (i = 1, . . . , n). Regarding that the displacement in the vertical direction is δ = 1, the calculated load is the bearing capacity of the foundation.

$$W_P = P(1 + K_h V_1 \cos(\lambda_1 - \varphi)) \quad (7)$$

$$W_{w_i} = (\gamma S_i V_i \sin(\lambda_i - \varphi)) + (K_h \gamma S_i V_i \cos(\lambda_i - \varphi)) \quad (8)$$

$$W_{d_i} = c d_i V_i \cos(\varphi) \quad (9)$$

$$W_{l_i} = c l_i V_{i.i+1} \cos(\varphi) \quad (10)$$

W_P : work of the load exerted on the foundation

W_{w_i} : work of the soil weight of block *i*

W_{d_i} : work of the cohesion force in d_i

W_{l_i} : work of the cohesion force in l_i

C : soil cohesion

φ : internal friction angle of the soil

λ_i : the angle between l_i and horizon

W_q : surcharge work

$$\overbrace{W_P + W_{w_i} + W_q}^{\text{External work}} = \overbrace{W_{d_i} + W_{l_i}}^{\text{Internal work}} \quad (11)$$

$$P(1 + K_h V_1 \cos(\lambda_1 - \varphi)) + \sum_{i=1}^{n} (\gamma S_i V_i \sin(\lambda_i - \varphi)) + (K_h \gamma S_i V_i \cos(\lambda_i - \varphi)) + W_q = \sum_{i=1}^{n} c d_i V_i \cos(\varphi) + \sum_{i=1}^{n-1} l_i V_{i.i+1} \cos(\varphi) \quad (12)$$

$$q_u = P = \frac{1}{(1 + K_h V_1 \cos(\lambda_1 - \varphi))} \left(\sum_{i=1}^{n} c d_i V_i \cos(\varphi) + \sum_{i=1}^{n-1} l_i V_{i.i+1} \cos(\varphi) - \sum_{i=1}^{n} (\gamma S_i V_i \sin(\lambda_i - \varphi)) + (K_h \gamma S_i V_i \cos(\lambda_i - \varphi)) + W_q \right) \quad (13)$$

If the foundation is located near the crest of the slope, the shape of the last soil rigid block is tetrahedral. Hence, the calculations of parameters such as area and work of weight force are different from the triangular soil rigid blocks. Details of this scenario are presented in Figure 2. Also, the relevant equations are presented in Equations 14 to 20.

$$x_l = x + df * \tan(\varepsilon - \frac{\pi}{2}) \quad (14)$$

$$g = \sqrt{x_l^2 + l_{n-1}^2 - 2 x_l l_{n-1} \cos a_n} \quad (15)$$

Per the Sine Rule:

$$\varepsilon_1 = \operatorname{Arcsin}(\frac{l_{n-1}}{g} * \sin(\alpha_n)) \quad (16)$$

$$B_1 = \operatorname{Arcsin}(\frac{x_l}{g} * \sin(\alpha_n)) \quad (17)$$

So:

$$q = 2\pi - \varepsilon - \alpha_n - \beta_n \quad (18)$$

$$d_n = g \frac{\sin(\varepsilon_2)}{\sin(q)} \quad (19)$$

$$S = \overbrace{\frac{1}{2}x_l l_{n-1}\sin(\alpha_n)}^{1} + \overbrace{\frac{1}{2}g d_n \sin(B_2)}^{2} \quad (20)$$

In the upper-bound solution used in this paper, the extreme value for bearing capacity was attained initially; gradually, by increasing the number of triangular blocks, the bearing capacity decreased, thereby converging to a prominent value. Besides, a more accurate result can be obtained by increasing the number of blocks. For instance, assume the foundation with B = 3 m, c = 20 kPa, φ = 30°, K_h = 0, Ɣ = 18 Ton/m^3, df =1 m. As shown in Figure 3 and Table 1, the results can be obtained in high resolution by considering the eight rigid triangular blocks. Hence, in this paper, all the analyses are carried out using eight rigid blocks.

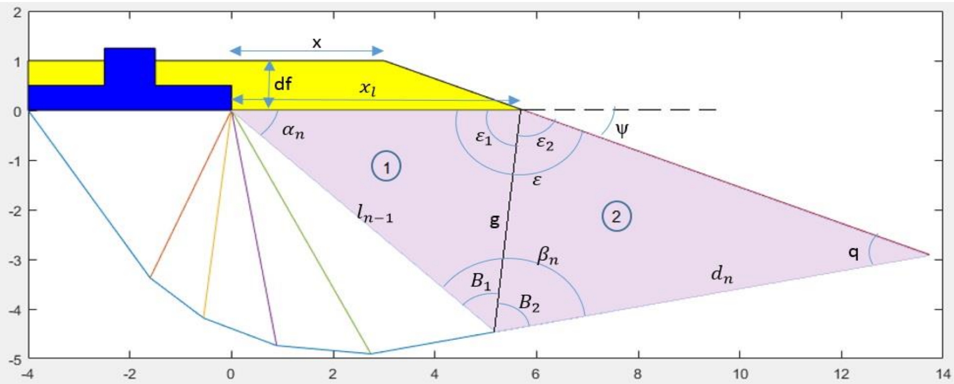
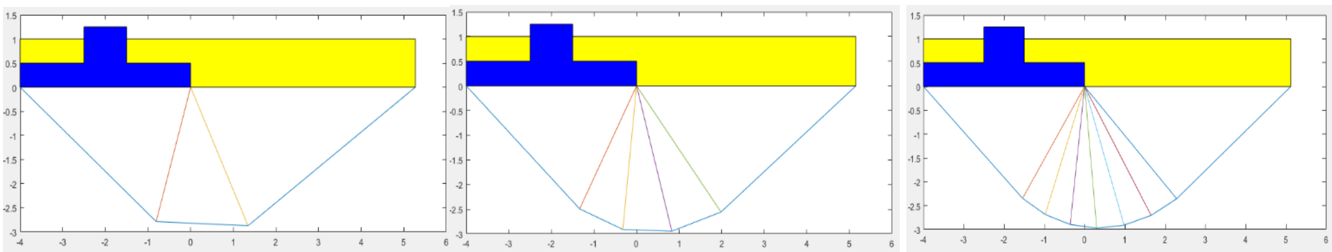


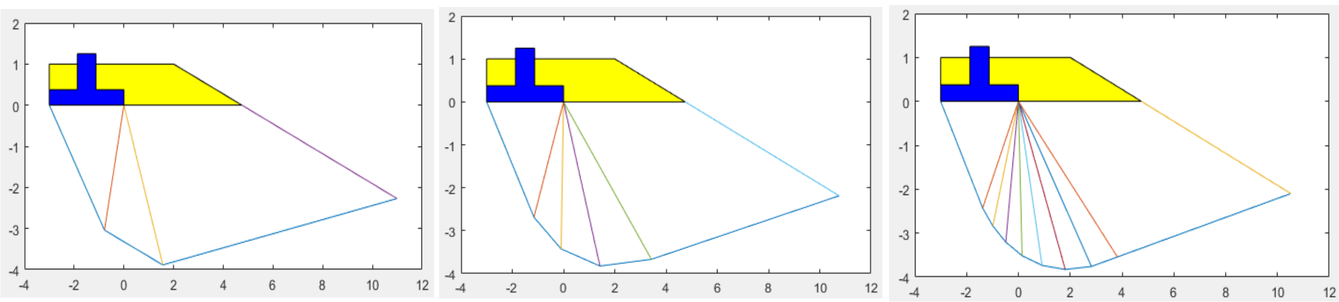
Fig. 2: Details of the nonsymmetrical multiblock failure mechanism in the near slope scenario.

Table 1: The convergence procedure by increasing the number of blocks.

Number of Blocks	Bearing Capacity Reduction (%) (Flat Ground)	Bearing Capacity Reduction (%) (Near slope)
3	5.03	4.62
4	2.15	1.91
5	0.8	0.44
6	0.38	0.43
7	0.13	0.17
8	0.05	0.07



(a) (b) (c)



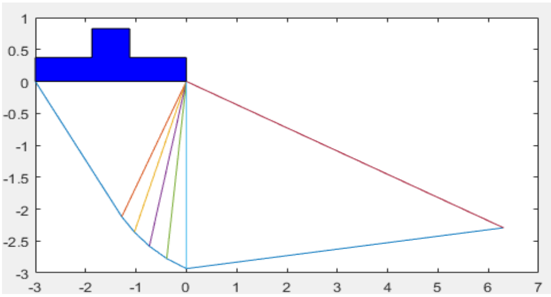
(a) (b) (c)

Fig. 3: Radial shear zone, a) three-block, b) five-block, and c) eight-block.

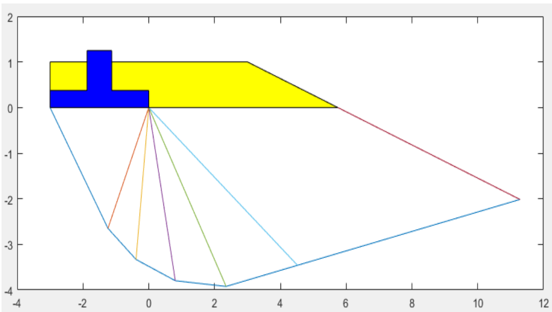
The foundation location, i.e., whether it is near or far from the crest of the slope, is expected to affect its bearing capacity. In the MATLAB code, the problem is initially analyzed on flat ground to consider whether the slope affects the bearing capacity. If the soil width involved in the rupture zone is more than the distance between the foundation and slope crest, the bearing capacity is affected by the slope. Suppose the width of the soil involved in the rupture zone is less than the mentioned distance. In that case, the slope does not affect the bearing capacity, and the foundation can be analyzed and designed by the realistic assumption that ignores the far slope. Table 2 and Figure 4 show the effect of the distance between the foundation and slope crest.

Table 2: The effect of the distance between the foundation and slope crest.

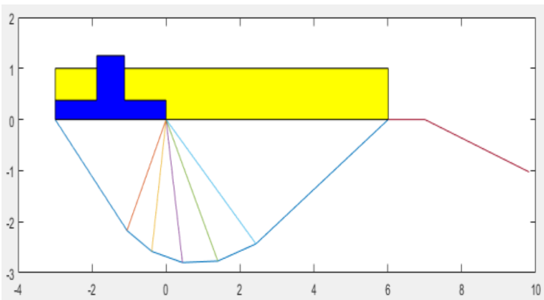
Distance (m)	Bearing Capacity (kPa)
0	1220
3	1890
5	2100
7	2205
9	2205
12	2205



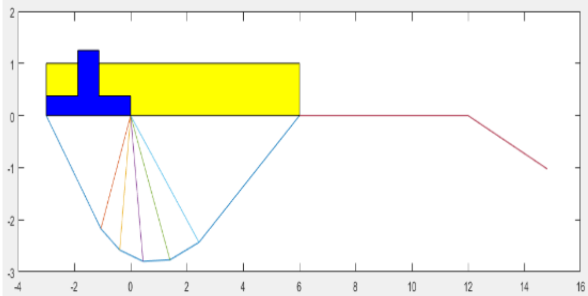
(a)



(b)



(c)



(d)

Fig. 4: Different distances between the foundation and slope crest, a) 0m, b) 3m, c) 7m, and d) 12m.

3. Reliability-Based Analysis (Practical Probabilistic Approach)

Low [28] proposed a practical probabilistic method for estimating the reliability index. The method provides a more intuitive definition of Hasofer-Lind's reliability index [29]. This approach is an extremely fast, precise, and easy method for calculating the first-order second-moment reliability index (FORM). This method is based on the perspective of an ellipsoid that touches the failure surface in the original space of the variables, and relevant calculations will be done using an optimization technic in the developed computer code. This perspective is mathematically equivalent to the widely adopted aspect of a sphere in the space of reduced variables. The variables must be transferred to a normal standard space for obtaining the reliability index in the traditional solutions. However, in Low's method, complex computations and transfers are not required, and all the process is done in the original space [30]. The reliability index reached by the practical strategy is presented as follows.

In Low's method, an inherent explanation of the meaning of the β is conceivable regarding that Eqs. 21 and 22 suggest that the Hosefor-Lind index can be obtained by minimizing the quadratic form (in this case, an ellipsoid) subject to the restriction that the ellipsoid meets the surface of the failure domain. The matrix formulation of the Hasofer-Lind index β is:

$$\beta_{HL} = \min_{x \in F} \sqrt{(x-m)^T C^{-1} (x-m)} \quad (21)$$

Or, equivalently:

$$\beta = \min_{x \in F} \sqrt{\left[\frac{x_i - m_i}{\sigma_i}\right]^T [R]^{-1} \left[\frac{x_i - m_i}{\sigma_i}\right]} \quad (22)$$

X is a vector describing random variables, m for the mean values, C for the covariance matrix, R for the correlation matrix, and F for the failure region. The value of β should be calculated by regarding the following requirements

(Equations. 23 and 24) and employing the nonlinear optimization technique [28]:

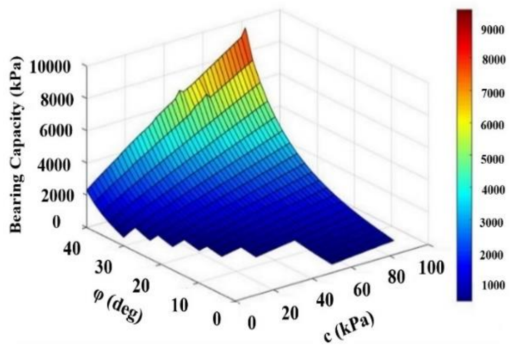
$$\text{Minimize:} \quad \beta = \min_{x \in F} \sqrt{\left[\frac{x_i - m_i}{\sigma_i}\right]^T [R]^{-1} \left[\frac{x_i - m_i}{\sigma_i}\right]} \qquad (23)$$

Subject to:

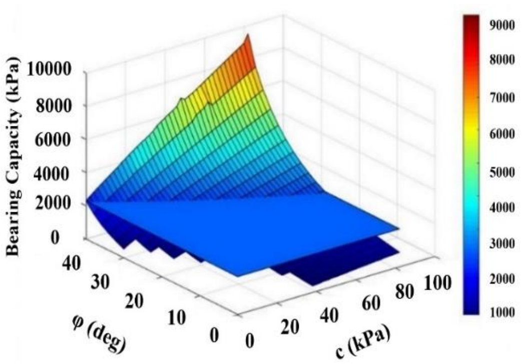
Performance Function= P-P_u =0 (24)

where P is the action load on the foundation, and P_u is the bearing capacity of the foundation.

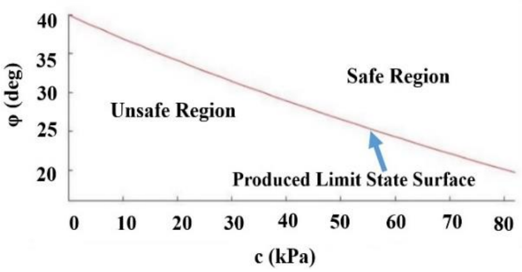
Figure 5a presents the spatial surface of the bearing capacity. As shown in Figure 5b, a limit state surface can be obtained by crossing a plane, representing the action load of the foundation by the spatial surface. The curve produced by the mentioned intercross, displayed in Figure 5c, can be recognized as the limit state surface. As a final step, Low's approach can estimate the reliability index by trying to minimize the distance from the mean-value point to the produced limit state curve, as shown in Figure 5d.



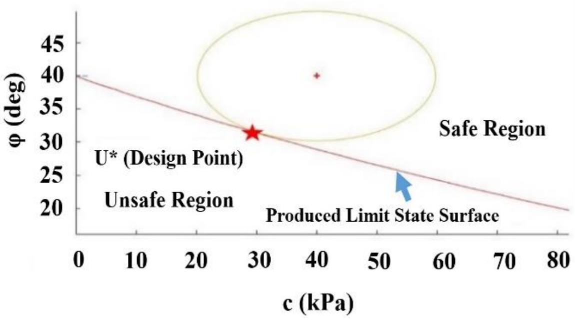
a) Various bearing capacities are calculated given different values of shear strength parameters



b) Cross-section of bearing capacity spatial surface by the action load plane



c) Produced limit state hypersurface in c-φ plane



d) The final step of optimization where the ellipsoid touches the surface of the failure region in the design point

4. Results and Discussion

This study investigates the importance of the reliability and safety factor on the foundation design and the effects of the foundation and slope properties on RBD. Meanwhile, three different soil types that would be good representatives of cohesive to granular soils are selected to be exhaustive. According to Eurocode 7 [31], the reliability index (β_{target} = 3.8) is considered for the reliability-based design of shallow foundations. The literature presents the eclectic values of the coefficient of variation of the internal friction angle and cohesion. Within the range of the internal friction, the corresponding coefficient of variation, as proposed by Phoon and Kulhawy (1999) [32], is essentially between 5 and 15%. For effective cohesion, the coefficient of variation varies between 10 and 70% [33]. In this paper, the illustrative values used for the statistical characteristics of variables are shown in Table 3.

In SBD, if a foundation located near a slope has to be designed, there are three probable different solutions to increase the bearing capacity of the foundation to reach a particular safety factor (e.g., FS = 3). The first one is to increase the width of the foundation (B), the second one is to increase the foundation embedmentdepth (d_f), and the last solution is to increase the distance between the foundation and the slope crest (x in Figure 2). The slope angle is one of the other effective parameters that cannot be regarded as a changeable item for designing a foundation. However, its effect on the reliability and safety factor of design is also investigated in this paper. As shown in Figure 6, the effects of the mentioned parameters are different on the reliability of the foundation design. At first glance, it appears that the reliability index of the foundation design will reach a certain value when the effective parameters on the foundation bearing capacity change to obtain a considerable safety factor (FS = 3). Some analyses are carried out to investigate the safety factor's value when the foundation design's reliability reaches the target reliability (β = 3.8). The results show that changing the effective parameters to achieve the target reliability leads to different safety factors. In other words, if an SBD is selected to design a shallow footing, it is essential to know how to increase the bearing capacity.

Table 3: Variable statistical characteristics of different soil types.

Variable	Distribution	Mean Value			Coefficient of Variation
		1st Soil Type	2nd Soil Type	3rd Soil Type	
Cohesion(c)	Log normal	30 kPa	50 kPa	0 kPa	20%
Internal friction angle(φ)	Log normal	40°	0°	40°	10%

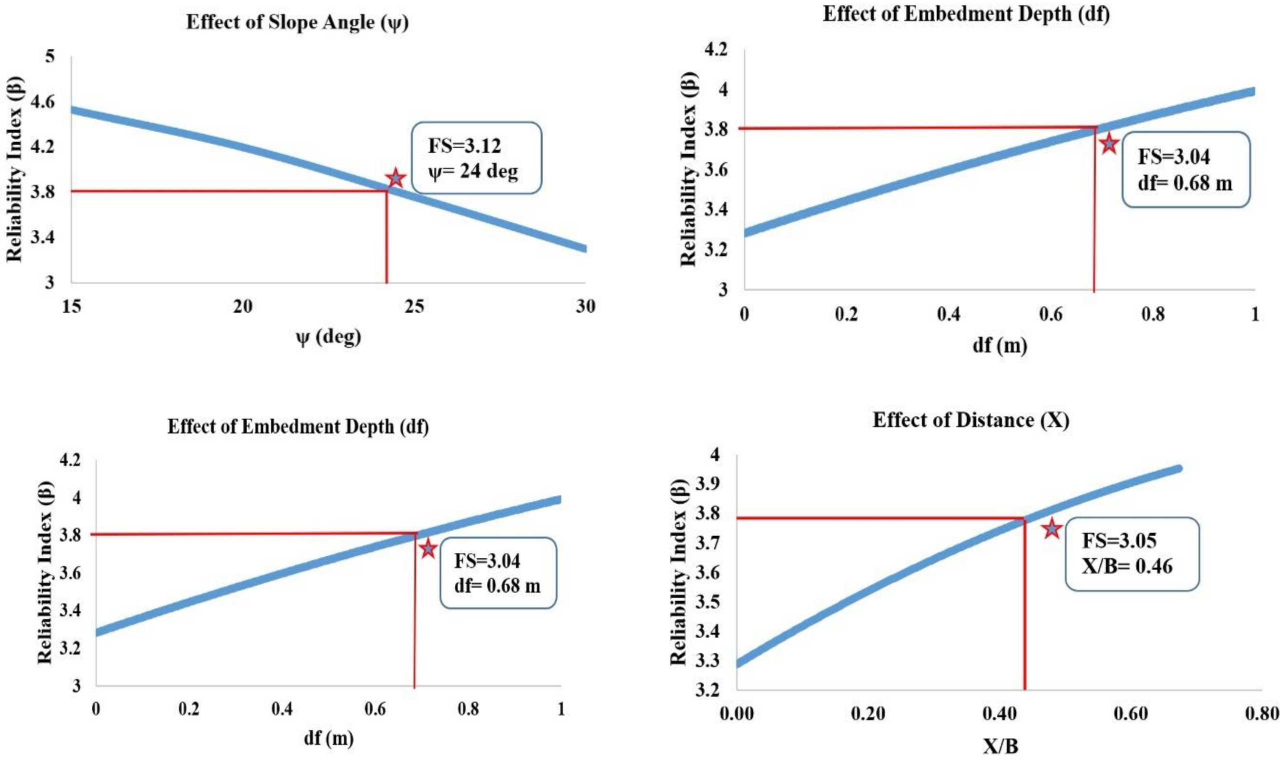


Fig. 6: The effects of different parameters on the reliability and safety factor.

Analyzing Figure 6 shows that different reliability and safety factors can be achieved by different scenarios used to increase the shallow foundation's bearing capacity. An important question that arises here is whether increasing the foundation width, which is the conventional and first-selected choice of engineers for increasing the foundation bearing capacity, is the most useful alternative or not. Three soil types and four effective parameters are comprehensively considered to investigate the relationship between the safety factor and reliability. For the 1st soil type, while the target safety factor (FS = 3) can be obtained by changing the effective parameters on bearing capacity (d_f, x, B, and ψ), the reliability index is different in each scenario. For this soil type, the effect of changing the value of the embedment depth (d_f) and the value of the distance between the foundation and slope crest (x) is more significant than the effect of changing in slope angle value (ψ) and foundation width (B). As given in Figure 7, increasing (x) and (d_f) provide a higher reliability index than increasing (B). Four different scenarios plus an initial condition of the foundation (Scenario 0th) are introduced in Table 4. Also, the action load is assumed to be 3000 kN.

Table 4: Different scenarios description (for 1st soil type).

Scenario description	Sc	B (m)	d_f (m)	X (m)	ψ (deg)	FS	β
Scenario 0 (initial condition)	Sc0	3	0	0	30	2.73	3.33
Scenario 1 (increase B to reach FS=3)	Sc1	3.42	0	0	30	3	3.61
Scenario 2 (increase d_f to reach FS=3)	Sc2	3	0.58	0	30	3	3.73
Scenario 3 (increase X to reach FS=3)	Sc3	3	0	1.21	30	3	3.71
Scenario 4 (decrease ψ to reach FS=3)	Sc4	3	0	0	25	3	3.68

Some digital outputs of numerical analyses are presented in the following to depict a clear and tangible picture of what happened to investigate the reason for the different reliability values despite the same safety factor value. As mentioned before and shown in Figure 8, the limit state hypersurface is obtained by crossing the bearing capacity spatial surface and the action load surface. For example, in the fourth scenario, the value of the slope angle decreases gradually until the bearing capacity reaches a value three times greater than the action load (FS = 3). The new bearing capacity spatial surface of the foundation with a new slope angle is shown in Figure 9.

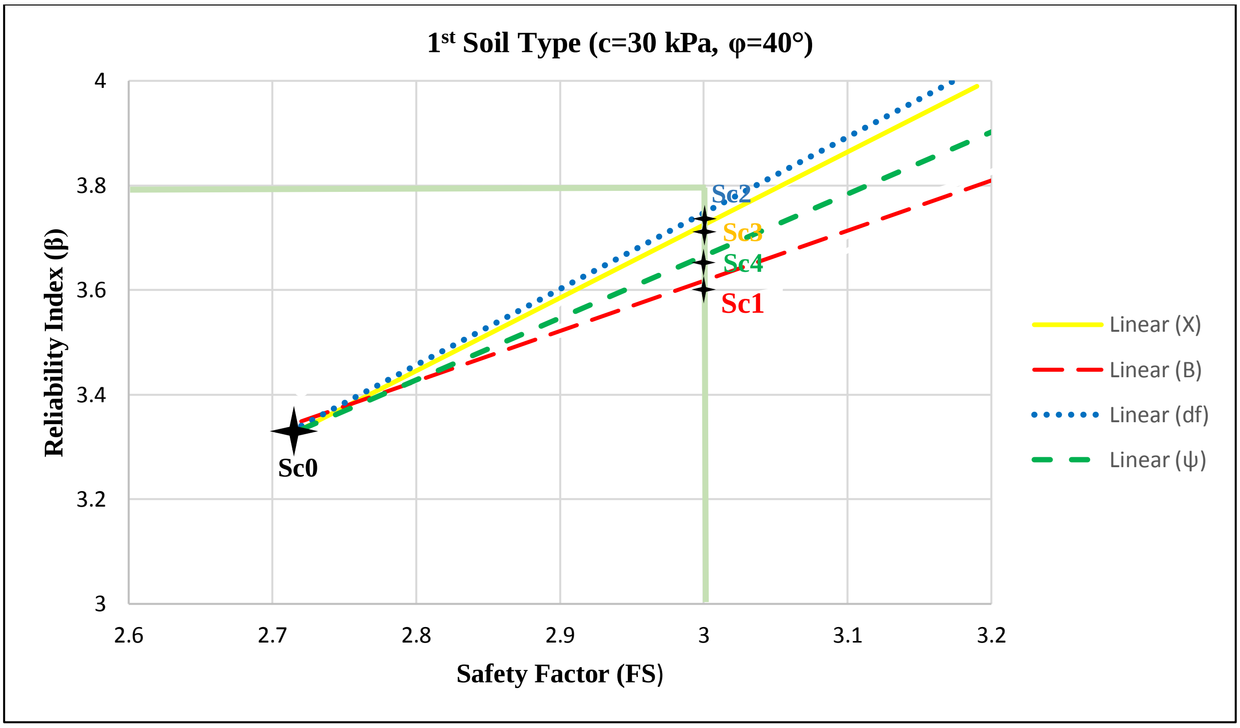


Fig. 7: The effects of different parameters on the reliability and safety factor of foundation rest on the 1st soil type.

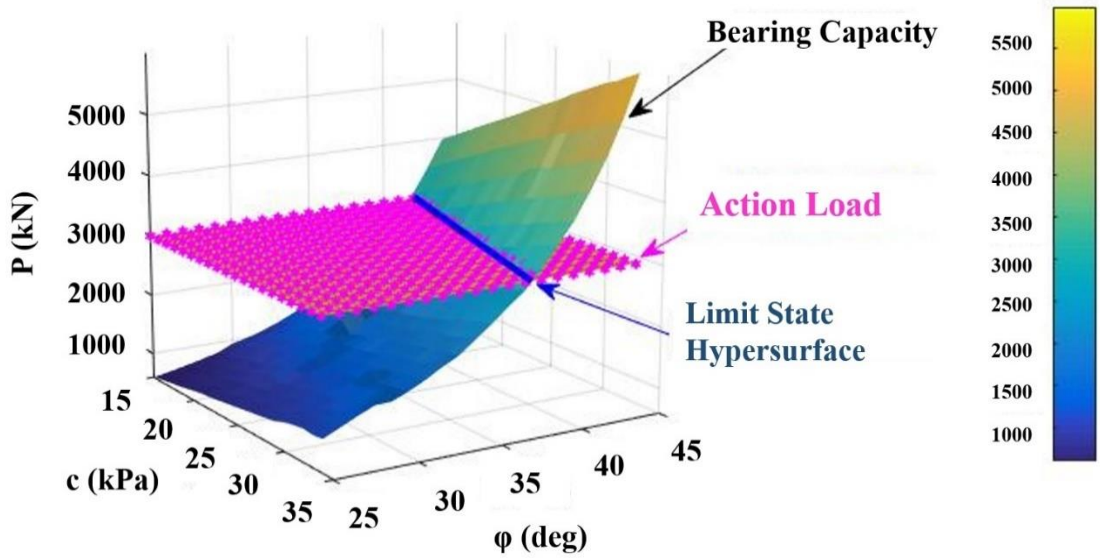


Fig. 8: The bearing capacity spatial surface of Sc0 crossed by the action load surface.

As shown in Figure 10, the limit state surface is dropped down by decreasing slope angle. In other words, by decreasing the value of ψ, the foundation bearing capacity reached the mentioned value in a lower range of cohesion (c) and friction (φ). Consequently, the reliability index, which is the minimum distance from the mean-value point to the produced limit state curve, is increased. The dispersion ellipsoids, mean-value point, and the comparison between two limit state curves, Sc. 0^{th} and Sc. 4^{th}, are presented in Figure10.

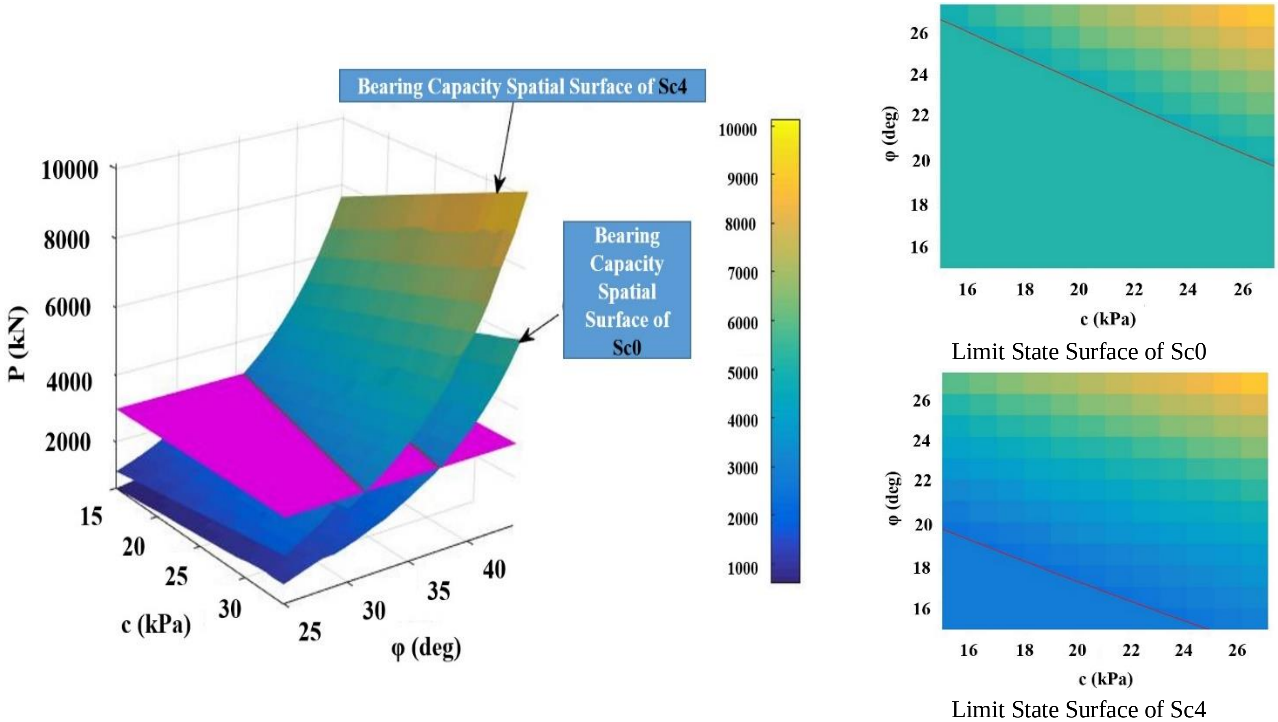


Fig. 9: Comparison between two different bearing capacity spatial surfaces.

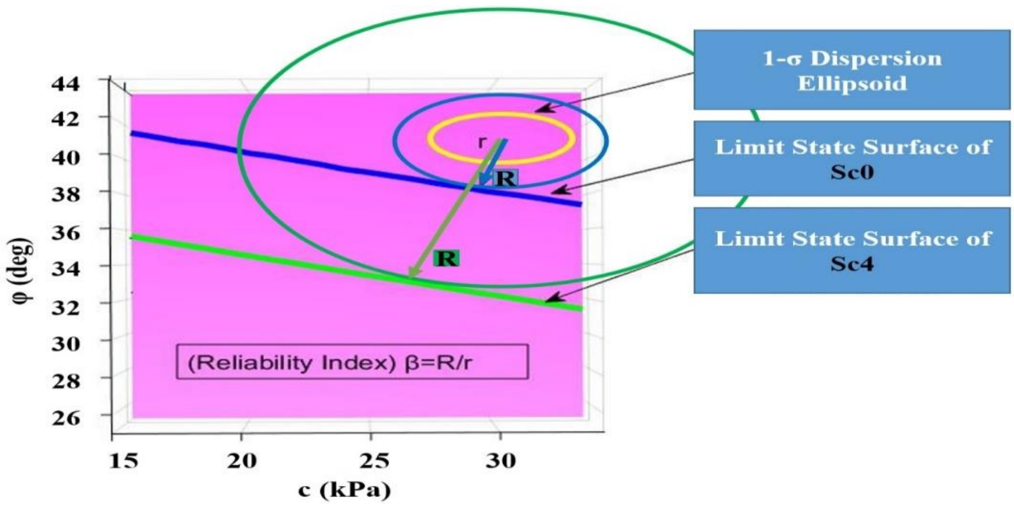


Fig. 10: Comparison between different produced limit state surfaces in the normal variable space.

Four effective parameters (B, x, d_f, and ψ) are changed independently in four different scenarios to reach the mentioned bearing capacity. Specific parameters values are obtained, as presented in Table 4. By employing particular obtained values of parameters, the bearing capacity spatial surfaces are analyzed and presented in Figure 11. Obviously, the limit state surface, which is far from the mean value (c = 30 kPa, φ = 40°), concludes a greater reliability index. Now, the results presented in Figure 7 are clarified by Figure 11. Therefore, the most helpful solution for increasing the foundation bearing capacity in terms of reliability is increasing (d_f) (Sc. 2nd), increasing (x) (Sc. 3rd), decreasing (ψ) (Sc. 4th), and increasing (B) (Sc. 1st), respectively. Finally, as a helpful hint, the conventional belief about the merit of increasing (B) as the best way to increase the bearing capacity is completely refused from a reliability point of view.

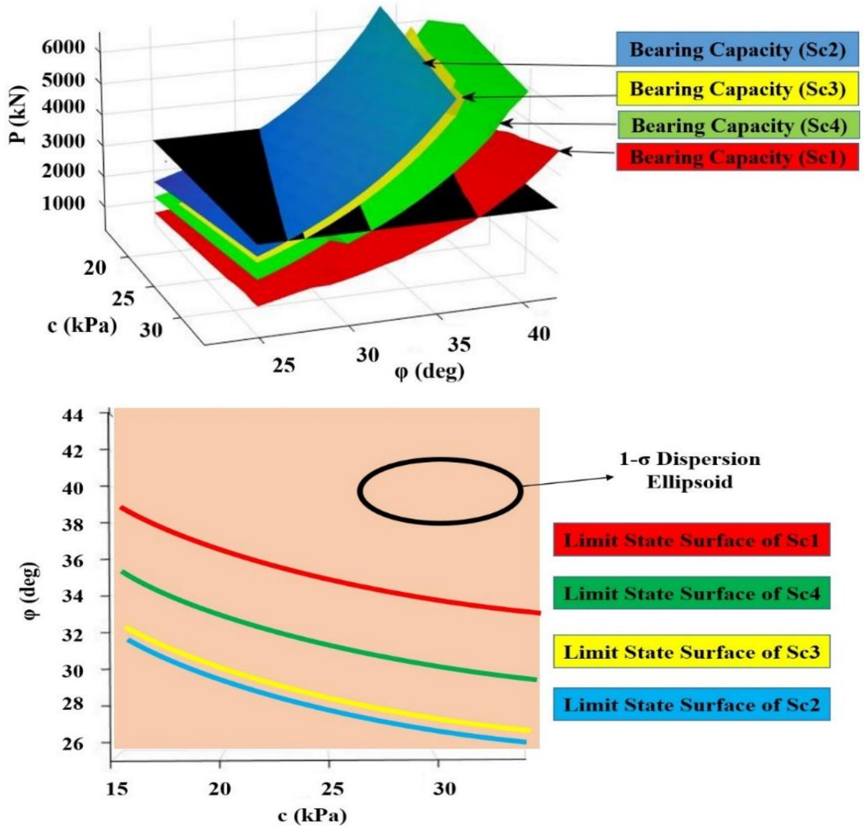


Fig. 11: The condition of different scenarios in terms of reliability.

The results are different for the 2nd soil type (cohesive soil), as shown in Figure 12. In cohesive soils, the most practical implementation for increasing the foundation bearing capacity in terms of reliability is decreasing (ψ), increasing (x), increasing (d_f), and increasing (B), respectively. Because of the highcohesion values in cohesive soils, the reliability index depends on the parameters which can directly affect the bearing capacity, such as the discontinuity lines of rigid soil blocks. Therefore, the location of the foundation and the slope angle play important roles in the reliability of foundation designs.

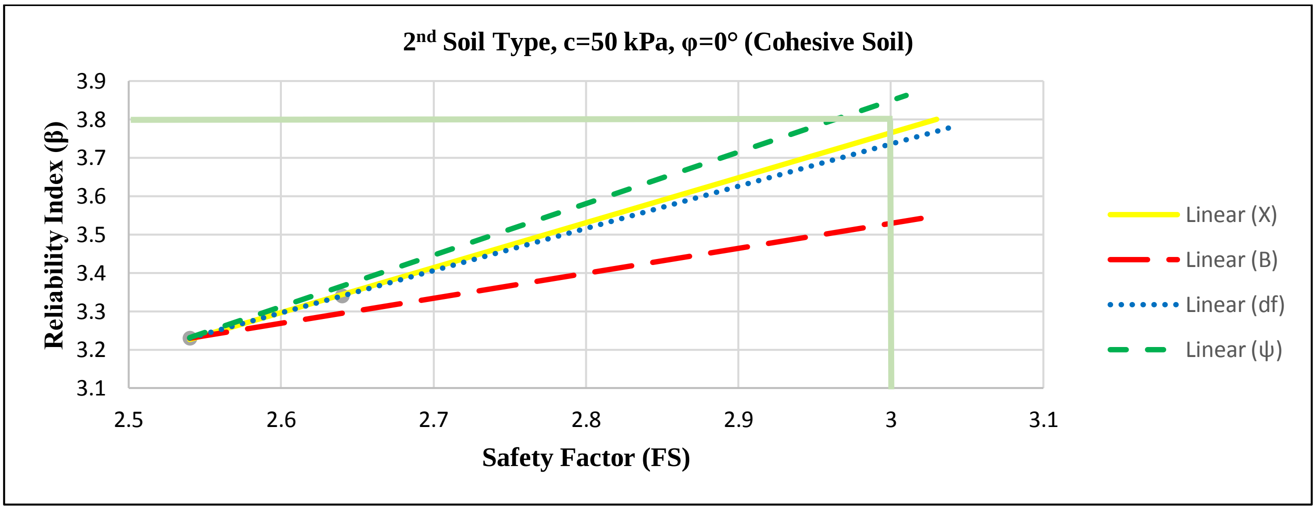


Fig. 12: The effects of different parameters on the reliability and safety factor of foundations on cohesive soils.

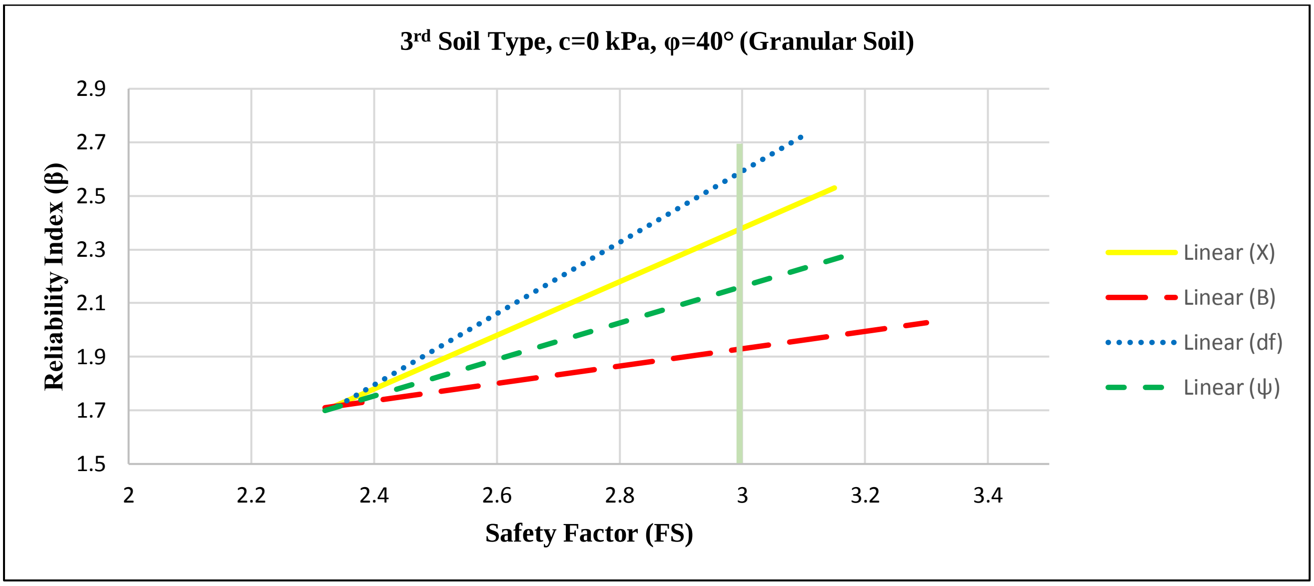


Fig. 13: The effects of different parameters on the reliability and safety factor of foundation rest on the granular soils.

Although in the 3rd soil type (granular soil), the order of most influential parameters on the reliability of foundation design is similar to the 1st soil type, the differences in reliability value between various scenarios are more considerable in comparison with the other soil types, as shown in Figure 13. Additionally, the foundation's reliability range according to the safety-factor method is not acceptable in granular soil (β = 1.9-2.6). As a result, in granular soils, which have the most critical circumstances in terms of reliability, conservative considerations should be applied, and the most useful scenario for increasing the bearing capacity should be selected.

5. Conclusion

From the risk assessment point of view, it is widely accepted that RBD is more reliable and efficient than SBD. Although reliability analysis has been used in various geotechnical engineering problems in recent years, Civil engineers traditionally have been practicing deterministic design approaches based on safety factors. That is because of the simplicity of SBD approaches in considering the broad spectrum of existing uncertainties. Some investigations have been conducted to discover the relationship and differences between reliability index and safety factor. However, no clear picture has provided practical hints for geotechnical engineers unfamiliar with the reliability concept to design more reliable shallow foundations by employing SBD methods. Hence, this study investigates the interrelation between the safety factor and reliability of a shallow foundation located near a slope in different design scenarios. Moreover, all designs are carried out using the upper-bound limit analysis method and practical probabilistic approach to be accurate and comprehensive. Some useful hints for practicing engineers unfamiliar with the reliability concept who prefer to design a foundation using SBD approaches are presented to achieve a more reliable design.

Suppose a foundation located near a slope wants to be designed using SBD. In that case, there are three different probable solutions to increase the bearing capacity to reach a target safety factor (e.g., FS = 3). The first one is to increase the width of the foundation (B), the second one is to increase the foundation embedment depth (d_f), and the last solution is to increase the distance between the foundation and the slope crest (x) in Figure 2). Although the increase in the bearing capacity of the foundation leads to an increase in the safety factor and reliability of the design, a monotonically increasing functional relationship between the safety factor and reliability does not exist. Generally, for all soil types, while the target safety factor (FS = 3) can be obtained by changing the effective parameters on bearing capacity [d_f, x, B, and ψ (slope angle)], the reliability index is different in each scenario.

As a result of carried out analyses, the effect of changing the value of (d_f) and (x) is more significant than the effect of changing the value of (ψ) and (B) for the 1st soil type. In other words, increasing (x) and (d_f) provide a higher reliability index than increasing the value of (B). Therefore, the most helpful solution for increasing the foundation bearing capacity in terms of reliability is increasing (d_f), increasing (x), decreasing (ψ), and increasing (B), respectively. Finally, as a useful hint, the conventional belief about the merit of increasing B as the best way for foundation designing is completely refused from a reliability point of view. The most practical implementation in cohesive soils (2nd soil type) is decreasing (ψ), increasing x, increasing (d_f), and increasing (B), respectively. In cohesive soils, because of the high cohesion values, the reliability index is very dependent on the parameters, which can directly affect the bearing capacity. Discontinuity lines of rigid soil blocks on which internal energy dissipation is not zero (the internal energy dissipation is zero in discontinuities of granular soils). Therefore, the location of the foundation and the slope angle play important roles in foundation designs' reliability. Although in granular soils, the order of most influential parameters on the reliability of foundation design is similar to the 1st soil type, the differences in reliability value between various scenarios are more considerable than in the other soil types.

Declaration of conflicting interests:
The authors declare that they have no conflict of interest.

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