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Optimization of the Bearing Capacity of Shallow Foundation

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ABSTRACT

Excess soil stress may lead to an additional settlement or shear failure of the soil, which in both cases, causes damage to the structure. Therefore, geotechnical and structural engineers who design the foundation must evaluate the bearing capacity of the soil. This study discusses the optimization of the bearing capacity of shallow foundations and a compares deterministic and probabilistic methods. In this study, the bearing capacity of shallow foundations were defined using the Monte Carlo method, finally suggests constructive solutions to improve shallow foundations' performance.

1. Introduction

Structures are supported by foundations that transfer the load to the soil beneath them. Structures are built on a foundation [1,2]. When a foundation is properly designed, the load is transferred to the soil without adding stress. An excessive amount of soil stress can result in additional settlement and shear failure of the soil, which can damage a structure [3].

In designing the foundation, geotechnical and structural engineers should consider the behavior of shallow foundations as one of the most important parameters in interaction issues in geotechnics. So that when the foundation undergoes shear failure, it can be determined if it is

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performing correctly [4]. It is necessary to explain that the distribution of pressure and instantaneous elastic settlement under the foundations is a function of two factors, the rigidity (flexibility) of the foundation and the type of soil under the foundation (sand or clay). There are two factors that must be considered when designing a foundation: 1- The soil under the foundation must withstand the load easily, without any shear ruptures. As a result, applying a suitable safety factor maintains the required distance until the foundation ruptures. 2- Settlement amounts should not exceed a certain amount. Despite the plan to prevent uneven settlements, most foundations will experience some asymmetric settlement, varying from two-thirds to three-fourths. As a result of dry and semi-arid climates (such as Iran), as well as moderate and semi-humid climates, and in all areas where underground water levels are lower than the natural level of the earth, soil in the situation is unsaturated [5]. Table 1 summarizes some of the research conducted in this field. In this research the optimization of the bearing capacity of shallow foundations and a compares deterministic and probabilistic methods will discussing. In this study, the bearing capacity of shallow foundations were defined using the Monte Carlo method, finally suggests constructive solutions to improve shallow foundations will perform.

Table1
List of articles and sources used in the progress of the study.

Researchers	Year	References to the subject studied and actions taken:
Mohammed et al. [6]	2020	Analytical investigation of the settlement of shallow foundations using the combination of the 5-phase neural network system. This research emphasizes numerical modeling based on the combined Fuzzy neural network system (ANFIS) using Particle Swarm Optimization(PSO), Ant Colony optimizer(ACO), Differential Evolution (DE), and Genetic Algorithm (GA) optimization algorithms as an effective approach to predict the bearing capacity of shallow foundations. The parameters studied in this article are footing width (B), amount of pressure exerted on the footing (qa, geometry, and dimension ratio of the footing (B/L, N STP number)), and the buried depth ratio of the footing D/B. According to the results, the PSO-ANFIS model can be considered as a method in general. A shallow foundation can be accurately predicted using this method.
Altaweel and Shakir. [7]	2021	In an article, the effect of interface on the settlement of shallow foundations based on clay soils was evaluated using the finite element method using 3D PLAXIS software. This study investigated two types of foundations: a strip foundation with a width of 1 meter and a circular foundation with a width of 1.5 meters. The three states of the simulated model are the first case, two adjacent strip foundations; the second state, two adjacent circular foundations; and the last state, two strip and circular foundations, next to each other. The results showed that up to the distance of 7B, the amount of settlement in strip foundations adjacent to each other increases up to 314% in comparison with single foundations. While in the adjacent circular foundations, the settlement amounts up to the distance B 4 has increased by 194%. In the third case, where the circular and strip foundations are adjacent, this settlement amount has increased to 152% compared to the strip foundation. It has risen by 164% compared to the circular foundation.

Rahimi et al., [8]	2020	The researchers presented a new calculation relationship to evaluate the bearing capacity of strip footings on two adhesive-frictional layers of ground. The calibration operation was conducted first to determine whether the results of the article were accurate by comparison with test results obtained from experimental models based on the relative thickness, density ratio, and shear strength parameters of soil layers that are effective. Regarding the load-displacement curve and damage, the numerical model and laboratory sample showed acceptable agreement. There is less than 5% (3.3%) difference between the numerical and laboratory results in terms of load capacity. Thus, the numerical simulation results can be trusted.
Saeedikhah and Bagherieh [9]	2019	The seismic bearing capacity of shallow foundations was evaluated using the lower bound finite element method. In this paper, using the lower bound finite element method using the Mohr-Columb criterion, a code has been designed and written in the MATLAB environment in such a way that by applying the lateral force (horizontal coefficient of earthquake acceleration) on the foundation surface, the weight of the soil mass below Based on the input load, the final load capacity is calculated. The research results show that the carrying capacity decreases by applying the effects of inertia. Therefore, considering the effects of inertia is a necessary point in the design of shallow foundations.
Kasbzadeh [10]	2019	Authors addressed the bearing capacity of shallow foundations in a deterministic way, in which they mentioned limited methods used in determining the bearing capacity of foundations. These methods can be placed in three general groups: limit equilibrium, characteristic lines, and limit analysis. In the limit equilibrium method, by choosing the rupture criterion and considering a hypothetical mechanism, the limit load is obtained by solving all or part of the equilibrium equations in the mass of ruptured soil. Then, the optimal limit load value is determined by changing the rupture mechanism and optimizing it. In this method, the location of the obtained solution is unclear concerning the exact solution. Also, in the method of characteristic lines, a system of hyperbolic differential equations is obtained from the combination of balance equations or dough surface equations, known as dough balance equations.
Rahimi et al. [11]	2019	They addressed a significant point that showed that as the soil becomes weaker, the total settlements increase, but the differential settlements decrease due to rigidity. Also, in the calculation methods of Janbo and Bowles, due to limitations such as the average consideration of the modulus of elasticity and adhesion of the soil, they are considered upstream methods, or in other words, with low-risk probability. On the other hand, the settlement values obtained from the analysis in 3D PLAXIS software are lower than the other two calculation methods; in other words, this method has a higher level of accuracy.
Iranmanesh and Soltani [12]	2018	They designed the suction matrix and water-soil characteristic curve. The parameter of the suction matrix in unsaturated soils has a significant effect on the behavior of the soil and is obtained by two direct and indirect methods. In the direct method, we are required to carry out tests in the laboratory, which, in addition to the fact that these tests are not

		very common in our country, are also expensive and time-consuming. In the indirect method, the estimation of the suction matrix is based on the water-soil characteristic diagram. Also, among the practical applications of the water-soil characteristic curve, we can mention the determination of shear strength, permeability coefficient, the retention coefficient of unsaturated water in the soil.
Ghiasi and Moradi [5]	2018	As a result of optimizing the foundation and the bearing capacity of the soil, which is defined as the capacity of the soil to support loads imposed by the foundation, the required final bearing capacity of the soil has been referred to as the final bearing capacity of soil (qu) and the net final bearing capacity of the soil (qnu). Therefore, among the characteristics of a good foundation, the following can be mentioned: 1- It does not lead to a shear rupture in the soil. 2- It should not lead to much settlement in the soil. The type and dimensions of the foundation are determined according to the type of building and the number of incoming forces, the texture of the layers, the type of soil, and the weather conditions of the region. In addition to the weight of the building, the number of floors, and the type of soil, the depth, length, and width of the foundations are determined by these factors. Foundations are classified based on depth and type of function. Generally, if the resistant layer is located at a small depth from the ground surface, the foundation is built near the ground surface. Otherwise, the foundation depth increases to reach the resistant layer.
Naseri and Hosseini [13]	2013	In this article, the sensitivity of the three methods presented by Mayne, Gazetas, and Schmertmann to numerically investigate the instantaneous settlement for the buried depth changes by keeping different parameters constant in different types of soil has been investigated. In a study, they investigated different methods for calculating the instantaneous settlement of a pile for its buried depth changes. The result from the research indicated that according to the theory of elasticity in the soil and the comparisons made, the Mayne method has more logical results than the other two methods.
Zarei et al. [14]	2014	Their study examined the sensitivity of different methods for calculating the instantaneous settlement of buried depths. The analysis of the research indicated that according to the theory of soil elasticity and the comparison made, Mayne's method was superior to both others. Others have more logical results.
Salimzadeh Shueili [15]	2008	Investigating the settlement of shallow foundations with the help of numerical modeling, in which four different soil models with five different states of the foundation with B/L ratios, three states of the soil depth ratio under the foundation B/H, and various loads in the finite element software were investigated. On the other hand, two common computational models of Janbo and Bowles (calculation of instantaneous settlement on saturated soil) were compared and differential settlements, as well as the effect of the wall, which was limited in previous research, were analyzed and evaluated. In the investigation of the performance of the studied foundations in terms of changes in the ratio of length to width B/L or the dimensions of the foundation, the results showed that with the increase in the B/L ratio, the amount of settlement of the foundation also takes an upward trend, so

		that the differential settlements in the ratio More ones show much higher values.
Massih et al. [16]	2008	The reliability analysis of shallow foundations can be analyzed from two different points of view. The first point of view is to calculate the bearing capacity of the foundation probabilistically and select the permissible bearing capacity by considering different confidence levels from the cumulative probability density function. The second point of view is the design of the shallow foundation according to the failure probability criterion. In this article, both points of view have been discussed and analyzed.
Braja M. Das [17]	2007	It has dealt with the principles of geotechnical engineering and soil mechanics. Any change in the structure and dimensions of the foundation includes strengthening the foundation. Resistance generally has its problems and complications. The cracks in the foundations of buildings are created in two ways, hidden or visible. The visible parts are obvious in crushing, etc., and the hidden parts are created due to settlement, soil swelling, building instability, etc. With time, they become noticeable cracks.
Pham et al. [18]	2008	They investigated the soil in a saturated state, and the soil is placed in this state. In this way, it is more appropriate to consider saturated soil and dry soil as a special state of unsaturated soil. In this case, the importance of examining these soils becomes more apparent. The calculation parameters in the unsaturated state are largely different from the saturated and dry states. Unsaturated soils are impacted by changes in negative pore water pressure and suction matrix, two factors with very different values.
Terzaghi [19]	1943	The Author was directed toward knowing the bearing capacity of shallow foundations in a saturated or dry state using conventional soil mechanics. However, soils are usually semi-saturated in arid and semi-arid regions. Therefore, estimating or determining the bearing capacity using classical soil mechanics may underestimate the bearing capacity and lead to costly and conservative designs. Several types of research were conducted on the bearing capacity of unsaturated soils. He designed special equipment and conducted studies to obtain the bearing capacity of shallow foundations in sandy soil. These studies showed that the bearing capacity of unsaturated soils with suction matrix values in the range of 2 to 6 kPa is 5 to 1 times the bearing capacity values. It is saturated.
Foundation engineering, bearing capacity of shallow foundations. (Coursebook of Civil Engineering Department of Bou Ali Sina University) [20]	2016	In this pamphlet, it is mentioned that in the design of a foundation, two factors should be considered simultaneously: 1- The soil under the foundation should easily be able to withstand the incoming load without any shear rupture or failure. The necessary distance is always maintained until the foundation breaks by applying a suitable safety factor. 2- The settlement amount created in the following should not exceed a certain limit. Despite the plan to prevent unequal settlements, most of the phase will have some asymmetric settlement, which may fluctuate from two-thirds to three-fourths of the total settlement.

Any change in the structure and dimensions of the foundation includes strengthening the foundation. Resistance generally has its problems and complications. The cracks in the foundations of buildings are created in two ways, hidden or visible. Visible parts are obvious in the form of crushing, etc.; hidden parts are created due to settlement, soil swelling, building instability, etc., and with time, they become visible cracks. The most common causes of foundation and it's vulnerability are as follows [20]:

- Insufficient bending or shear capacity - bending shear or piercing shear of the foundation section
- The presence of liquefaction potential, sand, and swelling potential in the soil under the foundation
- Occurrence of compressive stress exceeding the bearing capacity of the foundation under the foundation
- Existence of compressive or tensile force exceeding the geotechnical capacity of the piles

One of the goals of writing this research is to investigate the optimization of the bearing capacity and settlement of shallow foundations under the effect of variables such as the dimensions of the foundation L/B as well as the ratio of the soil depth under the foundation H/B in soils with different elastic properties and various loading conditions.

A. Researching and archiving building design documents for soil mechanics reports, soil investigation in the form of sampling and related tests, and measuring underground water level and water pressure.
B. Estimate the dimensions of the foundation of the building and the foundation of the walls. If necessary, some foundations are subjected to speculation, and in these speculations, the deterioration of the materials is checked.
C. Obtaining the necessary information from the building's geometry, configuration, executive plans, foundation, and loading.
D. Modeling and research.

Among the foundation improvement problems that can be mentioned include:

According to our information, in addition to the high cost of improving the foundation, this work is very difficult when the building is in use. During the strengthening of the foundations, we face the following problems:

- It is necessary to evacuate a part of the ground floor or basement to reinforce the foundation
- Destruction of the floor slab inside the building and the pavement outside it
- Limited height to equip the building and noise and vibrations of the building

2. Methods

The studies of Tarzaghi, 1943 and other researchers were directed toward knowing the bearing capacity of shallow foundations in a saturated or dry state using conventional soil mechanics. However, soils are usually semi-saturated in arid and semi-arid regions. Therefore, estimating or determining the bearing capacity using classical soil mechanics may underestimate the bearing capacity and lead to costly and conservative designs.

A deep foundation in soil is supported by the soil above it. There are three components to the bearing capacity equation 1; which is the weight of the soil and the reaction of the compressive block of the soil (Eq. 1). Carrying capacity is expressed as follows:

$$q_y = \frac{1}{2}\rho g \beta N_y \qquad (1)$$

Where in:

ρ:Density, g: Gravity, β: The angle(Radian)

$\boldsymbol{N_y}$: The bearing capacity coefficient of the second component is related to soil adhesion.

The amount of cohesion used in the analysis depends on how the shear strength of the soil is determined (Eq. 2). The third component is considered to apply the effect of soil overhead on the foundation floor (Eq. 3):

$$q_c = cN_c \qquad (2)$$

Where in:

$\boldsymbol{N_c}$**:** Coefficient of soil adhesion

$\boldsymbol{C}$ (kPa): Overall soil adhesion

$$q_q = \rho g \beta N_q \qquad (3)$$

Where in:

$\boldsymbol{N_q}$: Effective overhead factor in carrying capacity**.**

The final bearing coefficient of the soil can be expressed as the sum of the three components mentioned above (Eq. 4):

$$q_f = \frac{1}{2}\rho g \beta N_y + \gamma N_c + \rho g D_f N_q \qquad (4)$$

A suitable safety factor can reduce the final bearing capacity to the allowed bearing capacity. The above topic shows that the same plasticity theory is used for saturated and unsaturated soil types. The most important information required when using the theory of bearing capacity for unsaturated soils is related to the appropriate selection of shear strength parameters and the value of the suction matrix, an acceptable value for design.

Bearing capacity, lateral earth pressures, and slope stability are geotechnical applications that depend on soil shear strength. Soils used for engineering structures are often unsaturated. Unsaturated soil and changes in soil shear strength due to infiltration of water are important to measure. Unsaturated soils are subject to the same general rules as saturated soils when it comes to shear strength.

For example, the resistance of soil changes with the change in a stress state. Shear resistance can be related to the stress state of the soil. In the case of unsaturated soil, the stress state can be described by two corrections of effective stresses $(\sigma_n - u_a)$ and suction matrix $(u_a - u_w)$.

The shear strength of unsaturated soil is presented in two analytical and graphical methods. Presenting the laboratory test steps helps to visualize the changes caused by converting unsaturated soil to saturated soil and vice versa. In classical soil mechanics, the following relationship (Eq. 5) is used to express the shear strength:

$$\tau_f = c' + (\sigma - u_w)\tan\varphi \tag{5}$$

which in the above relation is the ultimate shear strength c' of adhesion, φ is the angle of internal friction of the soil, and τ_f is the effective stress perpendicular to the rupture. However, in generalized soil mechanics, several relations have been presented to calculate the shear resistance, among which we can refer to the relation of Fredland et al. Cited:

Where in:

$(\boldsymbol{\sigma_n - u_a})$: Effective stress,

$(\boldsymbol{u_a - u_w})$: Suction matrix.

$\boldsymbol{c'}$ **(kPa):** Effective adhesion or shear strength of the soil where both variables are zero in the case above.

φ'(degree): internal friction angle relative to the net normal stress change.

In these relations, all the parameters are definitively included in the calculations and cannot account for the existing uncertainties. Due to the existing uncertainties, the above method is unreliable, and methods considering these effects should be used. The reliability method is one of the methods proposed for this purpose. Reliability analysis makes it possible to quantitatively express existing uncertainties. Reliability analysis methods are generally divided into analytical, approximate, and simulation. In analytical methods, the probability density function of the input parameters is mathematically expressed, and then the reliability coefficient relationship is integrated based on the input variable parameters. By doing this, the probability density function of the confidence coefficient is determined. However, fewer studies have been done with this method due to its mathematical complexity.

Approximate methods of reliability analysis calculate the probability of occurrence of the phenomenon by using probability indicators such as mean, standard deviation, and coefficient variation.

The different bearing capacity analysis methods have been summarized in Table 2.

Table 2
Foundation bearing capacity analysis methods.

Foundation bearing capacity analysis results	Methods or researcher
Many researchers have been interested in approximate methods in recent years, and they have conducted a lot of research in this field. Each of these methods calculates the probability of failure with simplifying assumptions caused by this assumption, such as FORM (first-moment method), AFORM (advanced first-moment method), and PEM (point estimation method). Methods that simplify have decreased their accuracy, so they are called approximate methods. However, approximate methods cannot provide any information about the shape of the probability density function other than its mean and variance.	First, the second-order moment method, FOSM, and all related methods [21]
This method is one of the most widely used reliability analysis methods due to its simplicity and lack of comprehensive statistical and mathematical information. It is one of the appropriate and accurate methods of reliability analysis. This method can be used for any limit equilibrium method. In this method, a random value is defined for each of the input parameters according to its probability density function. Unlike the approximate methods, this method uses the entire area under the probability density function graph to construct the input numbers. These values are used for confidence factor calculations.	Monte Carlo simulation method [22]

Simulation methods are part of the detailed methods of reliability analysis. The Monte Carlo simulation method is one of the most practical in many geotechnical problems, such as roof stability, liquefaction, and retaining wall design. This method calculates the phenomenon's probability of occurrence by simulating the input parameters' random numbers and using repeated calculations. Today, this method has also expanded with the development and expansion of computer hardware.

3. Results and discussion

In order to observe the statistical distribution of the reliability coefficient, this process is repeated as many times as necessary. Statistical analysis of this distribution can be used to determine the mean and variance of the reliability coefficient as well as the probability of failure. The probability density function of each input random variable may have any shape, but the most common distributions are normal, log-normal, triangular, and beta. The Monte Carlo simulation consists of four stages:

a. According to the probability density function of each random input variable, a random value is selected.
b. In the second step, the reliability coefficient value is calculated using the performance function by placing the random numbers made in the previous step.
c. The first and second steps are repeated many times, and the value of the confidence coefficient is obtained for each repetition.
d. Using the reliability coefficient values obtained from the Monte Carlo simulation, the probability of failure, the average value, the variance of the reliability coefficient, and the form of the probability density function of the reliability coefficient can be obtained. The minimum number of computational steps required depends on the number of random input variables as well as the confidence level of the sample. Statistically, the following relationship (Eq. 6) can determine the number of Monte Carlo repetitions.

$$N = \left(\frac{d^2}{4(1-\varepsilon)^2}\right) \quad (6)$$

In this relation, N is the number of computational stages of Monte Carlo simulation, d and ε are, respectively, the standard deviations and the desired confidence level according to Table 1. m is the number of random input variables.

To generate random numbers, functions are often used that generate random numbers $R1,\ R2$, ..., Rn between zero and one and uniform probability distribution. Then, using relations, these numbers are converted into numbers with a standard normal probability distribution $(\mu, \sigma) = 0\ = 1$ (Table 3).

Table 3
Confidence Level and Standard Deviation (D).

Confidence Level	Standard Deviation (D)
80%	1.282
90%	1.465
95%	1.960
99%	2.576

To generate random numbers, functions are often used that generate random numbers $R1, R2, \dots, Rn$ between zero and one and uniform probability distribution. Then, using equations 7 and 8, these numbers are converted into numbers with a standard normal probability distribution:

$$N_1 = \sqrt{-2\ln R_1}\cos(2\pi R_2) \quad (7)$$

$$N_2 = \sqrt{-2\ln R_1}\sin(2\pi R_2) \quad (8)$$

The relationships presented are for cases where the generated random numbers are independent of each other. If random numbers with normal distribution are not independent of each other, then the second component of random numbers is calculated from the following equation (Eq. 9):

$$X_i = \mu_x + N_i\sigma_x \tag{9}$$

In the previous relationship, ρ_{xy} is the correlation coefficient between the random parameters X Y, $N1$ is the first random number generated with a standard normal distribution, N_2 is the second random number with a standard normal distribution, and $2 * N$ is a random number dependent on the number $N1$. To generate interdependent random numbers with a normal probability distribution, after generating random numbers, Equations 10, 11, and 12 can be used:

$$N_2^* = N_1\rho_{xy} + N_2\sqrt{\left(1-\rho_{xy}\right)^2} \tag{10}$$

$$X_1 = \mu_x + N_1\sigma_x \tag{11}$$

$$Y_1 = \mu_y + N_2^*\sigma_x \tag{12}$$

Load bearing analysis of shallow foundations using Monte Carlo simulation method. The reliability analysis of shallow foundations can be analyzed from two different perspectives. The first point of view is to calculate the bearing capacity of the foundation probabilistically and choose the permissible bearing capacity by considering different confidence levels from the cumulative probability density function. The second point of view is the design of the shallow foundation according to the failure probability criteria. In this article, we discuss both points of view:

The following formula is used to determine the bearing capacity of a foundation, taking the desired level of confidence into account:

Based on the bearing capacity of the foundation, the bearing capacity of the soil can be calculated according to the desired confidence level, and the bearing capacity of the foundation can be analyzed according to various performance levels. Analyzing the bearing capacity of the foundation involves four steps based on Monte Carlo simulation.

The first step in Monte Carlo simulation is generating random input numbers. Random numbers are based on average parameters, coefficient of variation, hypothetical probability distribution function, and correlation between parameters. As described in the second chapter, the coefficient of variation of soil parameters can be calculated in three ways. Due to the existing limitations, the coefficients suggested by previous researchers are the most useful in reliability analysis. The specifications of the random parameters are considered according to Tables 4 and 5.

Table 4
Characteristics of random parameters and correlation coefficients between parameters.

Parameter	Probability density function	Coefficient of variation (%COV)
C	Normal	30
φ	Normal	15
$\boldsymbol{\gamma}$	Normal	15

Table 5
Characteristics of random parameters and correlation coefficients between parameters(Internal friction angle and cohesion).

Parameter	C	$\boldsymbol{\varphi}$
C	1	**0/5**
φ	-0/5	**1**

Calculating the probability of foundation failure. In the first point of view, the bearing capacity of the foundation was discussed using different levels of confidence, and the method of calculation and its advantages were stated. In the first view, only the soil parameters were assumed as possible, and the calculations were done without considering the load. In the second point of view, the incoming load is also examined. According to the variable nature of the load, the correction calculations and the probability of foundation failure are determined. In this method, the probability of foundation failure is directly calculated with the determination of the load and its possible changes. It facilitates engineering judgment in the field of foundation design. Random parameters are generated based on their mean, coefficient of variation, and probability distribution function. The performance function is obtained according to $Eq(13)$based on the numbers made in step one.

$$\text{Performanc Functione} = \text{FS} = \text{q}/\text{p} \tag{13}$$

In the above relationship, q is the bearing capacity of the foundation, and p is the load on the foundation. Steps one and two are repeated many times, and each step's reliability coefficient is calculated. The failure probability is equal to the area under the confidence factor diagram in the range of responses smaller than one. Figure 1 shows an example of liquefaction calculation. The area under the graph is equal to the ratio of the number of responses smaller than.

$$P_L = \frac{N_c}{N_{total}} \tag{14}$$

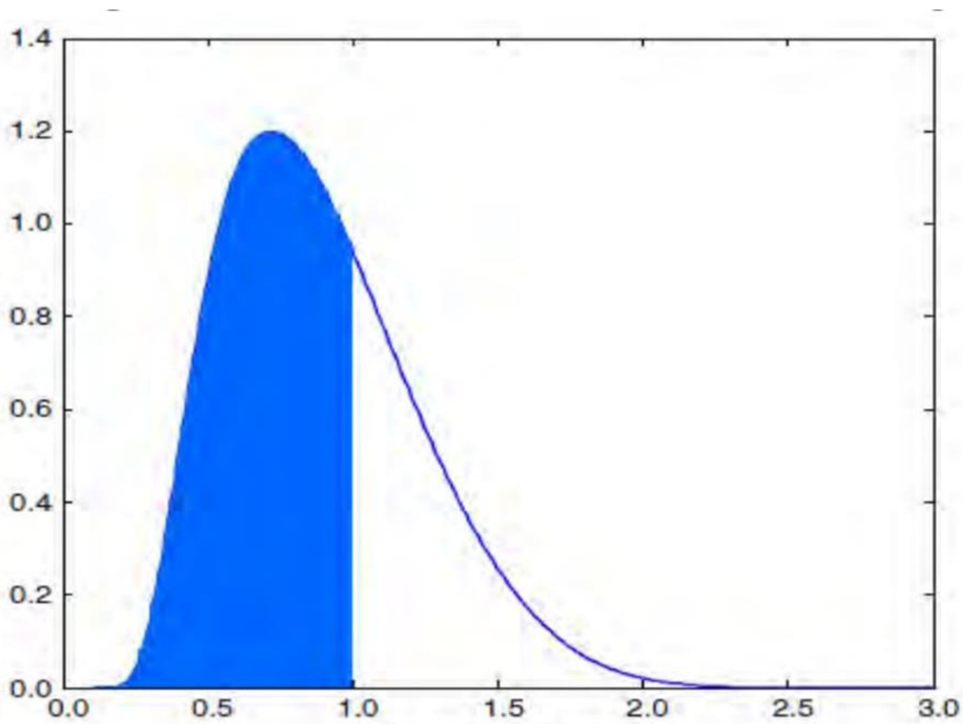

Fig. 1. The probability density function of confidence factor and foundation failure probability.

3.1 Sample Simulation

In this section, to show the capability of the presented model in analyzing the bearing capacity of foundations, a numerical problem has been solved with assumed data**:** Characteristics of parameters presented in Table 6.

Table 6
Characteristics of parameters.

Parameter	$\varphi(deg)$	$C(kPa)$	$\gamma\ (kPa)$	$B(m)$	$D(m)$	$Df(m)$
the amount of	30	5	20	1	1	1

The load capacity frequency diagram is finalized by repeated calculations and calculating the confidence factor in each step. Figure 2 calculates the permissible carrying capacity with a confidence level of 91%. As can be seen, it is completely continuous and follows the log-normal probability distribution function. Also, the number of simulation repetitions is 211 thousand times.

If the strip foundation with the mentioned specifications is analyzed using the Monte Carlo method, the cumulative distribution diagram of the bearing capacity will be shown in Figure 3. The final bearing capacity of the foundation is obtained using the deterministic method and

Hansen's relations as 742 $k\,N$. Therefore, t permissible bearing capacity is estimated to be 247 $k\,N$ considering the safety factor of 3 for normal structures and 148 $k\,N$ considering the safety factor of 5 for more important structures.

The cumulative distribution chart of the bearing capacity can be used to determine the permissible bearing capacity of the foundation based on the desired level of confidence. Based on a review of the technical literature, it appears that 91 to 98 percent confidence is required for structures. In the case of the 91% confidence level, 91% of the simulated cases exceed the allowed capacity.

In spite of the increase, the level of confidence in calculating the foundation's bearing capacity has also increased significantly. The permissible carrying capacity is equal to 381, 321, and 262 kN according to the confidence levels of 91, 95, and 98%, respectively. The equivalent confidence coefficient for 91 and 98 percent levels equals 1.95 and 2.83, respectively, by comparing the permissible values and the final carrying capacity. The mentioned reliability coefficients are much smaller than the reliability coefficients of 3 for normal structures and the reliability coefficient of 5 for structures with higher reliability coefficients which are common in the deterministic method (Table 7).

Table 7

Comparison of deterministic analysis methods and reliability in bearing capacity of the foundation.

Criterion	q_u	The importance of the structure	Confidence factor	q_{all}	Confidence level required	Possible carrying capacity	The ratio of probable capacity to definite load
state of 1	742	Normal	3	247	90	380	1/53
state of 2		medium	4	185	95	320	1/73
state of 3		Much	5	148	98	282	1/77

This table7 shows that by considering the reliability level criterion and the reliability method instead of the reliability coefficient criterion and the deterministic method, in addition to more reliability, the bearing capacity of the foundation has increased significantly. Ultimate Bearing Capacity of Foundation shown in Figure 2 and calculate the probability of liquefaction from the CDF function shown in Figure 3.

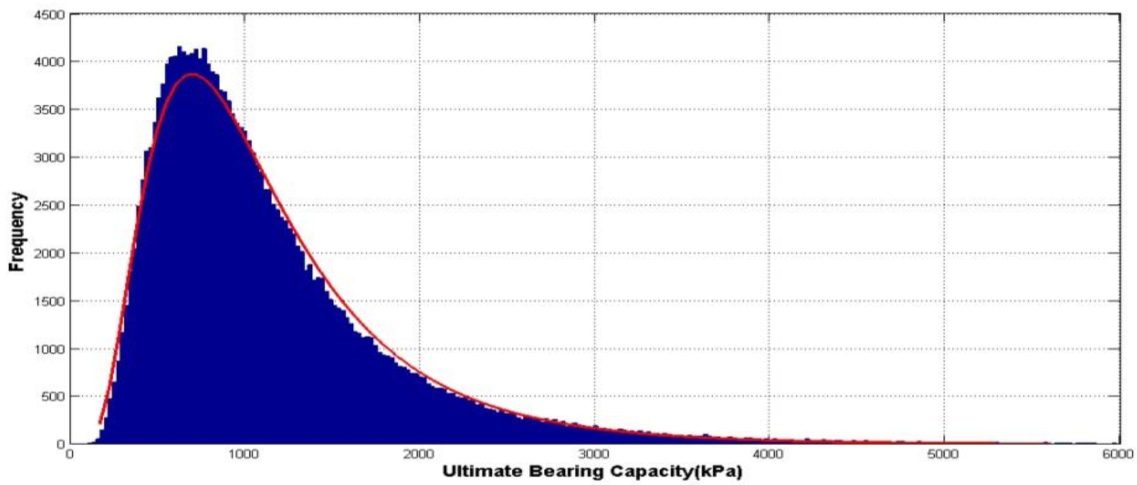

Fig. 2. Ultimate Bearing Capacity of Foundation.

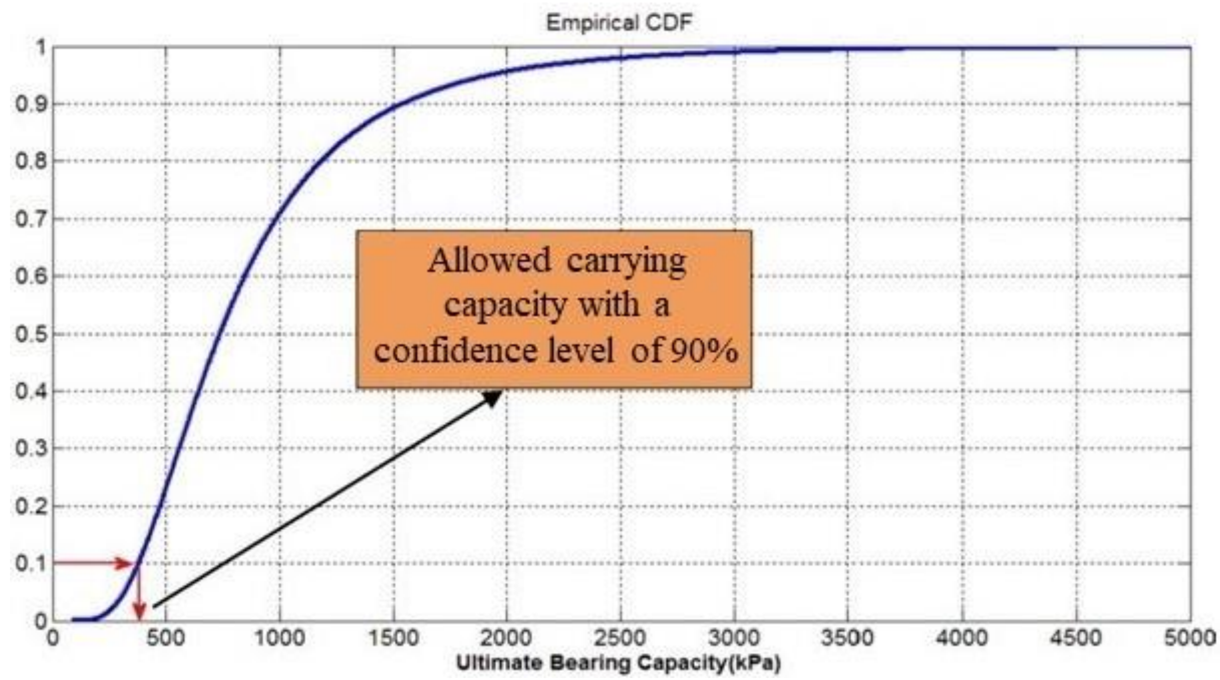

Fig. 3. Calculate the probability of liquefaction from the CDF function.

It should be noted that Figures number 1, 2, and 3, which have been briefly discussed earlier, are compiled from the second international conference on new research achievements in civil engineering, architecture, and urban management.

4. Conclusions

A load-bearing analysis of foundations influenced by natural changes in soil shear strength and behavior. Uncertainty in determining shear strength, incomplete knowledge of subsurface conditions and soil layers, local soil degradation and its effect on bearing capacity during or after construction, and uncertain theoretical and experimental methods of determining bearing capacity and settlement are the objectives of these analysis.

The reliability coefficient in determining the load-bearing capacity of foundations under the influence of factors such as natural changes in soil shear strength, complexity of soil behavior, uncertainty in the determination of shear strength, lack of complete knowledge of subsurface conditions, local deterioration of soil, and the effect on the bearing capacity during construction and afterward, and the uncertainty of theories and experimental methods of calculating the bearing capacity and settlement. For these reasons, a relatively large confidence factor is used in the analysis of the bearing capacity of the foundation. However, despite using high confidence coefficients and spending more money, due to the small effects of these uncertainties, there is not enough confidence in this method. It is suggested to provide laboratory equipment to determine the properties of unsaturated soil so that costs can be significantly reduced with optimal cost design in every project.

Also, in determining the carrying capacity represent:

According to the load-settlement graphs, the settlements increase when the load q increases. Therefore, this operation was done to compare and generalize the parametric analysis.

Authors also know that a relatively large confidence factor is used in the load-bearing analysis of the foundation. Despite using high confidence coefficients and spending more money, due to the small effects of these uncertainties, there is not enough confidence in this method. The use of reliability methods in the analysis and design of shallow foundations is superior to deterministic methods, especially in highly important structures, and its use in high-importance projects seems completely logical. It can increase safety and optimize the cost of projects.

If the strip foundation with the mentioned specifications is analyzed using the Monte Carlo method, the cumulative distribution diagram of the bearing capacity is shown in Figure 3. The final bearing capacity of the foundation is obtained using the deterministic method and Hansen's relations as 742 kN. Therefore, t permissible bearing capacity is estimated to be 247 kN considering the safety factor of 3 for normal structures and 148 kN considering the safety factor of 5 for more important structures.

To choose the permissible bearing capacity of the foundation, the cumulative distribution chart of the bearing capacity can be used according to the desired confidence level. Reviewing the technical literature shows that the level of confidence required for structures is around 91 to 98 percent. For example, the confidence level of 91% indicates that 91% of the simulated cases have a carrying capacity greater than the allowed capacity.

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