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ORIGINAL PAPER

COMPARISON OF A NEW VISUAL BASIC APPLICATION WITH CONVENTIONAL METHODS TO CALCULATE BEARING CAPACITIES FOR SOILS

Ebubekir KILIC * and Akin ISTEK

Geotechnical Program, Construction Department, Keban Vocational School, Firat University, Elazig, Türkiye

**Corresponding author's e-mail:* e.kilic@firat.edu.tr

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ABSTRACT

The selection and design of foundation and superstructure systems depend heavily on determining the soil parameters and bearing capacity. Currently, bearing capacity is commonly estimated using analytical equations that involve numerous variable parameters. However, employing multiple formulations and variables in calculating bearing capacity can introduce inaccuracies and computational difficulties. This study aims to reduce potential inaccuracies and computational complexities in calculating bearing capacity and to accelerate the process using a Visual Basic application. This application simultaneously calculates and compares bearing capacities by Terzaghi, Meyerhof, Hansen, and Vesic methods. For this purpose, an example problem involving the calculation of bearing capacity was solved using both the conventional methods and a Visual Basic application, and the results were compared. This study demonstrated that bearing capacity results can be obtained more rapidly and consistently using the Visual Basic application than with conventional methods.

1. INTRODUCTION

Bearing capacity is defined as the loading intensity that causes shear failure under a foundation (Blyth and Freitas, 1984). Waltham (2009) also defined ultimate bearing capacity as the load at failure, and Önalp and Sert (2006) referred to it as the maximum stress that the soil can carry without visibly collapsing.

The types of foundation and superstructure to be used in a structure can be predicted using basic geological data and information about the soils surrounding and under the structure. Krynine and Judd (1957) reported that understanding the characteristics of the rocks and soils that comprise the foundation material is essential for the sub- and superstructure. The structural damage caused by recent earthquakes highlights the importance of interaction between foundation soils and structures. Therefore, it is necessary to determine both the magnitude of the largest expected earthquake in the region and the bearing capacities of the soil beneath building foundations.

Tomlinson (1974) reported that soil mechanics is limited, and potential hazards arise when foundation designs are based on insufficient data or incorrect investigative methods are used. In this context, a bearing capacity equation for soils in shallow foundations was first proposed by Terzaghi (1943). Terzaghi (1943) extended this equation by adding shape factors for foundations to the failure mechanism suggested by Prandtl (1921). Skempton (1951) extended Terzaghi's (1943) equation by incorporating shape and depth factors s_c and d_c into the first term of the equation to estimate the bearing capacity of clayey soils.

Meyerhof (1951; 1953; 1956; 1963) also proposed a more comprehensive bearing capacity equation for soils, which included shape, depth, and inclination factors. Hansen (1961; 1970) developed a more complex equation than Meyerhof (1963) by incorporating factors such as shape, depth, base inclination, and ground slope.

The equation of Hansen (1961) was further expanded by Vesic (1963; 1973; 1975) by adding parameters such as base inclination and ground slope. The bearing capacity of soils has been determined experimentally by many authors (Terzaghi, 1943; Meyerhof, 1951; Hansen, 1970; Vesic, 1963) based on soil parameters. There are many parameters in each of these equations. Internal friction angle, cohesion, and density of soil, ground slope, groundwater level, footing shape, depth, inclination, base conditions, and the magnitude and direction of loads acting on the footing are factors that influence bearing capacity (Terzaghi, 1943; Meyerhof, 1951; Hansen, 1970; Vesic, 1963). The aforementioned equations are currently the most widely used methods for determining bearing capacity.

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Table 1 Bearing capacity coefficients, equations, and shape factors of foundation bases used by Terzaghi (1943).

$N_c = (N_q - 1)\cot \emptyset$

$N_q = \frac{a^2}{\cos\emptyset^2(45+\frac{\emptyset}{2})}$

$a = e^{\left(0,75\pi-\frac{\emptyset}{2}\right)\tan\emptyset}$

$N_\gamma = \frac{\tan\emptyset}{2}\left(\frac{K_{p\gamma}}{\cos\emptyset^2} - 1\right)$

	Strip	Round	Square
s_c	1	1.3	1.3
s_γ	1	0.6	0.8

Table 2 Bearing capacity coefficient equation formulas proposed by Meyerhof (1963).

$N_c = (N_q - 1)\cot \emptyset$
$N_q = e^{\pi\tan\emptyset}\tan^2\left(45+\frac{\emptyset}{2}\right)$
$N_\gamma = (N_q - 1)\tan(1.4\,\emptyset)$

Shill and Hoque (2015) ranked ultimate bearing capacity values obtained from the methods of Vesic (1963), Hansen (1970), Meyerhof (1951), and Terzaghi (1943) from largest to smallest for shallow foundations in soils with cohesion (c) and internal friction angle (c–Ø or Ø). Furthermore, these researchers reported that bearing capacity increases linearly with increasing cohesion and increases exponentially when the internal friction angle exceeds 20°. Using numerous equations and parameters to calculate bearing capacity leads to errors, complexity, and computational challenges unless a computer is employed. In this study, a new Visual Basic application has been developed to minimize these challenges and potential errors encountered in calculating the bearing capacity. This study aims to calculate the bearing capacity using both the conventional methods mentioned above and the Visual Basic (VBA) application and to compare the results with each other.

2. METHODS

In this study, an example problem taken from Bowles (1997) was used to calculate bearing capacity. This problem was first calculated manually with a calculator, then solved using the VBA application, and the results were graphed in Excel. The example problem was also calculated using artificial intelligence models such as MATLAB and Python. The results were compared with one another. The International System of Units was used to calculate the parameters and the bearing capacity equations.

2.1. TERZAGHI'S BEARING CAPACITY METHOD

Terzaghi (1943) modified the theory of Prandtl (1921) to develop the ultimate bearing capacity equation for soils. The author developed a basic equation for long strip foundations of unit width that produce plane strain conditions. Table 1 presents the bearing capacity coefficient formulas and shape factor values proposed by Terzaghi (1943) for different footing shapes.

According to the author, it is assumed that the building loads act perpendicular to the foundation material, the foundation rests on level ground, and the foundation base is flat. The ultimate bearing capacity equation, now generally considered the general bearing capacity equation for soils, is expressed as Eq. (1):

$$q_{ult} = c\,N_c\,s_c + \bar{q}\,N_q + 0.5\,\gamma\,B\,N_\gamma\,s_\gamma \quad (1)$$

This equation includes three terms. From left to right, the first term represents the effect of cohesion, the second term represents the effect of footing depth, and the third term represents the influence of footing width (B) and soil unit weight. Terzaghi (1943) devised a bearing capacity equation for soils in shallow foundations based on a general shear failure in dense soils and a local shear failure for loose soils.

2.2. MEYERHOF'S BEARING CAPACITY METHOD

Meyerhof (1951, 1953, 1956, and 1963) proposed an ultimate bearing capacity equation for soils similar to that of Terzaghi (1943) but more comprehensive. Table 2 illustrates the bearing capacity coefficient formulas proposed by Meyerhof (1963). The formulas for the shape, depth, and inclination factors proposed by Meyerhof (1963) are also presented in Table 3.

Meyerhof (1951; 1953; 1956; 1963) also added depth factors to Terzaghi's (1943) equation for vertical loads acting on foundations with a horizontal base (Eq. (2)). Furthermore, by adding the inclination factors for the effect of inclined loads to this formula, the author developed a more comprehensive bearing capacity equation for soils (Eq. (3)).

Vertical load:

$$q_{ult} = c\,N_c\,s_c\,d_c + \bar{q}\,N_q\,s_q\,d_q + 0.5\gamma B N_\gamma s_\gamma d_\gamma \quad (2)$$

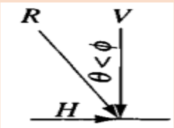
Inclined load:

$$q_{ult} = c\,N_c\,s_c\,d_c\,i_c + \bar{q}\,N_q\,s_q\,d_q\,i_q + 0.5\,\gamma\,B\,N_\gamma s_\gamma\,d_\gamma i_\gamma \quad (3)$$

2.3. HANSEN'S BEARING CAPACITY METHOD

Hansen (1961) proposed a comprehensive formula that considered factors such as footing shape, depth, inclination, base, and ground slope. Since bearing capacity equation of Hansen (1970) applies to any D/B ratio, it can be used for both shallow and deep foundations. Hansen added ground slope and footing base variables to the equations proposed by previous researchers. Table 4 illustrates the formulae for bearing capacity coefficients.

Table 3 Shape, depth, and inclination factors for bearing capacity equations of Meyerhof (1963)*.

Factors	**Formulae**	**For Ø**
Shape	$s_c=1+0.2\ K_p\frac{B}{L}$	Any Ø
	$s_q=s=1+0.1\ K_p\frac{B}{L}$	Ø>10°
	$s_q=s_\gamma=1$	Ø=0
Depth	$d_q=1+0.2\ K_p\frac{D}{B}$	Any Ø
	$d_q=d_\gamma=1+0.1\ K_p\frac{D}{B}$	Ø>10°
	$d_q=d_\gamma=1$	Ø=0
Inclination 	$i_c=i_q=\left(1-\frac{\theta^o}{90^o}\right)^2$	Any Ø
	$i_\gamma=\left(1-\frac{\theta^o}{\emptyset^o}\right)^2$	Ø>0
	$i_\gamma=0$ for θ>0	Ø=0

*$K_p = \tan^2(45 + Ø/2)$; θ = the angle of the resultant force R measured from the vertical without a sign. If θ = 0, then i_i = 1.0. H and V are horizontal and vertical forces.

Table 4 Formulas for coefficients of the bearing capacity equation used by Hansen (1970).

$\mathbf{N_c=(N_q-1)\cot Ø}$
$\mathbf{N_q=e^{\pi\tan Ø}\tan^2\left(45+\frac{Ø}{2}\right)}$
$\mathbf{N_\gamma=1.5(N_q-1)\tan Ø}$

Table 5 Factors of shape and depth, inclination, ground, and base for bearing capacity equations used by Hansen (1970) and Vesic (1963; 1973; 1975) *.

Shape factors	**Depth factors**	**Inclination factors**	**Ground factors**
$s'_{c(H)}=1+0.2\frac{B'}{L'}$ (Ø=0) $s_{c(H)}=1+\frac{N_q}{N_c}\times\frac{B'}{L'}$ $s_{c(V)}=1.0+\frac{N_q}{N_c}\times\frac{B}{L}$ $s_c=1$ for strip	$d'_c=1+0.4k$ (Ø=0) $d_c=s=1+0.4k$ k=D/B for D/B≤ 1 $k=\tan^{-1}(\frac{D}{B})>1$ k=in radians	$i'_c=\sqrt{1-\frac{H_i}{A_f\,c_a}}$ $i_c=i_q-\frac{1-i_q}{N_q-1}$ $i_q=\left[1-\frac{0.5\,H_i}{V+A_f\,c_a\cot Ø}\right]^{\alpha_1}$ $2\le\alpha_1\le 5$ $i_\gamma=\left[1-\frac{0.7\,H_i}{V+A_f\,c_a\cot Ø}\right]^{\alpha_2}$ $i_\gamma=\left[1-\frac{(0.7-\eta^o/450)H_i}{V+A_f\,c_a\cot Ø}\right]^{\alpha_2}$ $2\le\alpha_2\le 5$	$g'_c=\frac{\beta^o}{147^o}$ $g_c=1-\frac{\beta^o}{147^o}$ $g_q=g_\gamma=(1-0.5\beta)^5$
$s_{q(H)}=0.2\frac{B'}{L'}\sin Ø$ $s_{q(V)}=0.2\frac{B}{L}\tan Ø$ For all Ø	$d_q=1+2\tan Ø(1-\sin Ø)^2k$ k=in radian		**Base factors** $b'_c=\frac{\eta^o}{147^o}$ for Ø=0 $b_c=1-\frac{\eta^o}{147^o}$ for Ø>0 $b_q=\exp(-2\,\eta\tan Ø)$ $b_\gamma=\exp(-2.7\,\eta\tan Ø)$ η in radians
$s_{\gamma(H)}=1-0.4\frac{B'}{L'}\ \ge 0.6$ $s_{\gamma(V)}=1-04\frac{B}{L}\ \ge 0.6$	$d_\gamma=1.00$ for all Ø		

*H and V are subscripts for Hansen (1970) and Vesic (1963; 1973; 1975), respectively.

The formulas for shape, depth, ground slope, inclination, and base factors proposed by Hansen (1970) and Vesic (1963; 1973; 1975) are also presented in Table 5. The equation of Hansen (1970) is, in a sense, an extension of the bearing capacity equation of Meyerhof (1963). The most comprehensive ultimate bearing capacity equations are given in Equations (4) and (5).

$$q_{ult} = c\,N_c\,(s_c\,d_c\,i_c\,b_c\,g_c) + \bar{q}N_q\,(s_q\,d_q\,i_q\,b_e\,g_q) + + 0.5\gamma BN_\gamma\,(s_\gamma d_\gamma\,i_\gamma b_\gamma\,g_\gamma) \quad (4)$$

$$q_{ult} = 5.14\,s_u\,(1 + s'_c + d'_c - i'_c - b'_c - g'_c) + \bar{q} \quad \text{When } Ø = 0 \quad (5)$$

Table 6 Bearing capacity coefficients and equations used by Vesic (1963; 1973; 1975).

$N_c = (N_q - 1) \cot Ø$
$N_q = e^{\pi \tan Ø} \tan^2\left(45 + \frac{Ø}{2}\right)$
$N_\gamma = 2(N_q + 1) \tan Ø$

Table 7 Factors and formulae of inclination, ground, and base for bearing capacity equation used by Vesic (1963; 1973; 1975).

Inclination factors	Ground factors
$i'_c = \frac{m H_i}{A_f c_a N_c}$ Ø=0	$g'_c = \frac{\beta^\circ}{5.14}$ β in radians
$i_c = i_q - \frac{1 - i_q}{N_q - 1}$ Ø>0	$g_c = i_q - \frac{1 - i_q}{5.14 \tan Ø}$ Ø>0
$i_q = \left[1 - \frac{H_i}{V + A_f c_a \cot Ø}\right]^m$ H parallel to B	$g_q = g_q = (1.0 - \eta \tan Ø)^2$
$i_\gamma = \left[1 - \frac{H_i}{V + A_f c_a \cot Ø}\right]^{m+1}$ H parallel to L	**Base factors**
$m = m_B = \frac{2 + \frac{B}{L}}{1 + \frac{B}{L}}$	$b'_c = g'_c$ for Ø=0
	$b_c = 1 - \frac{2\beta}{5.14 \tan Ø}$
$m = m_L = \frac{2 + \frac{L}{B}}{1 + \frac{L}{B}}$	$b_q = b_\gamma = (1.0 - \eta \tan Ø)^2$

2.4. VESIC'S BEARING CAPACITY METHOD

Vesic (1963; 1973; 1975) proposed an equation similar to the bearing capacity equation of Hansen (1970), which considers parameters such as footing shape, depth, inclination, base inclination, and ground slope. Table 6 illustrates the bearing capacity coefficient formulas proposed by Vesic (1963, 1973, and 1975).

Vesic's (1975) formulae differ from those of Hansen (1970) in terms of inclination, base, and ground factors, as shown in Table 7. The application of the equation of Vesic (1975) for bearing capacity is slightly simpler than Hansen's (1970), because Vesic does not consider ground when calculating shape factors. Vesic (1975) considered the equation for the depth factor suggested by Hansen (1970). Sketch of Vesic (1975) identifying bearing capacity coefficients is presented in Table 8.

The ultimate bearing capacity calculated using the method of Vesic (1975) is higher than that obtained using the methods of Meyerhof (1963) and Hansen (1970) due to these coefficients. The ultimate bearing capacity equation proposed by Vesic (1975), given in Eq. (6), is as follows:

$$q_{ult} = c\, N_c\, (s_c\, d_c\, i_c\, b_c\, g_c) + \bar{q} N_q\, (s_q\, d_q\, i_q\, b_q\, g_q) + 0.5\, \gamma\, B\, N_\gamma\, (s_\gamma\, d_\gamma\, i_\gamma\, b_\gamma\, g_\gamma). \quad (6)$$

In this bearing capacity method, the non-horizontal orientation of the load and the base is an important difference from other methods. However, the most important difference is that the condition of D/B<1 is not required, unlike in the Terzaghi (1943) method. Furthermore, Hansen (1970) and Vesic (1975) used soil bearing capacity equations when the footing is located on a slope.

2.5. THE EFFECT OF GROUNDWATER LEVEL ON THE BEARING CAPACITY FOR SOILS

In all ultimate bearing capacity equations, consisting of three terms, the effect of groundwater level (GWL)is considered in the second and third terms. Bowles (1997) stated that instead of the soil unit weight (γ), the effective unit weight of the soil (γ_e) should be used in the second and third terms of the ultimate bearing capacity equations.

If the GWL is at or above the footing base level, the submerged unit weight (γ') is used instead of γ in Equation (1). According to Bowles (1997), γ_e should be used instead of γ in Equation (7) when the GWL lies between levels 2–2 and 1–1 shown in Figure 1.

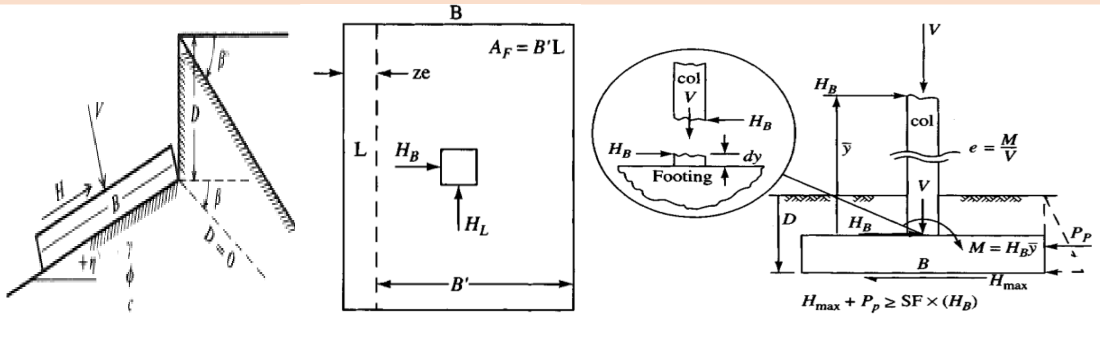
$$\gamma_e = 2\,H - d_w \left(\frac{d_w}{H^2}\, \gamma_{wet} + \frac{\gamma'}{H^2} (H - d_w)^2 \quad (7)$$

If the GWL is deeper than 0.5 B tan (45 + Ø/2) below the foundation base (levels 2–2 and 4–4), groundwater effects can be ignored. If the GWL lies between the footing base and a depth B below the base, as shown at level 5–5, the value of γ can be calculated by linear interpolation between levels 2–2 and 1–1.

2.6. AN EXAMPLE PROBLEM AND ITS CONVENTIONAL SOLUTIONS

Figure 2 illustrates the characteristics of the footing and soil: B = 2 m, L = 2 m, ground slope, β = 0, $A_f = B \times L$ = 2 m × 2 m, γ = 17.5 kN / m^3, Ø = δ = 25°, c = c_a = 25 kPa, V = 600 kN, H_B = 200 kN, and H_L = 0. The ultimate and allowable soil bearing capacities (q_{ult} and q_a) for this soil were calculated using conventional or manual (no automatic) procedures and the methods of Terzaghi (1943), Meyerhof (1963), Hansen (1970), and Vesic (1975), as presented below.

Table 8 Terms in the equation of the bearing capacity for soils used by Vesic (1963; 1973; 1975).

$\beta+\eta \leq 90^{o}$ Both β and η have signs (+)		
$\beta \leq Ø$		
		
For L/B ≤2, use $Ø_{tr}$	**in surface B, H_{max}=V tan δ c_a A_f**	
L/B>2, use $Ø_{ps}$=1.5 $Ø_{tr}$ -17	**δ= friction angle between base and soil (0.5 Ø ≤δ≤ Ø)**	
$Ø_{tr} \leq 34$, use $Ø_{tr}$= $Ø_{ps}$	**A_f=B' L'(effective area)**	**c_a=base adhesion(0.6 to 1.00 c)**

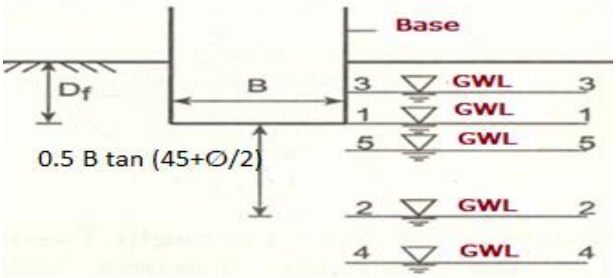


Fig. 1 The relationship of D_f and B to values of γ to be used in the second and third terms in Equation (1) of the bearing capacity for different cases of GWL.

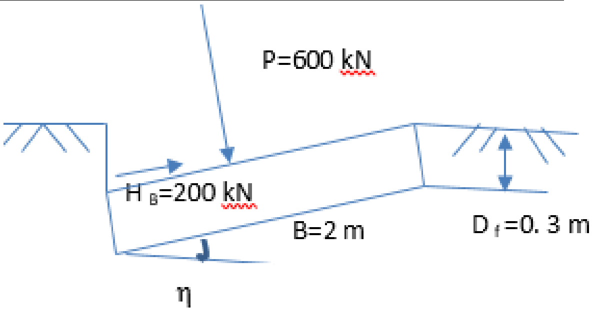


Fig. 2 Key characteristics of the soil and an inclined footing for the example problem.

2.7. SOLUTION BY THE TERZAGHI METHOD

For Ø = 25°, the bearing capacity coefficients according to Terzaghi (1943) were obtained as N_c = 25.1, N_q = 12.7, and N_γ = 9.7, and the shape factors were obtained as s_c = 1.3 and s_γ = 0.8 (square base) using the equations in Table 1.

By substituting the relevant parameter values into Equation (1), the ultimate bearing capacity in the B direction, $q_{ult,\ B,}$ was calculated as 25 (25.1) (1.3) + 0.3 (17.5) (12.7) + 0.5 (17.5) (2.0) (9.7) (0.8) = 815.75 + 66.67 + 135.8 = 1018.22 kPa. The allowable soil bearing capacity was calculated using Equation (8):

$$q_{a,B} = q_{ult,B}/\ 3 \qquad (8)$$

Thus, the allowable bearing capacity according to Terzaghi (1943) was obtained as $q_{a,B}$ = 1018.22/3 = 339.40 kPa.

2.8. SOLUTION BY THE MEYERHOF METHOD

Since Ø = 25° > 10°, the ratio D/B′ was obtained as 0.15. From Table 3, shape factors according to Meyerhof (1963) were calculated as K_p = 2.464, s_c = 1.0, and $s_q = s_\gamma$ = 1.25. Depth factors were obtained as d_c = 1.05 and $d_q = d_\gamma$ = 1.02. Inclination factors were obtained as θ = 18.4°, $i_c = i_q$ = 0.633, and i_γ = 0.0696 according to the equations in Table 3.

By substituting the relevant parameter values into Equation (3), the ultimate bearing capacity in the B direction of the footing according to Meyerhof (1963), or $q_{ult,B}$ was calculated as: 25 (20.7) (1) (1.05) (0.633) + 0.3 (17.5) (10.7) (1.25) (1.02) (0.633) + 0.5(17.5) (2.0) (6.8) (1.25) (1.02) (0.07) = 343.95 + 45.33 + 10.62 or 399.90 kPa. Substituting the calculated value of $q_{ult\ B}$ into Equation (7), the allowable bearing capacity according to Meyerhof (1963) was obtained as $q_{a,B}$ = 133.30 kPa.

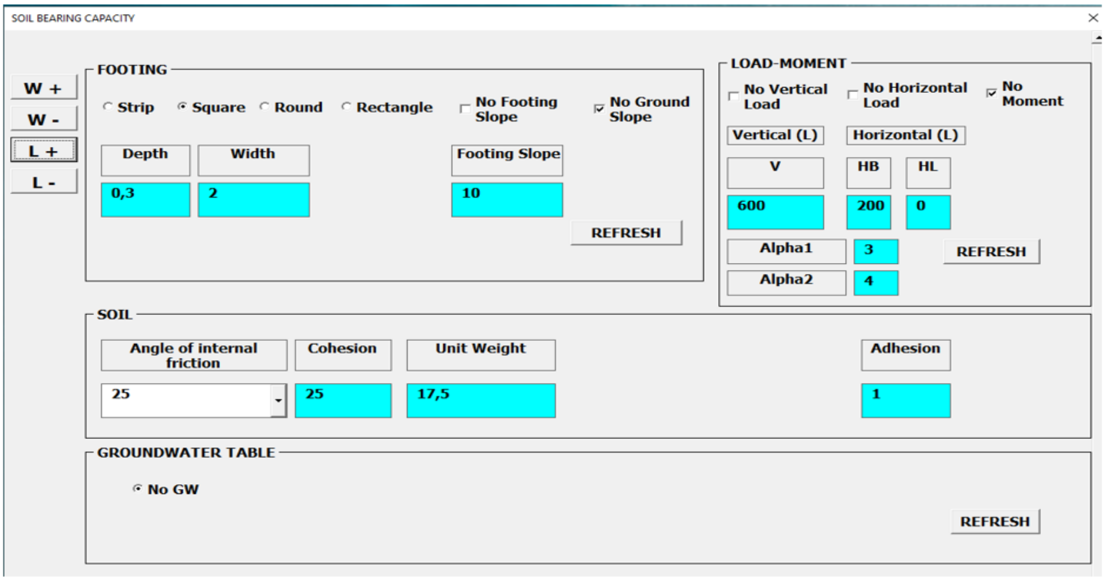


Fig. 3 The VBA entering panel or interface (user form) to calculate bearing capacities in soils.

2.9. SOLUTION BY THE HANSEN METHOD

Using the equations in Table 3, F_{max} equals 379.8 kN, and using the equations in Table 5, N_c = 20.7, N_q = 10.7, N_γ = 6.8, and N_q / N_c = 0.514 were obtained. $2\tan^2 Ø\ (1 - \sin Ø)^2$ and D/B = D/B′ = D/L are equal to relatively 0.311and 0.15. Using the equations in Table 5, the depth factors were obtained as d_c = 1.06, dγ = 1.00, and dq = 1.05.

V + (A_f) × (c_a) × cot Ø is equal to 814.4, and for α_1=3 and α_2=4, values of inclination factors were obtained as $i_{c,B}$ = 0.64, $i_{q,B}$ =0.675, $i_{q,B}$ = 0.481, and $i_{q,L}$ = 1.00 (because of H_L= 0.00) using the equations in Table 5.

Shape factors were calculated as $s_{c,B}$ = 1.329, $s_{q,B}$ = 1.285, and $s_{\gamma,B}$ = 0.808 > 0.60, and for $\eta^o = 10^o$ = 0.175 radians, base factors were also obtained as $b_{c,B}$ =0.93, $b_{q,B}$ = 0.849, and $b_{\gamma,B}$= 0.802 using the equations in Table 5. For a horizontal ground surface, all g_i values equal 1.00.

According to Equation 4, the ultimate bearing capacity in the B direction according to Hansen (1970), or $q_{ult,\ B}$ was calculated as 25 (20.7) (1.329) (1.06) (0.641) (0.93) + 0.3 (17.5) (10.7) (1.285) (1.05) (0.675) (0.849) + 0.5 (17.5) (2.0) (6.8) (0.808) (1.0) (0.481) (0.802) = 515.11 kPa. If we also substitute parameter values into Eq. 7, the allowable bearing capacity according to Hansen (1970), $q_{a,\ B}$, was obtained as 171.70 kPa.

2.10.SOLUTION BY THE VESIC METHOD

For H_L = 0.0, the bearing capacity coefficients in the Vesic (1975) method are N_c = 20.7, N_q =10.7, and N_γ = 10.9. From these, N_q / N_c equals 0.514 and $2 \tan Ø\ (1 - \sin Ø)^2$ equals 0.311. Using the formulations in Table 5, Vesic's (1975) shape factors were calculated as s_c = 1.514, s_q = 1.466, and s_γ = 0.60. The corresponding depth factors were obtained d_c = 1.06, d_q = 1.05, and d_γ = 1.00.

From the equations in Table 7, the value of m is determined as 1.5, and V + (A_f) (ca)cot Ø is calculated as 814.4. Using the equations given in Table 5, Vesic's (1975) inclination factors are obtained as i_c = 0.619, i_q = 0.655, and i_γ = 0.494. The base factors are obtained b_c = 1.0 (since the ground slope β = 0), and b_q and b_γ are both equal to 0.843. Since H is considered as 200 kN in the example problem, the corresponding inclination factors are calculated accordingly.

By substituting values of B = 2.0 m, γ = 17.5 kN/m^3, D = 0.3 m and other parameters in Equation (6) of Vesic (1975), in direction B the ultimate bearing capacity, or $q_{ult,\ B}$, is obtained as 25 (20.7) (1.514) (1.06) (0.619) (1.0) + 0.3(17.5) (10.7) (1.466) (1.05) (0.655) (0.843) + 0.5 (17.5) (2.0) (10.9) (0.60) (1.0) (0.494) (0.843) = 514.08 + 47.74 + 47.66= 609.48 kPa. The allowable bearing capacity or $q_{a,\ B}$ is then calculated as 609.48/3 or 203.16 kPa.

2.11.SOLUTION USING THE VISUAL BASIC APPLICATION

Although the example problem does not include slope and moment effects, as shown in section 2.10, the calculation of soil bearing capacity is time-consuming, difficult, and computationally complex. For this reason, an input interface for the VBA application, as seen in Figure 3, allowing the user to define input conditions, was developed to calculate soil bearing capacity. This input interface shows elements such as the foundation shape, dimensions, slope, load, and moment conditions, soil data, groundwater level, and safety factor on the input interface. These parameters are entered into the VBA input interface to calculate the ultimate and allowable bearing capacity.

In addition, the VBA application provides a warning when incorrect data is entered. For example, the adhesion value in the literature ranges from 0.6 to 1. When an incorrect adhesion value (for example, 2) is entered, the program suggests entering a value

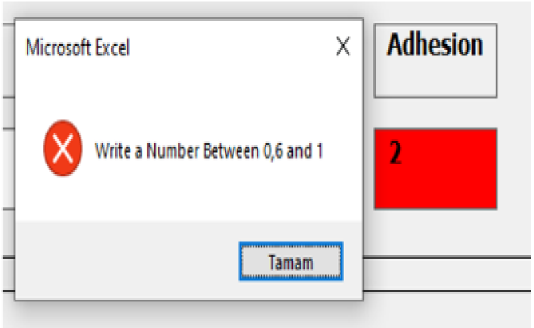


Fig. 4 Warning screen displayed when an incorrect value is entered.

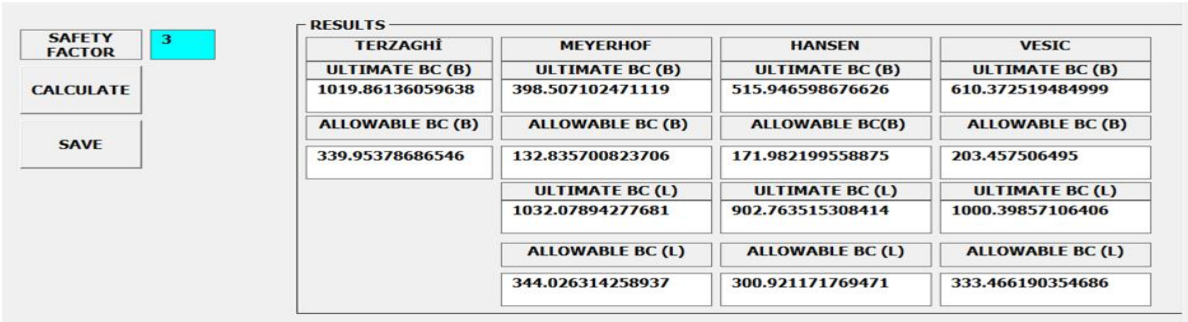


Fig. 5 Bearing capacity (BC) results in kPa in B and L directions calculated by the VBA application based on the example problem.

Table 9 The ultimate and allowable bearing capacities in B and L directions of the footing (kPa) calculated by the VBA application and conventional methods.

	Bearing capacity results					
	Terzaghi (1943)	Meyerhof (1963)	Hansen (1970)	Vesic (1975)	Mean	Mean except Terzaghi (1943)
Ultimate bearing capacity (B) by conventional methods	1018.22	399.90	515.11	609.48	635.67	
Allowable bearing capacity (B) by conventional methods	339.33	133.30	171.70	203.16	211.87	
Ultimate bearing capacity (B) by VBA	1019.86	398.51	515.95	610.37	636.17	508.28
Allowable bearing capacity (B) by VBA	339.95	132.84	171.98	203.46	212.06	169.43
Ultimate bearing capacity (L) by VBA		1032.08	902.76	1000.40	978.41	
Allowable bearing capacity (L) by VBA		344.03	300.92	333.47	326.14	

between 0.6 and 1. Figure 4 shows the warning screen displayed by the system when an incorrect value is entered.

The VBA application for bearing capacity consists of frames labeled Footing, Load Moment, Soil, and Groundwater, as illustrated below. The Footing frame contains tabs for Footing Shape, Footing Slope, and Ground Slope. It also provides options for Strip, Square, Round, and Rectangle tabs. The Footing frame also includes Depth and Width tabs. For this example, the Square footing option is selected, and the Depth and Width values are entered. Figure 5 shows bearing capacity values calculated by the VBA application.

If there is no footing slope, the No Footing Slope option can be selected, the footing slope can be set to zero, or the field may be left blank. In cases where vertical load is not present, the No Vertical Load option can be selected, it can be set to zero, or the field may be left blank; otherwise, the vertical load value is entered. When there is no horizontal load, the No Horizontal Load option can be selected, it can be set to zero, or the field may be left blank; otherwise, the values HB and HL are entered. Then the values of Alpha 1 and Alpha 2 are entered. If there is no moment, the No Moment option is selected; it can be set to zero, or the field can be left blank; otherwise, the moment value is input. The Soil frame contains fields for Angle of Internal Friction, Cohesion, Unit Weight, and Adhesion. After the groundwater table level at the site is input, ultimate bearing capacity values are calculated. Finally, the Safety Factor is entered, and after pressing the Calculate button, allowable bearing capacity values are calculated. Figure 5 shows the results obtained after pressing the Calculate button, and it is recorded after pressing the Save button. Figure 6 also shows graphical and numerical illustrations of the mean and comparative bearing capacity values.

3. RESULTS

The ultimate and allowable soil bearing capacities calculated by the VBA application and conventional methods in the B and L directions of the footing for the example problem (kPa) are presented in Table 9.

In this study, ultimate bearing capacity values in the B direction of the footing calculated using conventional methods were found as 1018.22, 609.48, 515.11, and 399.90 kPa, according to the methods of Terzaghi (1943), Vesic (1975), Hansen (1970), and Meyerhof (1963), respectively. The maximum ultimate bearing capacity value of 1018.22 kPa was calculated by the Terzaghi (1943) method, and the minimum value of 399.90 kPa by the Meyerhof (1963) method. The arithmetic mean of the four methods was found as 635.67 kPa, which was close to the ultimate bearing capacity value calculated using the Vesic (1975) method. If the largest value was ignored, the mean of the three smallest values was found as 511.5 kPa, which was consistent with the value of ultimate bearing capacity calculated by Hansen's (1970) method. Figure 6 shows a bar chart of the ultimate bearing capacity results in the B direction of the footing calculated by the VBA application and conventional methods according to the example problem.

In this study, ultimate bearing capacity values in the B direction of the footing calculated by the VBA application were found as 1019.86, 610.37, 515.95, and 398.51 kPa, according to the methods of Terzaghi (1943), Vesic (1975), Hansen (1970), and Meyerhof (1963), respectively. The arithmetic mean of the four methods was calculated as 636.17 kPa, which was close to the ultimate bearing capacity value calculated using the Vesic (1975) method. If the largest value, namely the value obtained by the Terzaghi (1943) method, was ignored, the mean of the three smallest values was found as 508.44 kPa, which was closest to the value of ultimate bearing capacity calculated by the Hansen (1970) method.

Using conventional calculation methods, allowable bearing capacities in the B direction of the footing were determined as 339.40, 203.16, 171.70, and 133.30 kPa according to the methods of Terzaghi (1943), Vesic (1975), Hansen (1970), and Meyerhof (1963), respectively. The maximum allowable bearing capacity value (339.40 kPa) was obtained using the Terzaghi (1943) method, whereas the minimum value (133.30 kPa) was obtained using the Meyerhof (1963) method. The arithmetic mean of the allowable bearing capacity values obtained from the four methods was found as 211.87 kPa, which was close to the value obtained using the Vesic (1975) method. If the largest value, namely the value obtained using the Terzaghi (1943) method, was ignored, the mean of the three smallest values was found as 169.43 kPa, which was close to the allowable bearing capacity obtained using the Hansen (1970) method. The small differences between the bearing capacity values calculated by the VBA application and conventional methods are due to the greater number of decimal places used in the VBA application; however, the VBA application produces more precise and consistent results than conventional methods.

Using the VBA application, allowable bearing capacities in the B direction of the footing were calculated as 339.95, 203.46, 171.98, and 132.84 kPa according to the methods of Terzaghi (1943), Vesic (1975), Hansen (1970), and Meyerhof (1963), respectively. The arithmetic mean of the four methods was found as 212.06 kPa, which was close to the allowable bearing capacity value obtained using the Vesic (1975) method. When the largest value obtained using the Terzaghi (1943) method is excluded, the mean of the remaining three values was calculated as 169.42 kPa, which was closest to the allowable bearing capacity calculated using the Hansen method. There was little difference between the allowable bearing capacity values calculated using the Vesic (1975) and Hansen (1970) methods. Figure 7 presents a bar chart comparing allowable bearing capacity values in the B direction of the footing calculated using both the VBA application and conventional methods for the example problem.

Using the VBA application, soil's ultimate bearing capacities in the L-direction of the footing were calculated as 1032.08, 1000.40, and 902.76 kPa according to the methods of Meyerhof (1963), Vesic (1975), and Hansen (1970), respectively. The arithmetic mean of the four methods was found as 978.41 kPa, which was close to the ultimate bearing capacity value obtained using the Vesic (1975) method. Using conventional methods, the soil's allowable bearing capacities in the L direction of the footing were calculated as 344.00, 333.47, and 300.92 kPa according to the methods of Meyerhof (1963), Vesic (1975), and Hansen (1970), respectively. The maximum allowable bearing capacity (344.03 kPa) was obtained using the Meyerhof (1963) method, whereas the minimum value (300.92 kPa) was obtained using the Hansen (1970) method. The arithmetic mean of the four methods was 326.14 kPa, which was close to the allowable bearing capacity obtained using the Vesic (1975) method. Except for the Terzaghi (1943) method, Figure 8 shows a bar chart comparing ultimate bearing capacities in B and L directions of the footing calculated using the VBA application.

Figure 9 shows ultimate and allowable bearing capacity values in the B direction of the footing calculated using the VBA application and their mean values, including and excluding the Terzaghi (1943) method.

4. DISCUSSION

Terzaghi's (1943) equation is computationally less complex than the other methods for calculating the ultimate bearing capacity because it requires fewer correction factors and computational steps. Owing to its simplicity, this method can also be used as a reference framework for comparative analyses and

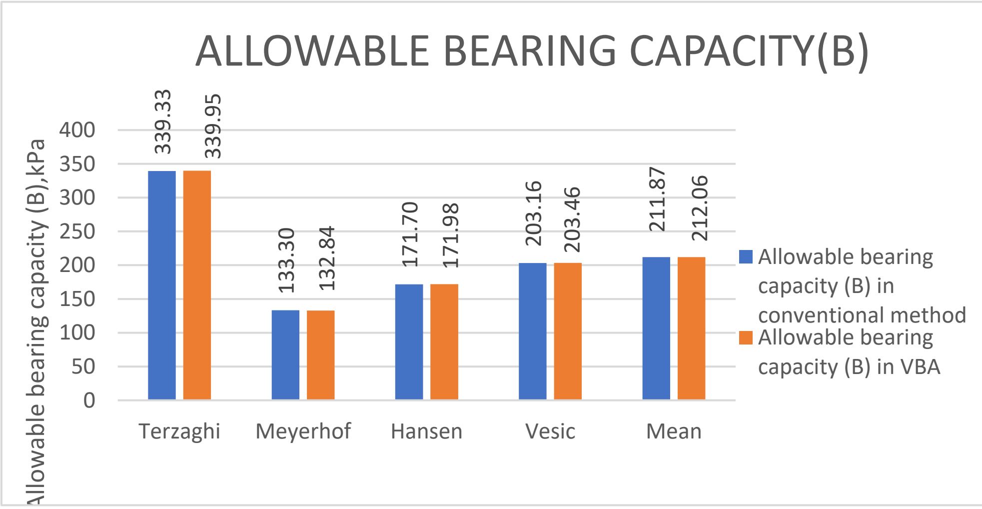


Fig. 7 Comparison of allowable bearing capacity values in the B direction of the footing calculated using the VBA application and conventional (manual) methods for the example problem.

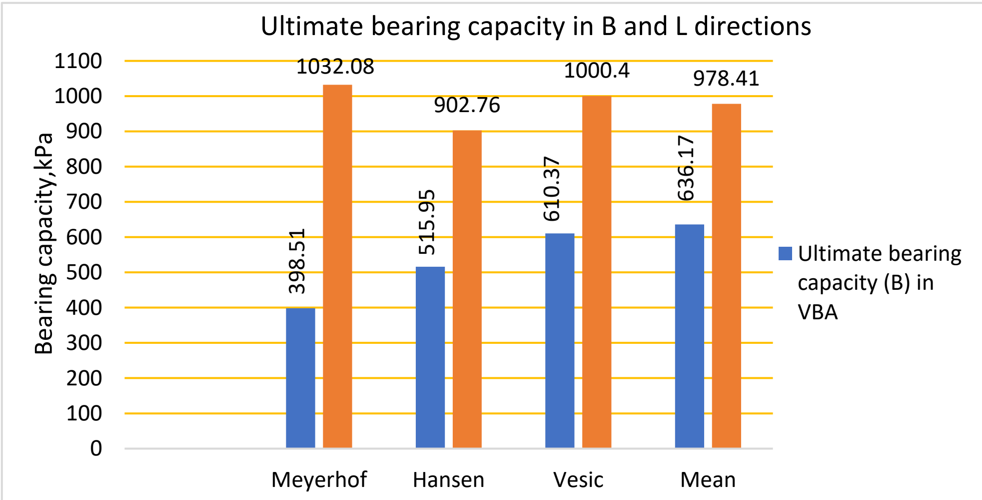


Fig. 8 Bar chart comparison of results of ultimate bearing capacities in B and L directions of the footing calculated using the VBA application for the example problem.

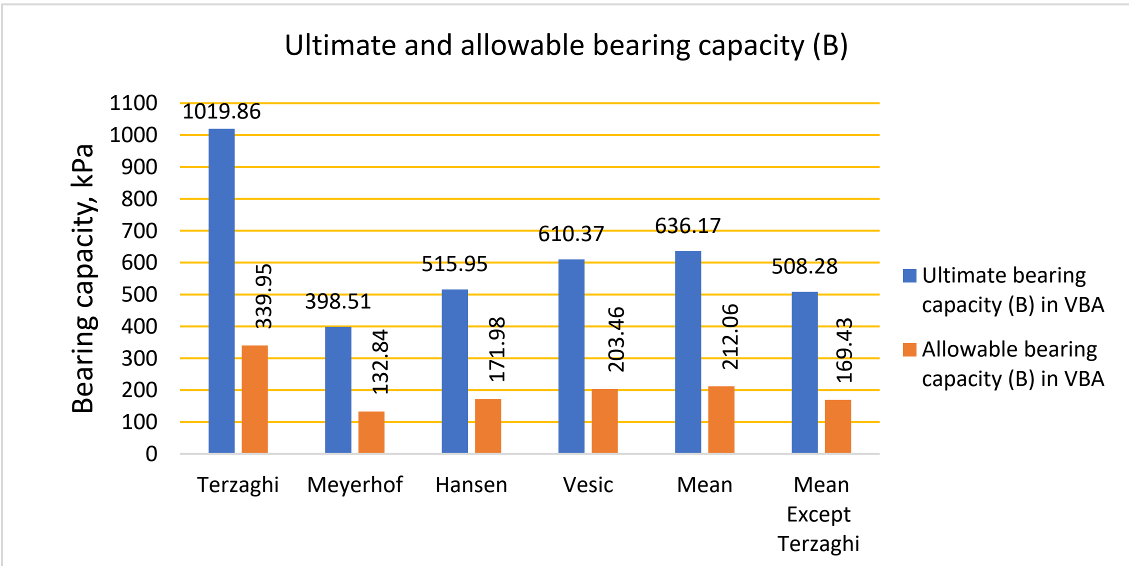


Fig. 9 Comparison of ultimate and allowable bearing capacities in the B direction of the footing calculated using the VBA application and their mean values, including and excluding the Terzaghi (1943) method.

may serve as a basis for developing bearing capacity equations. The other ultimate bearing capacity methods are more complex, involve a greater number of parameters, and are more difficult to apply than the Terzaghi (1943) method. However, bearing capacities in the L-direction of the footing could not be calculated using the Terzaghi (1943) method, as the method is not suitable for this case. In the other methods, higher bearing capacity values were observed in the L direction of the footing, as shown in Fig. 8. In addition, bearing capacities in the L direction of the footing were calculated using the methods of Meyerhof (1963), Hansen (1970), and Vesic (1975), as well as the VBA application, and the results were presented as graphical comparisons. Even if the mean values of soil parameters from a given field are entered into the VBA application, bearing capacity values can be estimated consistently. Accordingly, using preliminary geological information, the VBA application may assist a predicting engineer in the preliminary type of foundation and decision-making process.

Load eccentricity and moment effects are incorporated in the methods of Meyerhof (1963), Hansen (1970), and Vesic (1975), whereas these effects are not incorporated in the Terzaghi (1943) method. The Terzaghi (1943) method is generally suitable for simplified bearing capacity analyses and preliminary assessments. The methods of Hansen (1970), Meyerhof (1963), and Vesic (1975) can be applied under various conditions depending on the characteristics of the soil and foundation system. The methods of Hansen (1970) and Vesic (1975) are particularly suitable when $D/B > 1$, when the footing is placed on a sloping ground, or when the base inclination is considered. It is recommended to compare the ultimate bearing capacity values calculated using two or more methods.

Ultimate soil bearing capacity values in the B direction of the footing by the developed VBA application were calculated as 1019.86, 610.37, 515.95, and 398.51 kPa, according to the methods of Terzaghi (1943), Vesic (1975), Hansen (1970), and Meyerhof (1963), respectively.

Ultimate bearing capacity values, calculated using by MATLAB based-model using data from the example question, were found as 1042.85, 1244.99, 1314.50, and 1618.30 kPa, according to the methods of Terzaghi (1943), Meyerhof (1963), Hansen (1970), and Vesic (1975), respectively, when an example problem is analyzed using an artificial intelligence engine, Microsoft Copilot.

Ultimate bearing capacity values of the soil, calculated by Python-based artificial intelligence model with data from example question, were found as 1034.69, 1235.25, 1304.23, and 1606.09 kPa, according to the methods of Terzaghi (1943), Meyerhof (1963), Hansen (1970), and Vesic (1975), respectively, when an example problem is analyzed using the artificial intelligence engine, Microsoft Copilot.

The comparison shows that bearing capacity values calculated using the MATLAB-based model were found to be higher than bearing capacity values calculated using the Python-based artificial intelligence model, whereas bearing capacity values calculated using the VBA application were found to be smaller than those of MATLAB and the Python-based artificial intelligence models.

Mahmoud El Gendy (2025) developed a Python-based computational model to predict the ultimate bearing capacity of cohesionless soil under shallow foundations using machine learning (ML) and deep learning (DL) techniques. In contrast, the present study focuses on developing a Visual Basic application to simplify and accelerate the calculation of bearing capacity using conventional or manual methods. Using a comprehensive dataset of 116 footing experiments, eleven Machine Language (ML) models—Gaussian Process Regression (GPR), Extreme Gradient Boosting (XGBoost), Gradient Boosting Machine (GBM), Random Forest (RF), and Categorical Boosting (CatBoost), among others—and five Deep Language (DL) models, including Artificial Neural Network (ANN) and Deep Neural Network (DNN), were trained and compared with conventional methods. The results demonstrated that the ML and DL models significantly outperformed traditional equations, achieving higher prediction accuracy.

Tonyali (2011) compared and discussed the applicability of different soil bearing capacity calculation methods using experimental data within the MATLAB-based model. The relationships between ultimate bearing capacities obtained from 50 soil investigations conducted at various construction sites in Türkiye were primarily evaluated based on the Terzaghi and Meyerhof methods. Subsequently, the consistency among the results obtained from the different methods was examined. The analysis revealed that the classical methods produced highly comparable results.

The VBA application represents a computer-based implementation of classical approaches for calculating bearing capacity and provides consistent numerical results (e.g., 902.76 kPa). The method is reliable, widely accepted in engineering practice, and transparent in terms of verification and reproducibility. However, classical methods may not fully reflect field conditions because they rely on simplified assumptions for complex soil conditions. Despite these limitations, classical methods remain fundamental reference approaches in geotechnical engineering.

Artificial intelligence (AI)–based models, such as MATLAB- and Python-based ones, can provide more realistic prediction ranges and enable additional analyses. However, despite these advantages, AI- based models may still have limitations in fully capturing complex soil behavior under field conditions. Classical methods and AI–based approaches can complement and validate each other.

Artificial intelligence models provide a powerful tool for rapidly evaluating numerous parameters, particularly under complex ground conditions. Therefore, the most reliable approach is to use artificial intelligence together with classical calculations for cross-validation and comparative analysis. Also, the more methods used to calculate bearing capacity, the safer the outcome.

5. CONCLUSION

In this study, an example problem involving soil bearing capacity was solved using both conventional or manual calculation methods and a Visual Basic Application (VBA), and the results were compared. The findings indicated that the VBA application enabled faster, more reliable calculations than conventional or manual methods, which were time-consuming and more prone to human error. Bearing capacity was simultaneously used to compute with a VBA application and the Terzaghi, Meyerhof, Hansen, and Vesic methods. The obtained results were compared. The results demonstrated that the VBA significantly reduced calculation time while maintaining accurate and consistent numerical results for complex geotechnical problems. Therefore, the proposed VBA application offered a practical and efficient alternative to conventional or manual calculations and has the potential to be applied in various engineering computation fields in the future.

SYMBOLS

c	Cohesion of the soil below the foundation (kN/m^2)
γ	Density of the soil below the foundation (kN/m^3)
B	The width of the foundation (short side or diameter, m)
B'	= B/2 when base dimension = B
L	Base or footing length
K p	Passive earth pressure coefficient = $\tan^2(45 + (Ø/2)$
q	Overburden pressure
q ult	Ultimate bearing pressure
q a	Allowable bearing pressure
m	Exponent for inclination factor
a	Is used as a coefficient for the bearing capacity coefficient N_q
R	Resultant force
β	Slope angle of ground
α	Angle
γ'	Effective unit weight computed, as $\gamma' = \gamma - \gamma_w$
η	Base tilt angle
Ø	Angle of internal friction of soil
Ø'	Effective angle of internal friction of soil
$Ø_{tr}$	Ø value obtained from three axial tests
$Ø_{ps}$	Ø value obtained from plane strain test
N_c, N_q, N_γ	Bearing capacity coefficients of the soil below the foundation level, which change according to the angle of shear resistance, Ø
$\bar{q}$	An effective or total stress value at the level of the foundation base
σ'	Vertical effective stress (σ'= σ — u), (kN/m^2)
u	Pore water pressure
σ	Total stress
d_w	Depth to the water table below the base of the footing
γ_{wet}	unit weight of soil d_w in depth
s_c, s_q, s_γ	Shape factors
d_c, d_q, d_γ	Depth factors
i_c, i_q, i_γ	Load inclination factors
b_c, b_q, b_γ	Base inclination factors
g_c, g_q, g_γ	Ground surface inclination factors
$\gamma_A = \gamma'$	Submerged density of soil material
γ_{sat}	Saturated density of soil material
γ_w	Density of water
γ_n	Natural unit weight of soil
A_f	Effective footing area, B'× L'
c_a	Cohesion of soil
e_B, e_L	Eccentricity of load concerning the center of the footing area
H	Horizontal component of footing load with $H \leq V \tan \delta + c_a A_f$
V	Total vertical load on the footing
δ	Friction angle between base and soil, usually δ = Ø for concrete on soil

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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