

Determination of Bearing Capacity of Circular Footing by a Computer Program Using Meyerhof's Analysis

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ABSTRACT: There are many factors and parameters that need to be considered in designing a foundation. Manual calculations for determining the ultimate bearing capacity are quite complicated, take longer time and increase human errors. This study is done to develop a computer programme by using Microsoft Excel spread sheets to calculate the bearing capacity of circular footing of different diameters & depths and also the effect of soil properties, size & depth of footing and contact area of footing on the bearing capacity of circular footing. In present investigation three different soil samples of density 16.17 KN/m³, 16.67 KN/m³, and 17.16 KN/m³ were selected for determination of bearing capacity of circular footing of diameter 0.68 m, 1.016 m and 1.35 m having different footing depth of 1.0 m and 2.0 m. The analysis and results obtained by computer programme were compared with the results obtained by manual calculations and it was found that the determination of bearing capacity of circular footing using computer program is easier, faster and reduces the human error thus concluding that the developed computer programme runs correctly.

KEYWORDS: Bearing capacity, circular footing, computer programme, Meyerhof's analysis, Microsoft Excel.

I. INTRODUCTION

Foundation is the lower most part of any structure and it receives a huge amount of load from superstructure. Design of foundations must satisfy two main requirements which are - complete failure of the foundation must be avoided with an adequate margin of safety, and the total & relative settlements of the foundation must be kept within the limits that can be tolerated by the superstructure. The ultimate bearing capacity of a foundation is defined as the maximum load that the foundation can sustain (general shear failure); where the load-settlement curve does not exhibit a peak load, the bearing capacity is taken as the load at which the curve passes into a steep and fairly straight tangent (local shear failure) (Terzaghi, 1943). The bearing capacity of foundation depends on the mechanical properties of the soil such as density, shearing strength and deformation characteristics. Besides, original stresses, the water conditions in the ground, load eccentricity, physical characteristics of the foundation such as size, depth, shape & roughness and also on the way in which the foundation is installed are the factors that affect the calculations.

The bearing capacity and settlement for circular footings have already been one of the most highly interesting areas in geotechnical engineering for researchers and practical engineers. Defining the correct bearing capacity of the footing is a very important factor in economic terms. A lot of observations have been made in the literature in order to calculate bearing capacity of circular footings using the limit equilibrium method. In recent years, numerical methods such as finite element method (FEM) and the finite difference method have been widely used to compute the bearing capacity of strip and circular footings. Nowadays, more and more circular footings are used for axis-symmetric structures such as silos, chimneys and storage tanks and so on.

The use of circular footings decrease the amount of material used and is more economical. This has led to an increasing use of circular footing in countries which construction material is more expensive. Proposed different relations for prediction of the bearing capacity and settlement of strip, circular and square footings aren't suitable for the circular footings. Therefore, the theoretical prediction of ultimate bearing capacity and settlement for circular

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footings is a requirement in the design. Solutions to calculate the elastic settlements of circular foundations are available in the literature. Some experiments have also been performed to compute the bearing capacity of circular footings.

In view of the above, it is ascertained that there are many factors and parameters which are to be considered in designing a foundation. Besides, manual calculation for determining the ultimate bearing capacity is quite complicated, increases human errors and takes longer time to determine the load bearing capacity of foundations for a project. Due to this matter, it was decided to develop a computer programme by Microsoft Excel that will be able to analyze and design the foundation. The reason for using Microsoft Excel software is because it is accessible and economic. Biggest advantage is instant calculation of totals and functions. In general, Microsoft Excel spreadsheets allow a layout that is organized and easy to understand. Spreadsheets can do things automatically. different dry densities. Bishop's method has been used in this analysis.

II. METHODOLOGY

2.1 MEYERHOF'S ANALYSIS (1951)

The form of equations used by Meyerhof (1951) for determining the ultimate bearing capacity of symmetrically loaded strip footings is the same as that of Terzaghi but his approach to solve the problem is different. He assumed that the logarithmic failure surface ends at the ground surface, and as such took into account the resistance offered by the soil and surface of the footing above the base level of the foundation. The different zones considered are shown in Figure 1.

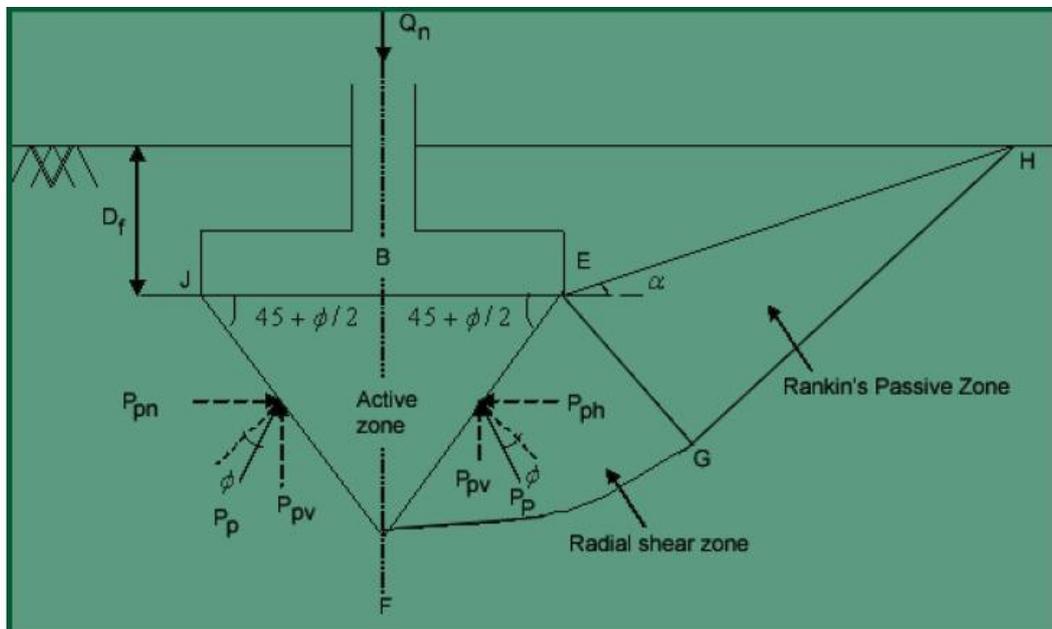


Figure 1: Failure zone considered by Meyerhof

In the above figure, EF failure surface is considered to be inclined at an angle of $(45^\circ - \phi/2)$ with the horizontal surface followed by FG which is log spiral curve and then the failure surface extends to the ground surface (GH).

Meyerhof (1951, 1963) proposed an equation for ultimate bearing capacity of strip footing which is similar in form to that of Terzaghi but includes shape factors, depth factors and inclination factors. Meyerhof's equation is

$$q_f = cN_c S_c d_c i_c + qN_q S_q d_q i_q + 0.4B\gamma N_\gamma S_\gamma d_\gamma i_\gamma$$

Meyerhof's bearing capacity factors are expressed as:

$$N_q = e^{\pi \tan \phi} \tan^2 (45^\circ + \phi/2)$$

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$$N = (N_q - 1) \cot \phi$$

$$N_{\gamma} = (N_q - 1) \tan (1.4\phi)$$

The Shape factors are given by:

$$S_c = 1 + 0.2k_p B/L \text{ for any } \phi$$

$$S_q = S_{\gamma} = 1.0 \text{ for } \phi = 0^\circ$$

$$S_q = S_{\gamma} = 1 + 0.1k_p B/L \text{ for } \phi \geq 10^\circ$$

$$d_c = 1 + 0.2\sqrt{k_p} D/B \text{ for any } \phi$$

$$d_q = d_{\gamma} = 1.0 \text{ for } \phi = 0^\circ$$

$$d_q = d_{\gamma} = 1 + 0.1k_p B/D \text{ for } \phi \geq 10^\circ$$

The inclination factors are given by:

$$i_c = i_q = (1 - \theta/90^\circ)^2 \text{ for any } \phi$$

$$i_{\gamma} = 1.0 \text{ for } \phi = 0^\circ$$

$$i_{\gamma} = (1 - \theta/\phi)^2 \text{ for } \phi \geq 10^\circ$$

Where $k_p = \tan^2 (45^\circ + \phi/2)$ and $\theta =$ angle of inclination of load with respect to vertical surface.

The Meyerhof's bearing capacity factors can be obtained by chart as shown in Figure 2:

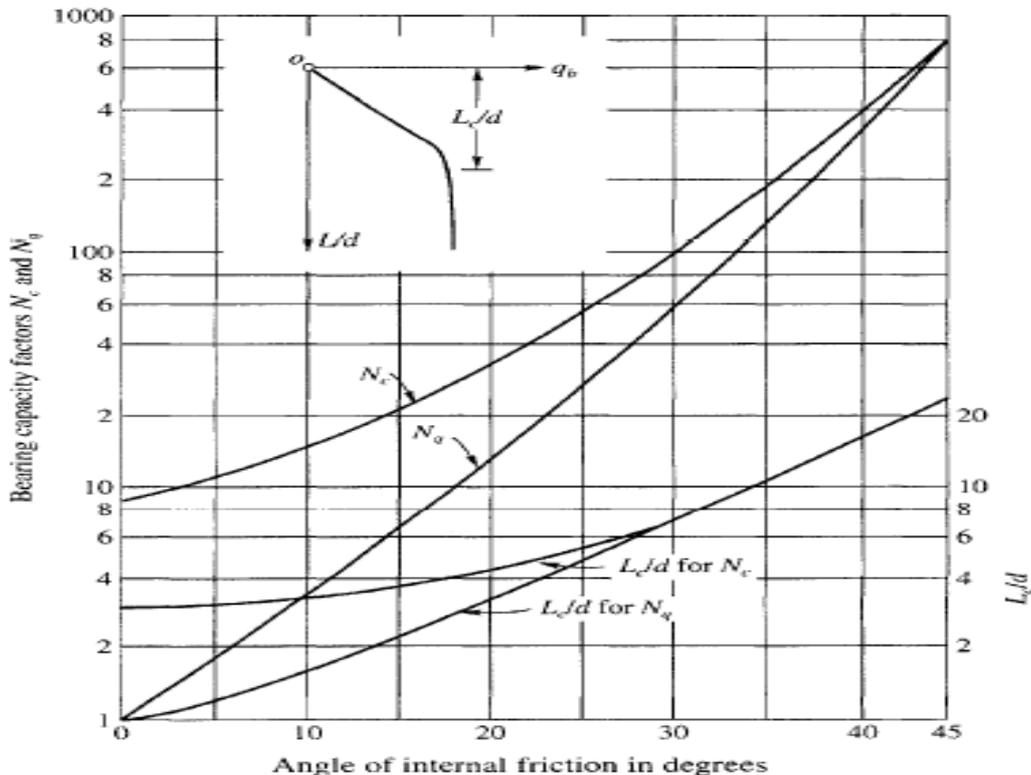


Figure 2: Bearing capacity factors and critical depth ratios L_c/d

2.2 COMPUTER PROGRAMMING AND DEVELOPMENT

To calculate the bearing capacity of circular footing by faster way and to minimize the human errors a combination of Microsoft Excel and Visual basic programme (Figure 3) has been developed. Developing the programme started by creating the interface required and deciding the boundary needed to be covered by this programme. Coding in Microsoft Visual basic programme has been done by providing all the formulae needed to evaluate the bearing capacity

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so as to make sure that the programme runs smoothly. A study called sensitivity analysis was also conducted to identify which parameters in the calculation of bearing capacity of shallow foundation gives the greater impact towards the results of bearing capacity of shallow foundation.

Two examples of case study have been solved by using the computer programme. Manual calculations were also performed so as to compare the results with the computer programme results. The purpose of this comparison is to make sure that there is no error with the spreadsheets developed and it works correctly at par with the manual calculations. This is the advantage of using the Microsoft visual basic programme over the manual calculations. All the results were converted into graphs so as to understand them distinctly.

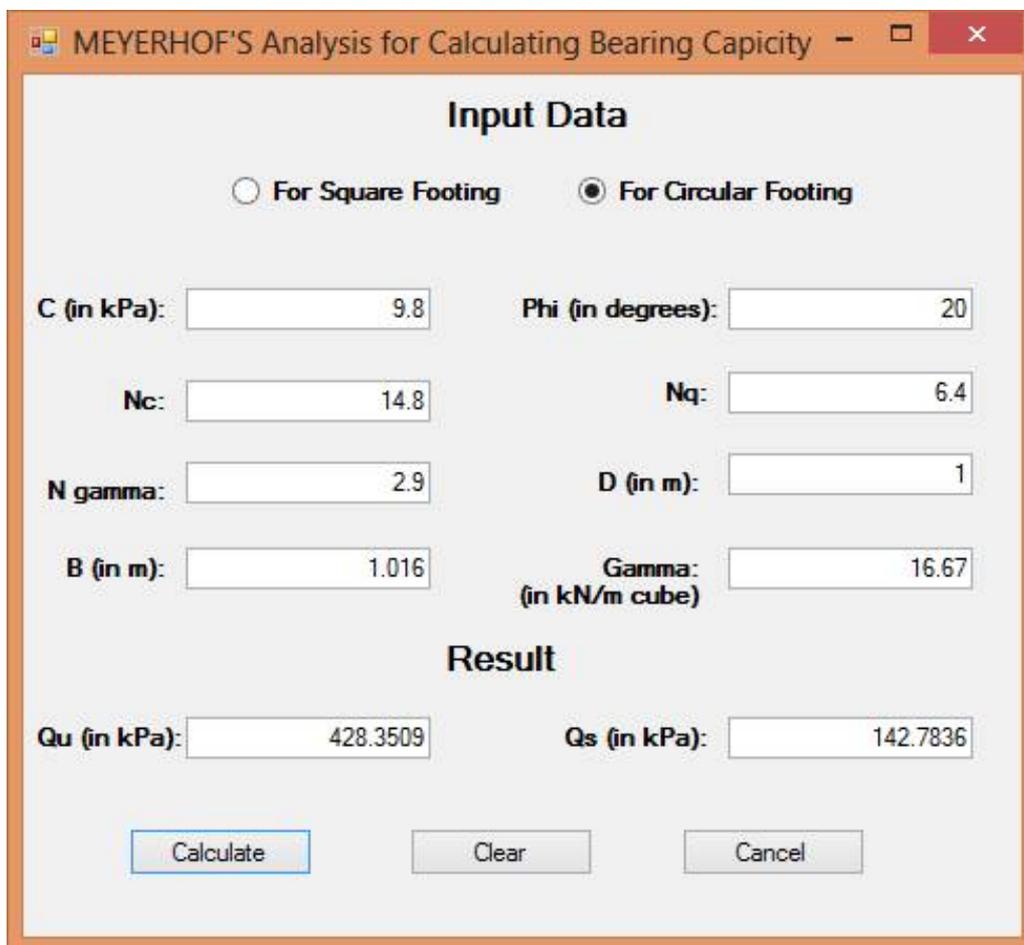


Figure 3: Microsoft Visual Basic Programme Developed Using Meyerhof's Analysis

III. INVESTIGATIONS RESULTS

3.1 RESULTS OF LABORATORY TESTS

Three soil samples of different properties were selected for the present study. For determination of shear strength parameters (c and ϕ), standard penetration number (N-value), unit weight of soil (γ) and water content of these soil samples Direct Shear test, Standard Penetration test, Core Cutter test and Oven Drying test were performed respectively. The following are the values of the above parameters obtained by these experiments:

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Table 1: Various Geotechnical Properties of Soil Samples

C (kpa)	ϕ	N	γ (kN/m ³)
0	30°	7	16.17
9.8	20°	6	16.67
19.6	15°	5	17.16

3.2 RESULTS OF COMPUTER PROGRAMME

Results of ultimate bearing capacity (Q_u) and safe bearing capacity (Q_s) of circular footing calculated by computer program and variation of contact area of circular footing on its ultimate bearing capacity having different sizes of footing, different depths of footing and different soil parameters are given in Tables 2 to 13 and Figures 4 to 15.

Table 2: Ultimate and Safe Bearing Capacity of Circular Footing of Different Diameter at Depth D = 1.0 m and $\gamma = 16.17$ kN/m³

N	C (kpa)	ϕ^o	γ (kN/m ³)	B (m)	D (m)	Q_u (kpa)	Q_s (kpa)
7	0	30	16.17	0.68	1.0	569.7809	189.927
7	9.81	20	16.17	0.68	1.0	454.6793	151.5598
7	19.62	15	16.17	0.68	1.0	492.5164	164.1721
7	29.43	10	16.17	0.68	1.0	479.1926	159.7309
7	0	30	16.17	1.016	1.0	570.4666	190.155
7	9.81	20	16.17	1.016	1.0	423.3498	141.1166
7	19.62	15	16.17	1.016	1.0	453.325	151.1083
7	29.43	10	16.17	1.016	1.0	440.94	146.98
7	0	30	16.17	1.35	1.0	587.222	195.7407
7	9.81	20	16.17	1.35	1.0	410.4705	136.8235
7	19.62	15	16.17	1.35	1.0	434.7364	144.9121
7	29.43	10	16.17	1.35	1.0	422.154	140.718

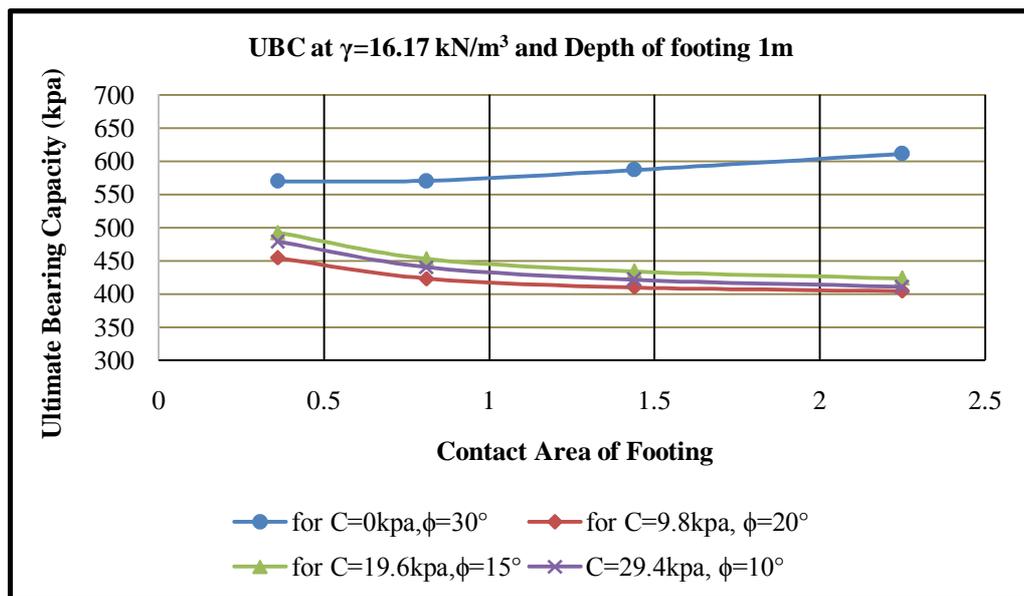


Figure 4: UBC at $\gamma = 16.17$ kN/m³ and Depth of footing 1m

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Table 3: Ultimate and Safe Bearing Capacity of Circular Footing of Different Diameter at Depth D = 2.0 m and $\gamma = 16.17 \text{ kN/m}^3$

N	C (kpa)	ϕ^o	γ (kN/m ³)	B (m)	D (m)	Qu (kpa)	Qs (kpa)
7	0	30	16.17	0.68	2	1269.275	423.091
7	9.81	20	16.17	0.68	2	745.9719	248.6573
7	19.62	15	16.17	0.68	2	720.2307	240.0769
7	29.43	10	16.17	0.68	2	659.7252	219.9084
7	0	30	16.17	1.016	2	1172.217	390.739
7	9.81	20	16.17	1.016	2	660.3141	220.1047
7	19.62	15	16.17	1.016	2	630.3988	210.1329
7	29.43	10	16.17	1.016	2	577.1239	192.3746
7	0	30	16.17	1.35	2	1140.03	380.0105
7	9.81	20	16.17	1.35	2	620.2324	206.7441
7	19.62	15	16.17	1.35	2	586.4542	195.4847
7	29.43	10	16.17	1.35	2	536.1323	178.7108

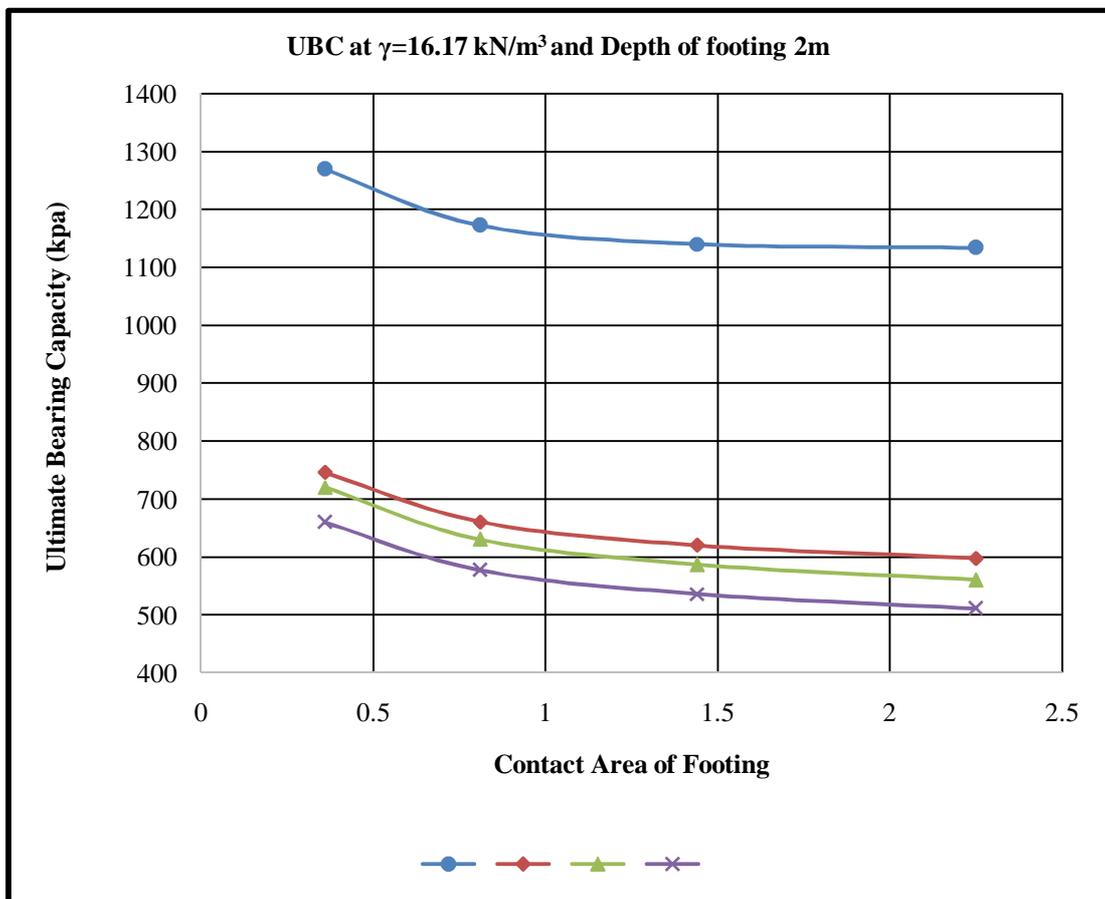


Figure 5: UBC at $\gamma=16.17 \text{ kN/m}^3$ and Depth of footing 2 m

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Table 4: Ultimate and Safe Bearing Capacity of Circular Footing of Different Diameter at Depth D = 1.0 m and $\gamma = 16.67 \text{ kN/m}^3$

N	C (kpa)	ϕ°	γ (kN/m ³)	B (m)	D (m)	Qu (kpa)	Qs (kpa)
7	0	30	16.67	0.68	1	587.3994	195.799
7	9.81	20	16.67	0.68	1	459.772	153.2573
7	19.62	15	16.67	0.68	1	495.3912	165.1304
7	29.43	10	16.67	0.68	1	480.925	160.3083
7	0	30	16.67	1.016	1	588.1063	196.035
7	9.81	20	16.67	1.016	1	428.3509	142.7836
7	19.62	15	16.67	1.016	1	456.1201	152.04
7	29.43	10	16.67	1.016	1	442.6127	147.5376
7	0	30	16.67	1.35	1	605.3798	201.793
7	9.81	20	16.67	1.35	1	415.5125	138.5042
7	19.62	15	16.67	1.35	1	437.5235	145.8412
7	29.43	10	16.67	1.35	1	423.8083	141.2694

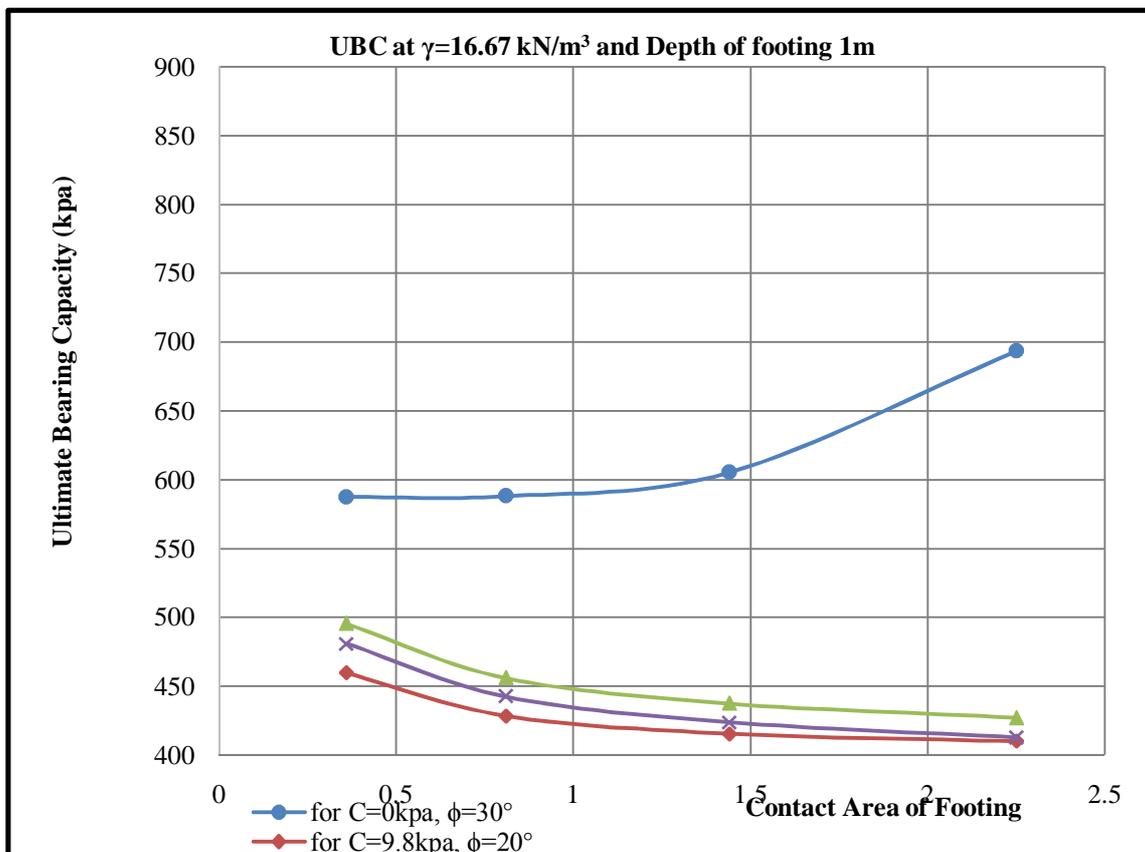


Figure 6: UBC at $\gamma=16.67 \text{ kN/m}^3$ and Depth of footing 1 m

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Table 5: Ultimate and Safe Bearing Capacity of Circular Footing of Different Diameter at Depth D = 2.0 m and $\gamma = 16.67 \text{ kN/m}^3$

N	C (kpa)	ϕ^o	γ (kN/m ³)	B (m)	D (m)	Qu (kpa)	Qs (kpa)
7	0	30	16.67	0.68	2	1308.523	436.174
7	9.81	20	16.67	0.68	2	757.4196	252.4732
7	19.62	15	16.67	0.68	2	726.7234	242.2411
7	29.43	10	16.67	0.68	2	663.6439	221.2146
7	0	30	16.67	1.016	2	1208.464	402.821
7	9.81	20	16.67	1.016	2	670.8674	223.6225
7	19.62	15	16.67	1.016	2	636.3781	212.126
7	29.43	10	16.67	1.016	2	580.7347	193.5782
7	0	30	16.67	1.35	2	1175.283	391.760
7	9.81	20	16.67	1.35	2	630.4246	210.1415
7	19.62	15	16.67	1.35	2	592.2084	197.4028
7	29.43	10	16.67	1.35	2	539.6003	179.8668

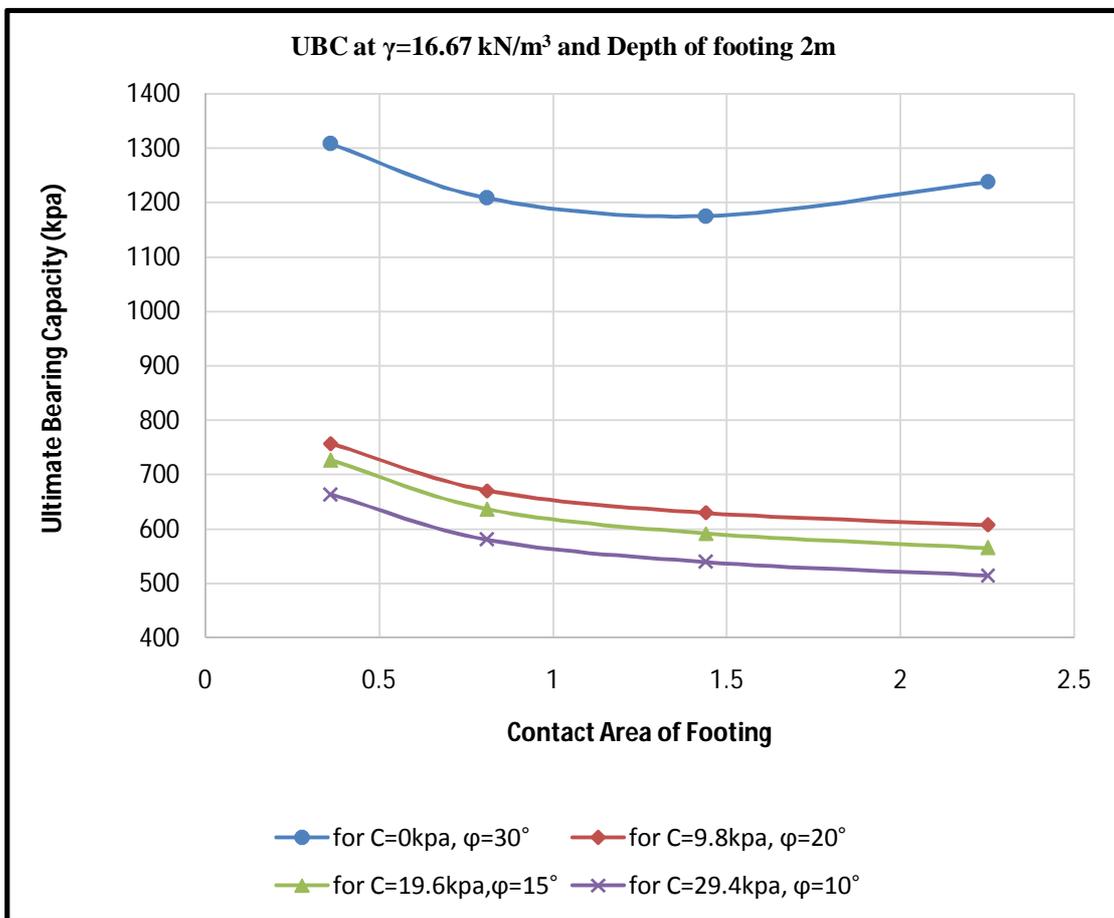


Figure 7: UBC at $\gamma=16.67 \text{ kN/m}^3$ and Depth of footing 2 m

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Table 6: Ultimate and Safe Bearing Capacity of Circular Footing of Different Diameter at Depth $D = 1.0$ m and $\gamma = 17.16$ kN/m³

N	C (kpa)	ϕ°	γ (kN/m ³)	B (m)	D (m)	Qu (kpa)	Qs (kpa)
7	0	30	17.16	0.68	1	604.6655	201.555
7	9.81	20	17.16	0.68	1	464.7629	154.921
7	19.62	15	17.16	0.68	1	498.2085	166.0695
7	29.43	10	17.16	0.68	1	482.6229	160.8743
7	0	30	17.16	1.016	1	605.3932	201.797
7	9.81	20	17.16	1.016	1	433.252	144.4173
7	19.62	15	17.16	1.016	1	458.8593	152.9531
7	29.43	10	17.16	1.016	1	444.252	148.084
7	0	30	17.16	1.35	1	623.1743	207.724
7	9.81	20	17.16	1.35	1	420.4537	140.1512
7	19.62	15	17.16	1.35	1	440.2549	146.7516
7	29.43	10	17.16	1.35	1	425.4294	141.8098

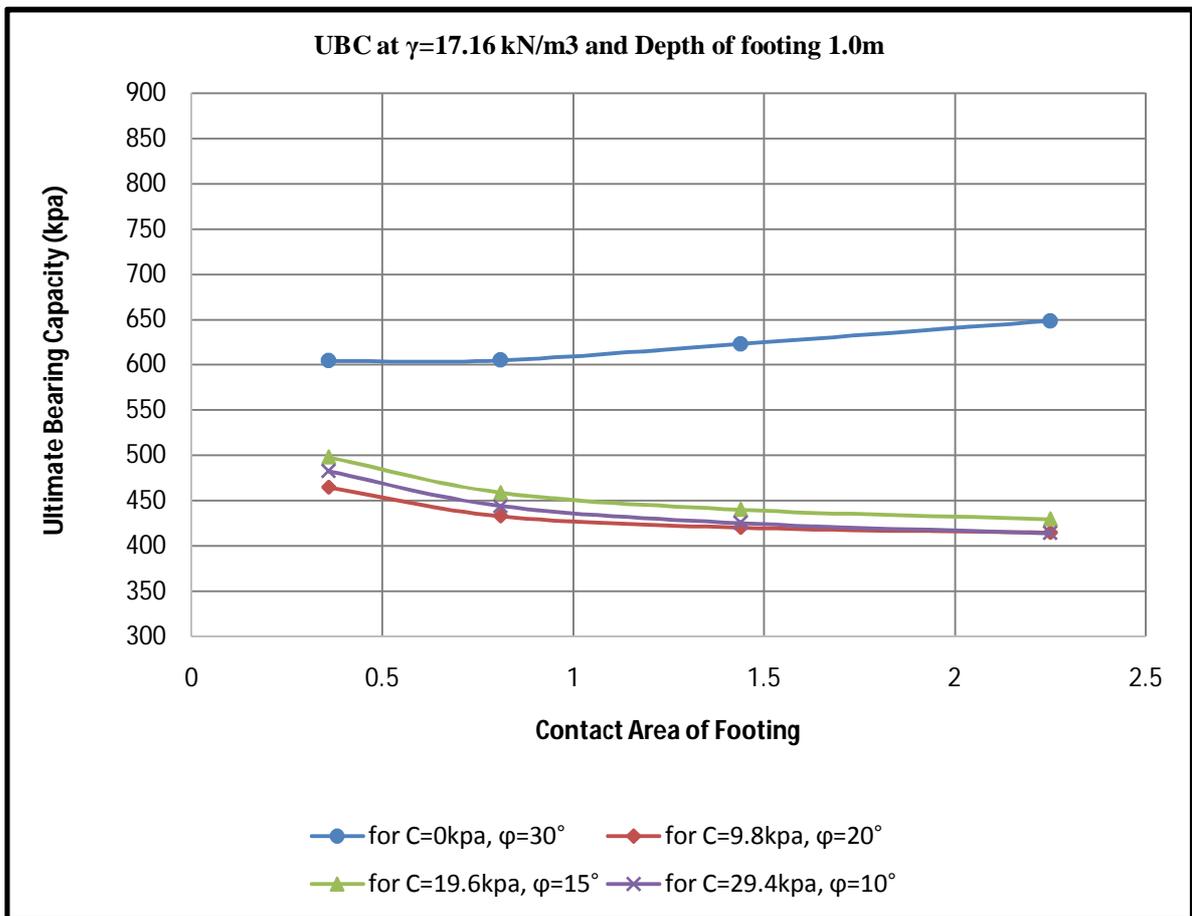


Figure 8: UBC at $\gamma=17.16$ kN/m³ and Depth of footing 1 m

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Table 7: Ultimate and Safe Bearing Capacity of Circular Footing of Different Diameter at Depth D = 2.0 m and $\gamma = 17.16 \text{ kN/m}^3$

N	C (kpa)	ϕ^o	γ (kN/m ³)	B (m)	D (m)	Qu (kpa)	Qs (kpa)
7	0	30	17.16	0.68	2	1346.986	448.995
7	9.81	20	17.16	0.68	2	768.6382	256.2127
7	19.62	15	17.16	0.68	2	733.0862	244.3621
7	29.43	10	17.16	0.68	2	667.4843	222.4948
7	0	30	17.16	1.016	2	1243.985	414.661
7	9.81	20	17.16	1.016	2	681.2096	227.0699
7	19.62	15	17.16	1.016	2	642.2377	214.0792
7	29.43	10	17.16	1.016	2	584.2733	194.7578
7	0	30	17.16	1.35	2	1209.829	403.276
7	9.81	20	17.16	1.35	2	640.413	213.471
7	19.62	15	17.16	1.35	2	597.8474	199.2825
7	29.43	10	17.16	1.35	2	542.9989	180.9996

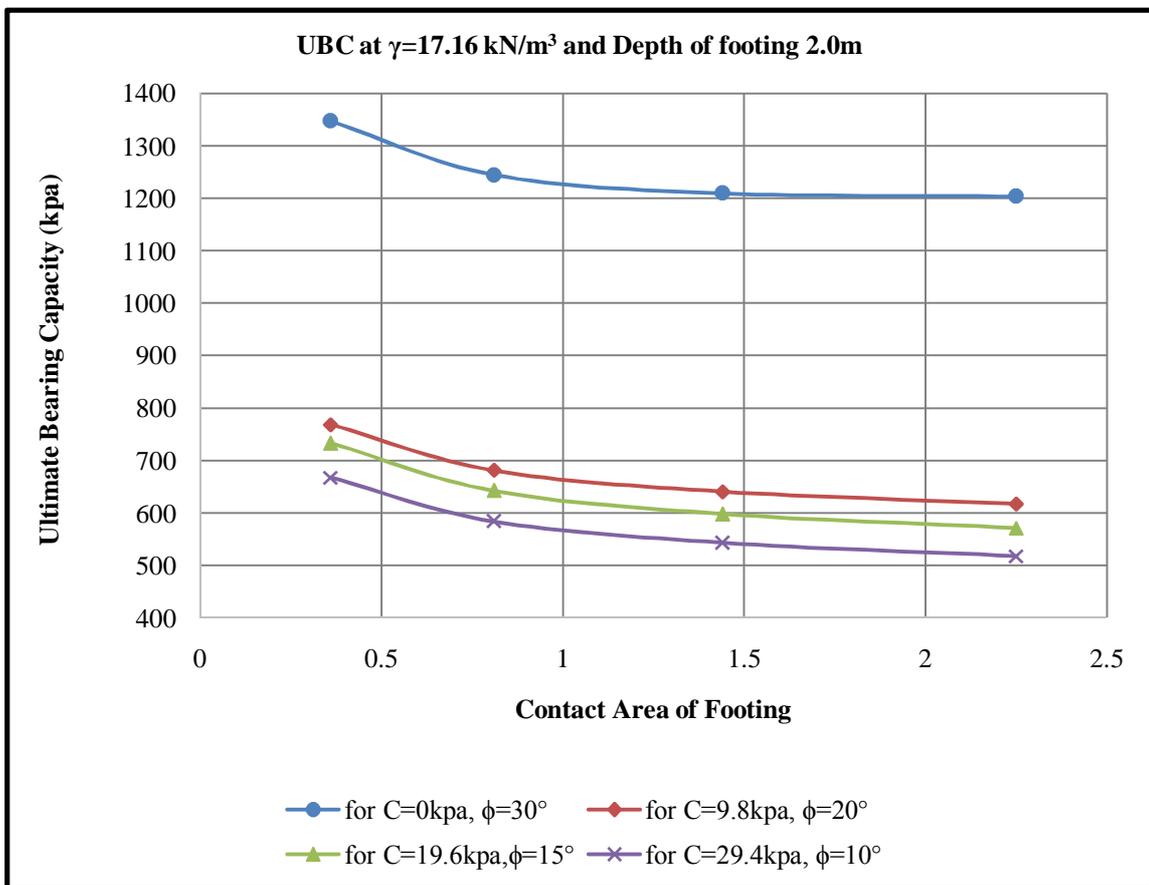


Figure 9: UBC at $\gamma=17.16 \text{ kN/m}^3$ and Depth of footing 2m

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IV. CONCLUSIONS

- 1) It is obvious that as the depth of footing increases, the ultimate bearing capacity also increases (Figures 4 to 9).
- 2) It can be seen that as the depth of footing increases, the ultimate bearing capacity increases sharply for cohesionless soil ($c=0$) because friction angle (ϕ) for such soil is highest i.e. equal to 30° , due to which N_c , N_q , N_γ , S_c , S_q , S_γ , d_c , d_q and d_γ increases which causes a sharp increase in UBC (Figures 4 to 9).
- 3) It can also be seen that for soil of $c=9.81$ kpa and $c=19.6$ kpa the ultimate bearing capacity with depth of footing curves are intersecting with each other, because for $c =9.81$ kpa, ϕ is 20° and for $c=19.6$ kpa, ϕ is 15° i.e. for value of ϕ is decreasing due to which S_c , S_q , S_γ , d_c , d_q , d_γ , N_c , N_q and N_γ decrease UBC decreases (figure 5.1 to 5.16).
- 4) It can also be seen that UBC decreases with increase in contact area of footing because as the value of ϕ decreases, bearing capacity factors, shape factors and depth factors reduces and therefore UBC decreases also decreases.
- 5) It can be seen that for $c=0$, the bearing capacity values are more as compare to $c-\phi$ soil because of the greater values of bearing capacity factors, shape factors and depth factors for $\phi=30^\circ$.
- 6) Calculating the bearing capacity of circular footing by using Microsoft Visual Basic Programme is easier and faster. It also reduces the human error. User can determine the parameter which gives most impact towards the value of bearing capacity of circular footing.

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