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

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ABSTRACT

This paper utilizes a computer program to determine the bearing capacity of square footing and also the effect of soil properties, size and depth of footing and contact area of footing on the bearing capacity of square footing. In present investigation four different soil samples (having different values of unit weight, cohesion and angle of internal friction) were selected for determination of bearing capacity of square footing having sizes 0.6 m x 0.6 m, 0.9 m x 0.9 m, 1.2 m x 1.2 m and 1.5 m x 1.5 m having different depth 1.0 m, 1.5 m and 2.0 m. To calculate the bearing capacity of square footing by manual calculation for a project is very time consuming and complicate and it also increases human errors. Therefore, to analyze and design the foundation with less error and better speed, it was decided to develop a computer program by Microsoft Visual Basic using Meyerhof's analysis. By comparing the bearing capacity values calculated by computer program with manual calculation, it was found that determination of bearing capacity of footing using computer program is easier and faster and also reduces the human error.

Key words: Computer program, contact area of footing**,** Meyerhof's Analysis, square footing, safe bearing capacity, ultimate bearing capacity

INTRODUCTION

[Foundation is the lower most and very important part of any structure whether it is onshore or offshore structure. It is the part which receive huge amount of load from superstructure and distribute it to ground. The foundation should be strong enough to sustain the load of superstructure. The performance of a structure mostly depends on the performance of foundation] .[Selection of foundation type shall be based on an assessment of the magnitude and direction of loading, depth to suitable bearing materials, evidence of previous flooding, potential for liquefaction, undermining or scour, swelling potential, frost depth and cost of construction]. [Since it is a very important part, it should be designed properly. Design of foundation consists of two different parts:

1. The ultimate bearing capacity of soil below foundation.
2. The acceptable settlement that a footing can undergo without any adverse effect on superstructure].

Bearing capacity of foundations have always been one of the most interesting research subjects in geotechnical engineering with numerous published papers and reports. [Ultimate bearing capacity means the load that the soil under the foundation can sustain before shear failure while settlement consideration involves estimation of the settlement caused by load from superstructure which should not exceed the limiting value for the stability and function of the superstructure]. In other words, ultimate bearing capacity is the magnitude of bearing pressure at which the supporting ground is expected to fail in shear a collapse will take place. All structures placed on a soil foundation, geotechnical engineers must ensure that the soil has sufficient load carrying capacity so that the foundation does not collapse or become unstable under any conceivable loading. The bearing capacity of foundation depends upon various properties of soil such as unit weight, shearing strength parameters and deformation characteristics. In further we also discuss the depth factor, inclination factor, roughness, shape, size and depth of foundation which effect the mathematical calculation to determine the ultimate bearing capacity of foundation.

In this research paper bearing capacity of square footings is observed for different conditions. To calculate the bearing capacity for square footing by manual calculation is very complicated and time consuming. It also increases human errors and takes longer time to calculate the bearing capacity for square footings for a project. The difficulty comes from multiple sources of variability and uncertainty. By using the powerful ability of computers a comprehensive set of solutions have been obtained, therefore reducing the uncertainties apparent in previous solutions. So for better speed and less errors it was decided to develop a computer programming by Microsoft Visual Basic that will be able to analyse and design the foundation. The use of Microsoft Visual Basic program is economical and accessible and it was not used in the past in any research. In this study, Meyerhof's analysis has been used to analyse a range of bearing capacity problems in undrained soil. The numerical models account for a range of variables including footing size, shape, embedment depth, soil layering and undrained bearing capacity of footings on slopes.

METHODOLOGY

Meyerhof's Analysis

The form of equation used by Meyerhof's [3] for determining ultimate bearing capacity of symmetrically loaded strip footings is the same as that of Terzaghi's [4] 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 fig 1.

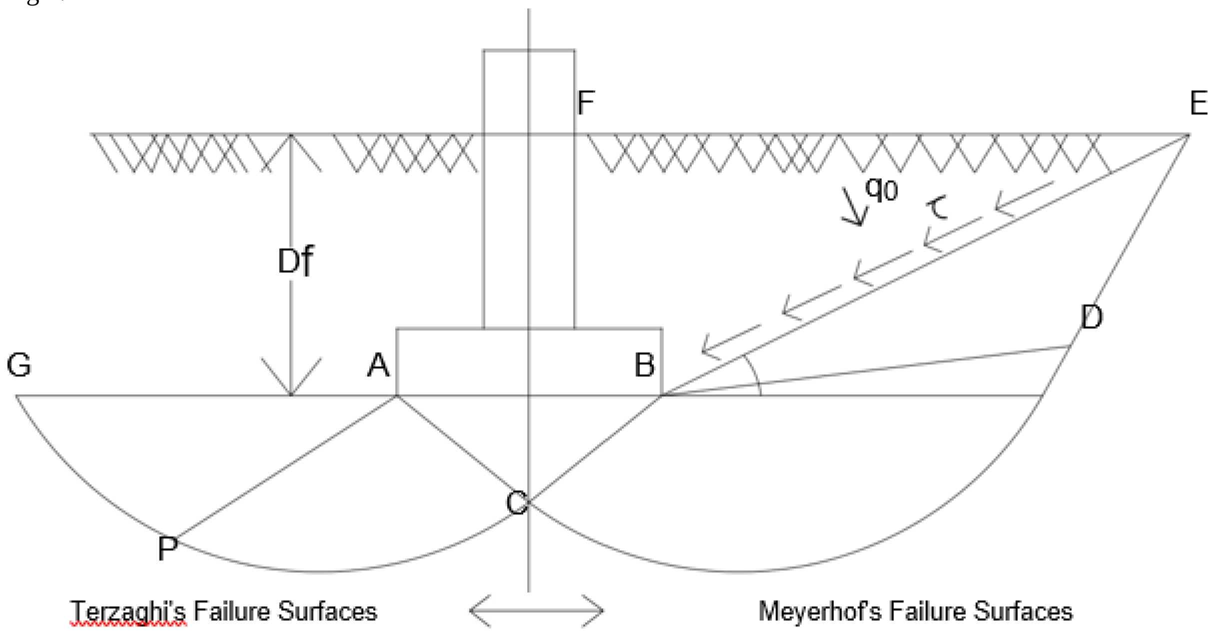

Fig. 1 Terzaghi's surface and Meyerhof's surface failures

Meyerhof's (1951-53) proposed an equation for ultimate bearing capacity of strip footing which is similar in form to that of Terzaghi's but includes shape factors, depth factors and inclination factors. Meyerhof's equation

$$Q_U = cN_c s_c d_c i_c + qN_q s_q d_q i_q + 0.5\,\gamma B N_\gamma\, s_\gamma d_\gamma i_\gamma$$

Meyerhof's bearing capacity factors are expressed as

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

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

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

The shape factors are given by

$$s_C = 1 + [0.2K_p\,(\frac{B}{L})] \text{ for any } \phi$$

$$s_q = s_\gamma = 1.0 \text{ for } \phi = 0$$

$$s_q = s_\gamma = 1 + [0.1K_p\,(\frac{B}{L})] \text{ for } \phi \geq 10$$

$$d_c = 1 + [0.2\sqrt{K_p}\,(\frac{D}{B})] \text{ for any } \phi$$

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

$$d_q = d_\gamma = 1 + [0.1\sqrt{K_p}\,(\frac{D}{B})] \text{ for any } \phi \geq 10$$

The inclination factors are given by

$$i_C = i_q = [1 - (\frac{\theta}{90})]^2 \text{ for any } \phi$$

$$i_\gamma = 1 \text{ for } \phi = 0$$

$$i_\gamma = [1 - (\frac{\theta}{\phi})]^2 \text{ for } \phi \geq 10$$

Where $K_P = \tan^2(45 + \frac{\phi}{2})$ and θ =angle of inclination of load with respect to vertical. It is further suggested that the value of ϕ for the plane strain condition expected in long rectangular footings can be obtained from $\phi_{triaxial}$ as

$$\phi_{ps} = [1.1 - 0.1\,(\frac{B}{L})]\ \phi_{triaxial}]$$

Objectives of Present Study

Methodology explains how the study is carried out in order to achieve the objectives mentioned.

1. To analysis the value of ultimate bearing capacity (Q_U) and safe bearing capacity (Q_S) (considering a factor of safety of 3) by taking the relevant factor using Meyerhof's analysis.
2. To identify the appropriate design of square shape footing with the help of all variable using computer programming with Meyerhof's analysis are taken to develop computer program for calculating the bearing capacity of shallow foundation.
3. To identify the parameters in the calculation of bearing capacity of square footing that give most impact towards the values of bearing capacity.
4. To compare the result between computer program and manual calculation.

Developing the programme start by creating the interface required and deciding the boundary those need to cover by this programme. By providing all the formula needed to calculate the bearing capacity by inserting coding in Microsoft visual basic to make the programme run smoothly and the programme only left to have a trial run. After justification of programme run smoothly two examples of case study have been given to solve it by using the programme. A manual calculation will be completed to compare with the computer program results. The purpose of this comparison is to make sure that nothing wrong with the spreadsheet and it work correctly as manual calculation.

A study called sensitivity analysis will be conducted to identify which parameters in the calculation of bearing capacity of shallow foundation that gives the greater impact towards the results of bearing capacity of shallow foundation. This is the advantage using Microsoft visual basic programme rather than manual calculation. All the result will be converted into graph to make it easier to understand.

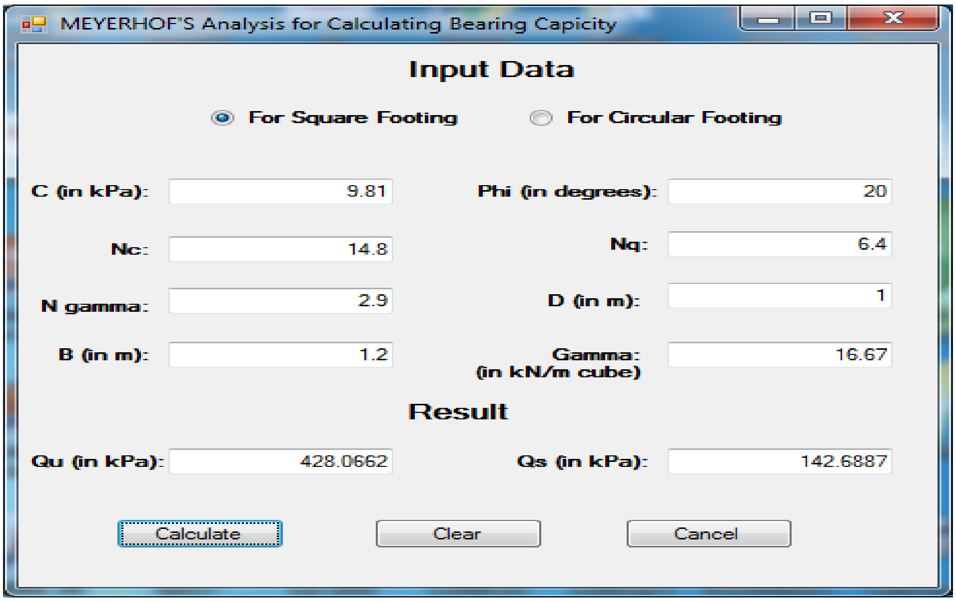

Fig. 2 Microsoft Visual Basic Program Using Meyerhof's Analysis

INVESTIGATION RESULTS

Field and Laboratory Tests Results

Four soil samples having different properties have selected for present investigation. For determination of various parameters of these soil samples on which bearing capacity depends, various tests were performed. Direct shear test, Standard penetration test, Core cutter method test and Oven drying method test are used for determination of shear strength parameters (c and ϕ), standard penetration number (N-value), unit weight of soil (γ) and water content respectively. The values of above parameters after conducting the mentioned experiments are given in Table -1.

Results of Computer Programme

Results of ultimate bearing capacity and safe bearing capacity of square footing calculated by computer program and variation of contact area of square 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 3 to 14.

Table-1 Various Geotechnical Properties of Soil Samples

Soil Sample No.	C (kpa)	ϕ	N	γ (kN/m³)
1.	0	30°	7	16.17
2.	9.8	20°	6	16.67
3.	19.6	15°	5	17.16
4.	29.4	10°	4	17.64

Table-2 Ultimate and Safe Bearing Capacity of Square Footing having Different Sizes at Depth D = 1.0 m and γ = 16.17 kN/m³

Ultimate Bearing Capacity (γ = 16.17 kN/m³) at Depth D = 1.0 m							
N	C (kpa)	ϕ	γ (kN/m³)	B (m)	D (m)	Qu (kpa)	Qs (kpa)
7	0	30°	16.17	0.6	1.0	600.5143	200.1714
7	9.81	20°	16.17	0.6	1.0	472.7513	157.5838
7	19.62	15°	16.17	0.6	1.0	510.6653	170.2218
7	29.43	10°	16.17	0.6	1.0	495.7159	165.2386
7	0	30°	16.17	0.9	1.0	602.8993	200.9664
7	9.81	20°	16.17	0.9	1.0	437.2037	145.7346
7	19.62	15°	16.17	0.9	1.0	465.9525	155.3175
7	29.43	10°	16.17	0.9	1.0	452.0125	150.6708
7	0	30°	16.17	1.2	1.0	623.8936	207.9645
7	9.81	20°	16.17	1.2	1.0	422.8173	140.9391
7	19.62	15°	16.17	1.2	1.0	444.8452	148.2818
7	29.43	10°	16.17	1.2	1.0	430.6039	143.5346
7	0	30°	16.17	1.5	1.0	652.3316	217.4439
7	9.81	20°	16.17	1.5	1.0	416.8954	138.9651
7	19.62	15°	16.17	1.5	1.0	433.1803	144.3934
7	29.43	10°	16.17	1.5	1.0	418.1133	139.3711

Table-3 Ultimate and Safe Bearing Capacity of Square Footing having Different Sizes at Depth D = 1.5 m and γ = 16.17 kN/m³

Ultimate Bearing Capacity (γ = 16.17 kN/m³) at Depth D = 1.5 m							
N	C (kpa)	ϕ	γ (kN/m³)	B (m)	D (m)	Qu (kpa)	Qs (kpa)
7	0	30°	16.17	0.6	1.5	944.9095	314.9698
7	9.81	20°	16.17	0.6	1.5	622.3881	207.4627
7	19.62	15°	16.17	0.6	1.5	630.9601	210.3200
7	29.43	10°	16.17	0.6	1.5	592.7374	197.5791
7	0	30°	16.17	0.9	1.5	900.7714	300.2571
7	9.81	20°	16.17	0.9	1.5	558.2650	186.0883
7	19.62	15°	16.17	0.9	1.5	558.6331	186.2110
7	29.43	10°	16.17	0.9	1.5	524.4466	174.8155
7	0	30°	16.17	1.2	1.5	898.5042	299.5014
7	9.81	20°	16.17	1.2	1.5	529.5908	176.5303
7	19.62	15°	16.17	1.2	1.5	523.7188	174.5729
7	29.43	10°	16.17	1.2	1.5	490.7443	163.5814
7	0	30°	16.17	1.5	1.5	912.9851	304.3284
7	9.81	20°	16.17	1.5	1.5	515.0963	171.6988
7	19.62	15°	16.17	1.5	1.5	503.7697	167.9232
7	29.47	10°	16.17	1.5	1.5	470.8775	156.9592

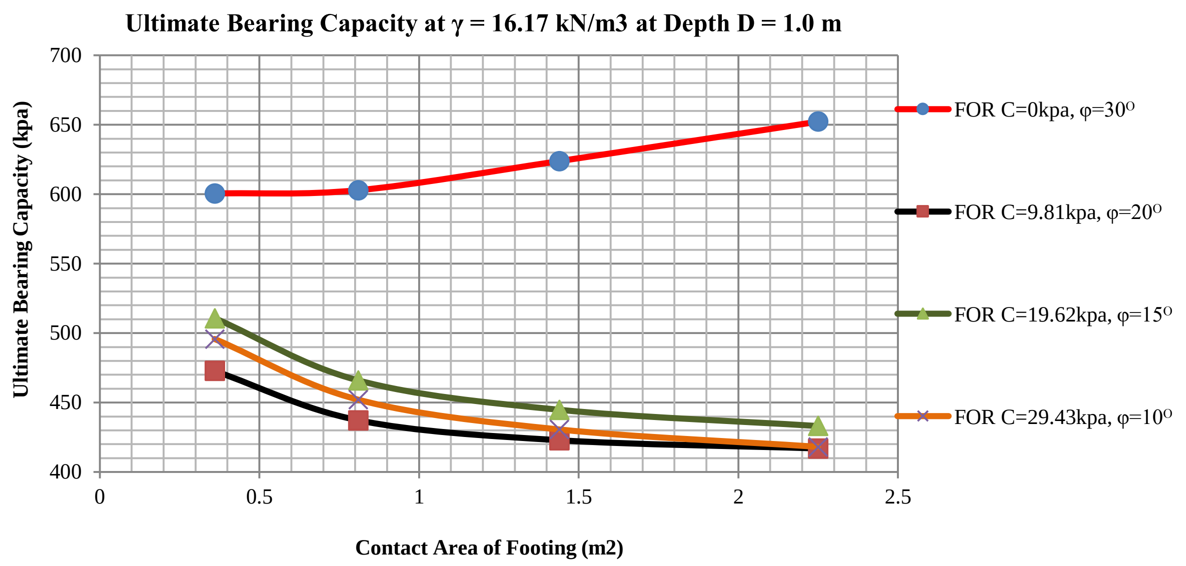

Fig.3 Variation of Ultimate Bearing Capacity with Contact Area of Footing at Depth D = 1.0 m and γ = 16.17 kN/m³

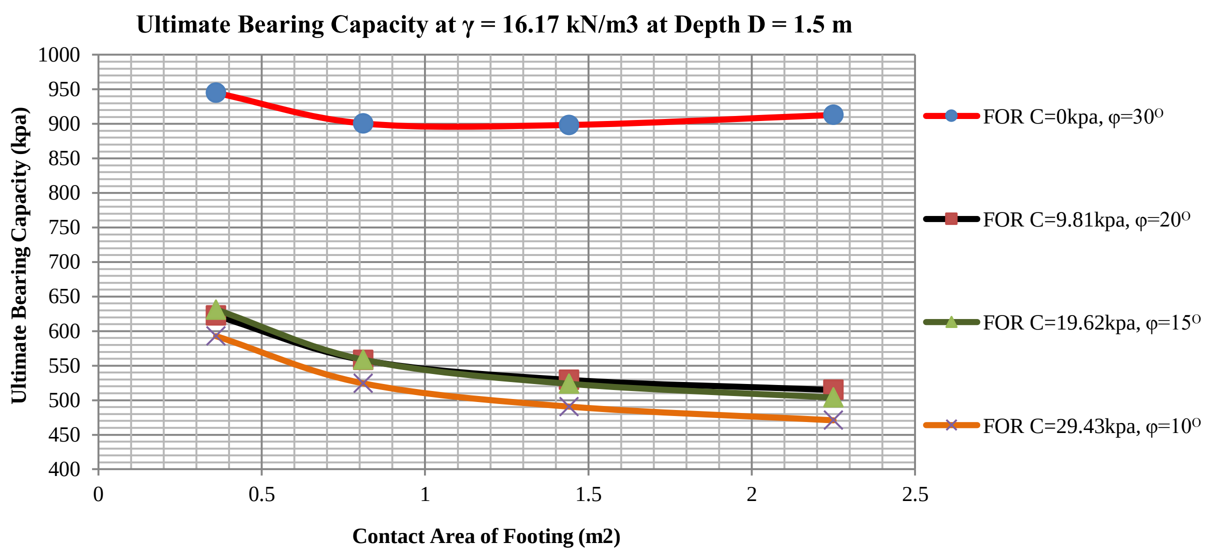

Fig.4 Variation of Ultimate Bearing Capacity with Contact Area of Footing at Depth D = 1.5 m and γ = 16.17 kN/m³

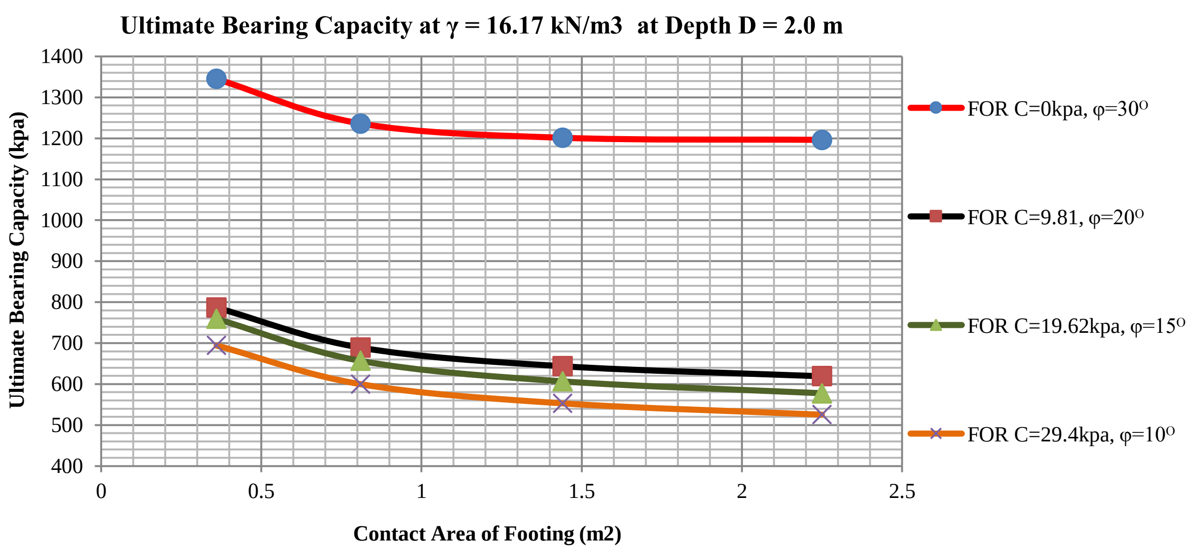

Fig.5 Variation of Ultimate Bearing Capacity with Contact Area of Footing at Depth D = 2.0 m and γ = 16.17 kN/m³

Table-4 Ultimate and Safe Bearing Capacity of Square Footing having Different Sizes at Depth D = 2.0 m and γ = 16.17 kN/m³

Ultimate Bearing Capacity (γ = 16.17 kN/m³) at Depth D = 2.0 m							
N	**C (kpa)**	**ϕ**	**γ (kN/m³)**	**B (m)**	**D (m)**	**Qu (kpa)**	**Qs (kpa)**
7	0	30°	16.17	0.6	2.0	1345.133	488.3775
7	9.81	20°	16.17	0.6	2.0	786.8531	262.2844
7	19.62	15°	16.17	0.6	2.0	759.2719	253.0906
7	29.43	10°	16.17	0.6	2.0	694.3438	231.4479
7	0	30°	16.17	0.9	2.0	1235.862	411.9540
7	9.81	20°	16.17	0.9	2.0	689.2118	229.7373
7	19.62	15°	16.17	0.9	2.0	656.6583	218.8861
7	29.43	10°	16.17	0.9	2.0	599.9373	199.9791
7	0	30°	16.17	1.2	2.0	1201.029	400.3428
7	9.81	20°	16.17	1.2	2.0	643.7786	214.5928
7	19.62	15°	16.17	1.2	2.0	606.6008	202.2003
7	29.43	10°	16.17	1.2	2.0	553.1771	184.3924
7	0	30°	16.17	1.5	2.0	1195.970	398.6566
7	9.81	20°	16.17	1.5	2.0	619.2285	206.4095
7	19.62	15°	16.17	1.5	2.0	577.5657	192.5219
7	29.43	10°	16.17	1.5	2.0	525.4756	175.1586

Table-5 Ultimate and Safe Bearing Capacity of Square Footing having Different Sizes at Depth D = 1.0 m and γ = 16.67 kN/m³

Ultimate Bearing Capacity (γ = 16.67 kN/m³) at Depth D = 1.0 m							
N	**C (kpa)**	**ϕ**	**γ (kN/m³)**	**B (m)**	**D (m)**	**Qu (kpa)**	**Qs (kpa)**
6	0	30°	16.67	0.6	1.0	619.083	206.3610
6	9.81	20°	16.67	0.6	1.0	478.0397	159.3466
6	19.62	15°	16.67	0.6	1.0	513.5707	171.1902
6	29.43	10°	16.67	0.6	1.0	497.4927	165.8309
6	0	30°	16.67	0.9	1.0	621.5418	207.1806
6	9.81	20°	16.67	0.9	1.0	442.3959	147.4653
6	19.62	15°	16.67	0.9	1.0	468.7716	156.2572
6	29.43	10°	16.67	0.9	1.0	453.7222	151.2407
6	0	30°	16.67	1.2	1.0	643.1853	214.3951
6	9.81	20°	16.67	1.2	1.0	428.0662	142.6887
6	19.62	15°	16.67	1.2	1.0	447.6591	149.2197
6	29.43	10°	16.67	1.2	1.0	432.2937	144.0979
6	0	30°	16.67	1.5	1.0	672.5026	224.1675
6	9.81	20°	16.67	1.5	1.0	422.2621	140.7540
6	19.62	15°	16.67	1.5	1.0	436.0213	145.3404
6	29.43	10°	16.67	1.5	1.0	419.8022	139.9341

Table-6 Ultimate and Safe Bearing Capacity of Square Footing having Different Sizes at Depth D = 1.5 m and γ = 16.67 kN/m³

Ultimate Bearing Capacity (γ = 16.67 kN/m³) at Depth D = 1.5 m							
N	**C (kpa)**	**ϕ**	**γ (kN/m³)**	**B (m)**	**D (m)**	**Qu (kpa)**	**Qs (kpa)**
6	0	30°	16.67	0.6	1.5	974.1276	324.7092
6	9.81	20°	16.67	0.6	1.5	630.7990	210.2663
6	19.62	15°	16.67	0.6	1.5	635.6066	211.8689
6	29.43	10°	16.67	0.6	1.5	595.5878	198.5293
6	0	30°	16.67	0.9	1.5	928.6246	309.5415
6	9.81	20°	16.67	0.9	1.5	566.1976	188.7325
6	19.62	15°	16.67	0.9	1.5	562.9911	187.6637
6	29.43	10°	16.67	0.9	1.5	527.1118	175.7039
6	0	30°	16.67	1.2	1.5	928.6246	308.7624
6	9.81	20°	16.67	1.2	1.5	537.3890	179.1297
6	19.62	15°	16.67	1.2	1.5	527.9704	175.9901
6	29.43	10°	16.67	1.2	1.5	493.3306	164.4435
6	0	30°	16.67	1.5	1.5	941.2159	313.7386
6	9.81	20°	16.67	1.5	1.5	522.8976	174.2992
6	19.62	15°	16.67	1.5	1.5	507.9876	169.3292
6	29.43	10°	16.67	1.5	1.5	473.4274	157.8091

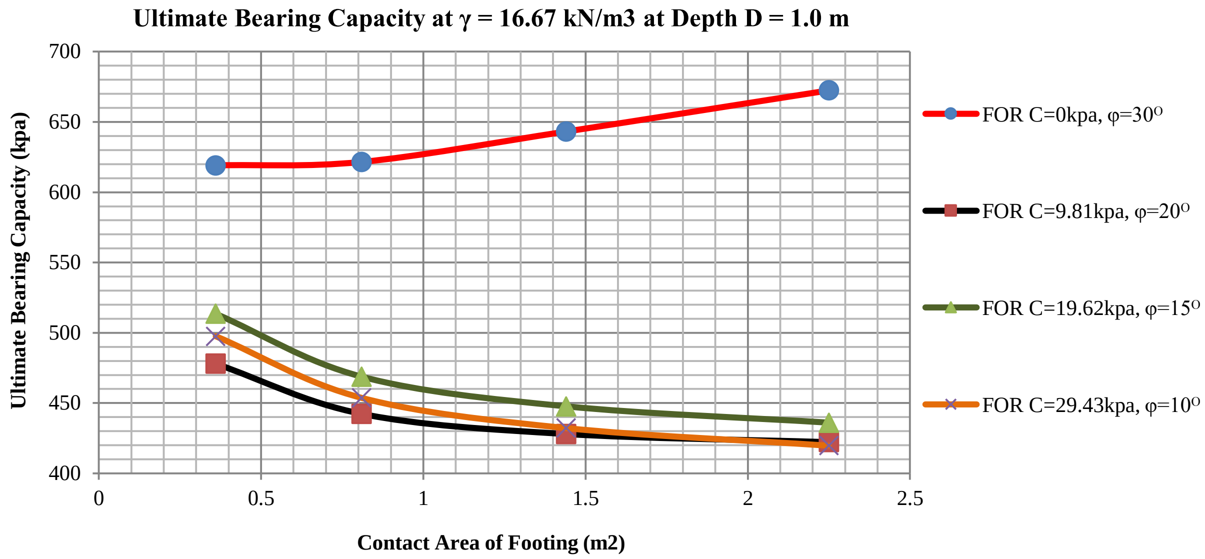

Fig.6 Variation of Ultimate Bearing Capacity with Contact Area of Footing at Depth D = 1.0 m and γ = 16.67 kN/m^3

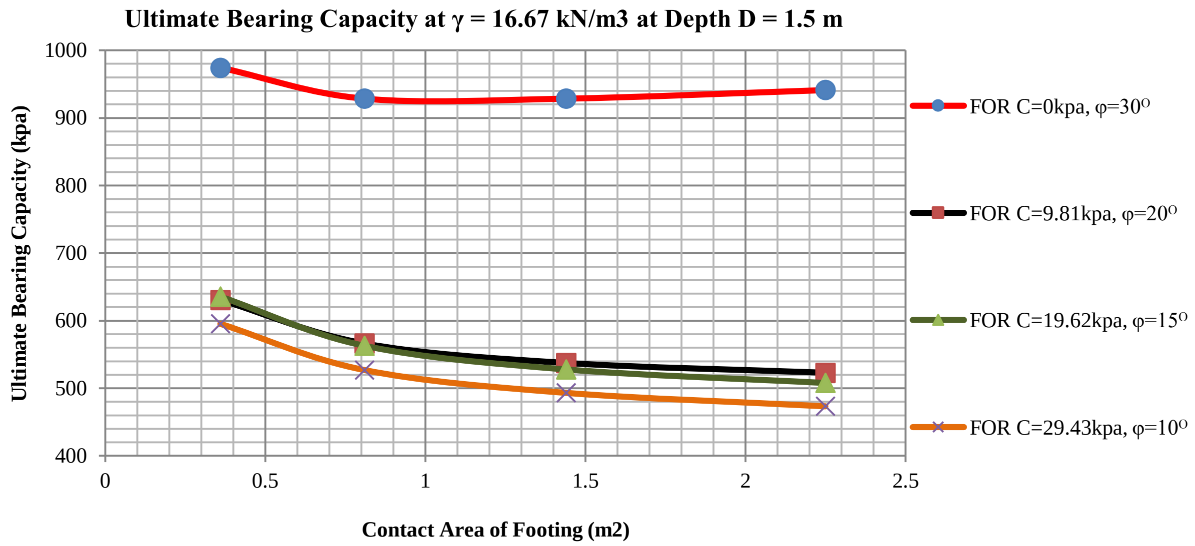

Fig.7 Variation of Ultimate Bearing Capacity with Contact Area of Footing at Depth D = 1.5 m and γ = 16.67 kN/m^3

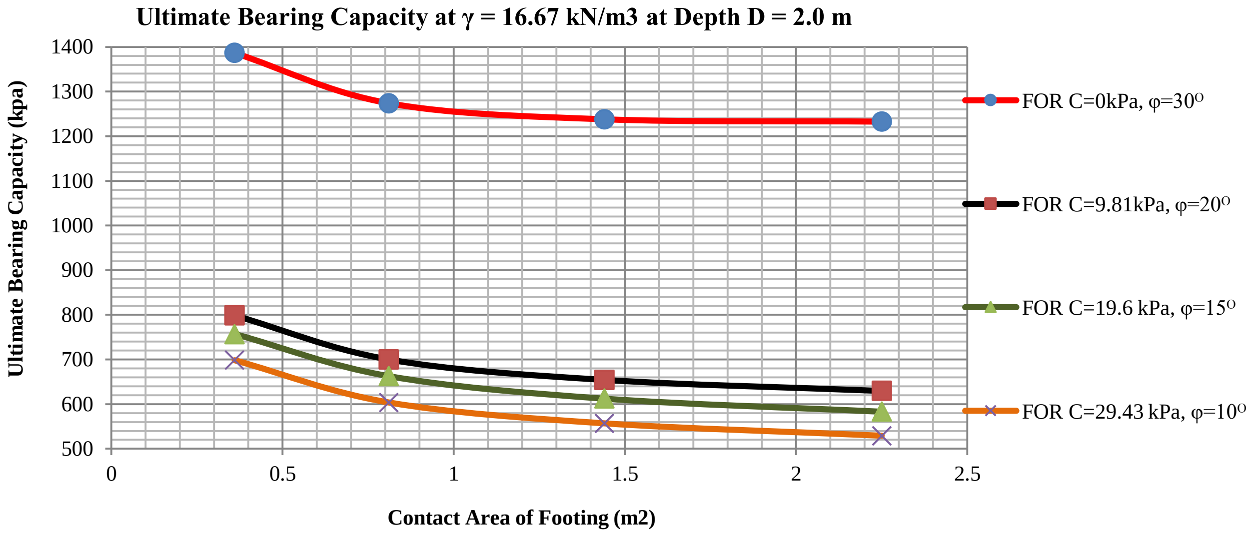

Fig.8 Variation of Ultimate Bearing Capacity with Contact Area of Footing at Depth D = 2.0 m and γ = 16.67 kN/m^3

Table-7 Ultimate and Safe Bearing Capacity of Square Footing having Different Sizes at Depth D = 2.0 m and γ = 16.67 kN/m³

Ultimate Bearing Capacity (γ = 16.67 kN/m³) at Depth D = 2.0 m							
N	C (kpa)	ϕ	γ (kN/m³)	B (m)	D (m)	Qu (kpa)	Qs (kpa)
6	0	30°	16.67	0.6	2.0	1386.726	462.2420
6	9.81	20°	16.67	0.6	2.0	798.8451	266.2817
6	19.62	15°	16.67	0.6	2.0	765.9023	255.3008
6	29.43	10°	16.67	0.6	2.0	698.4097	232.8032
6	0	30°	16.67	0.9	2.0	1274.077	424.6922
6	9.81	20°	16.67	0.9	2.0	700.1905	233.3968
6	19.62	15°	16.67	0.9	2.0	662.7170	220.9057
6	29.43	10°	16.67	0.9	2.0	603.6525	201.2175
6	0	30°	16.67	1.2	2.0	1238.166	412.7220
6	9.81	20°	16.67	1.2	2.0	654.3553	218.1185
6	19.62	15°	16.67	1.2	2.0	612.4114	204.1371
6	29.43	10°	16.67	1.2	2.0	556.7307	185.5769
6	0	30°	16.67	1.5	2.0	1232.951	410.9836
6	9.81	20°	16.67	1.5	2.0	629.6480	209.8827
6	19.62	15°	16.67	1.5	2.0	583.2578	194.4193
6	29.43	10°	16.67	1.5	2.0	528.9432	176.3144

Table-8 Ultimate and Safe Bearing Capacity of Square Footing having Different Sizes at Depth D = 1.0 m and γ = 17.16 kN/m³

Ultimate Bearing Capacity (γ = 17.16 kN/m³) at Depth D = 1.0 m							
N	C (kpa)	ϕ	γ (kN/m³)	B (m)	D (m)	Qu (kpa)	Qs (kpa)
5	0	30°	17.16	0.6	1.0	637.2805	212.4268
5	9.81	20°	17.16	0.6	1.0	483.2224	161.0741
5	19.62	15°	17.16	0.6	1.0	516.4760	172.1587
5	29.43	10°	17.16	0.6	1.0	499.2339	166.4113
5	0	30°	17.16	0.9	1.0	639.8115	213.2705
5	9.81	20°	17.16	0.9	1.0	447.4843	149.1614
5	19.62	15°	17.16	0.9	1.0	471.5908	157.1969
5	29.43	10°	17.16	0.9	1.0	455.3976	151.7992
5	0	30°	17.16	1.2	1.0	662.0911	220.6971
5	9.81	20°	17.16	1.2	1.0	433.2101	144.4034
5	19.62	15°	17.16	1.2	1.0	450.4730	150.1577
5	29.43	10°	17.16	1.2	1.0	433.9498	144.6499
5	0	30°	17.16	1.5	1.0	692.2703	230.7567
5	9.81	20°	17.16	1.5	1.0	427.5214	142.5071
5	19.62	15°	17.16	1.5	1.0	438.8623	146.2874
5	29.43	10°	17.16	1.5	1.0	421.4573	140.4858

Table-9 Ultimate and Safe Bearing Capacity of Square Footing having Different Sizes at Depth D = 1.5 m and γ = 17.16 kN/m³

Ultimate Bearing Capacity (γ = 17.16 kN/m³) at Depth D = 1.5 m							
N	C (kpa)	ϕ	γ (kN/m³)	B (m)	D (m)	Qu (kpa)	Qs (kpa)
5	0	30°	17.16	0.6	1.5	1002.761	334.2537
5	9.81	20°	17.16	0.6	1.5	639.0416	213.0139
5	19.62	15°	17.16	0.6	1.5	640.2532	213.4177
5	29.43	10°	17.16	0.6	1.5	598.3813	199.4604
5	0	30°	17.16	0.9	1.5	955.9207	318.6402
5	9.81	20°	17.16	0.9	1.5	573.9716	191.3238
5	19.62	15°	17.16	0.9	1.5	567.3491	189.1164
5	29.43	10°	17.16	0.9	1.5	529.7236	176.5745
5	0	30°	17.16	1.2	1.5	953.5145	317.8382
5	9.81	20°	17.16	1.2	1.5	545.0313	181.6771
5	19.62	15°	17.16	1.2	1.5	532.2219	177.4073
5	29.43	10°	17.16	1.2	1.5	495.8651	165.2884
5	0	30°	17.16	1.5	1.5	968.8822	322.9607
5	9.81	20°	17.16	1.5	1.5	530.5430	176.8477
5	19.62	15°	17.16	1.5	1.5	512.2056	170.7352
5	29.43	10°	17.16	1.5	1.5	475.9263	158.6421

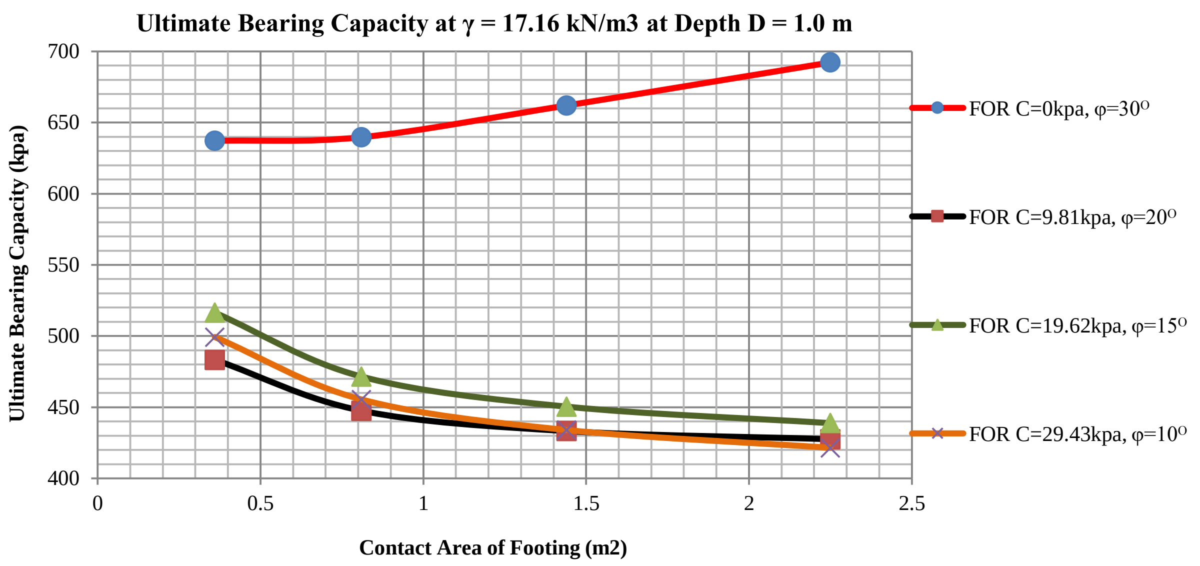

Fig.9 Variation of Ultimate Bearing Capacity with Contact Area of Footing at Depth D = 1.0 m and γ = 17.16 kN/m^3

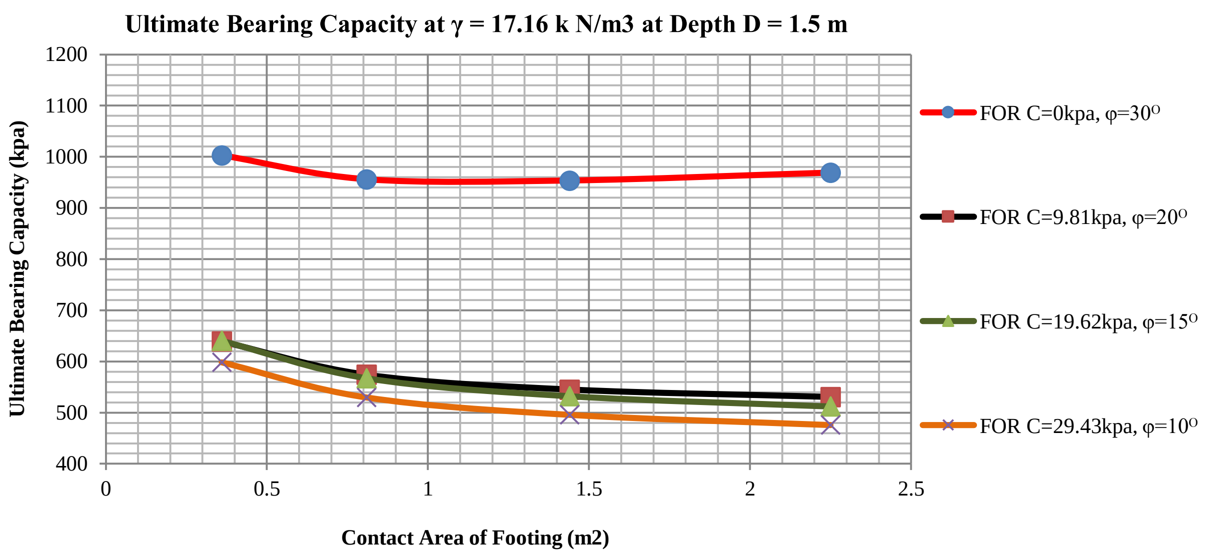

Fig. 10 Variation of Ultimate Bearing Capacity with Contact Area of Footing at Depth D = 1.5 m and γ = 17.16 kN/m^3

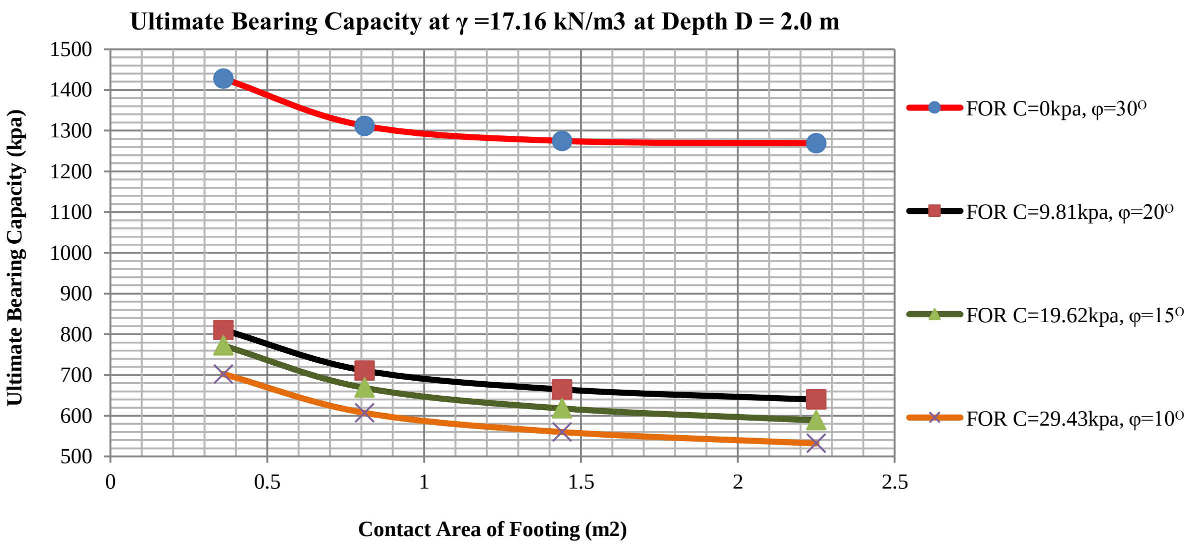

Fig.11 Variation of Ultimate Bearing Capacity with Contact Area of Footing at Depth D = 2.0 m and γ = 17.16 kN/m^3

Table-10 Ultimate and Safe Bearing Capacity of Square Footing having Different Sizes at Depth D = 2.0 m and γ = 17.16 kN/m^3

Ultimate Bearing Capacity (γ = 17.16 kN/m^3) at Depth D = 2.0 m							
N	**C (kpa)**	**ϕ**	**γ (kN/m^3)**	**B (m)**	**D (m)**	**Qu (kpa)**	**Qs (kpa)**
5	0	30°	17.16	0.6	2.0	1427.488	475.8292
5	9.81	20°	17.16	0.6	2.0	810.5972	270.1991
5	19.62	15°	17.16	0.6	2.0	772.5328	257.5109
5	29.43	10°	17.16	0.6	2.0	702.3942	234.1314
5	0	30°	17.16	0.9	2.0	1311.527	437.1757
5	9.81	20°	17.16	0.9	2.0	710.9496	236.9832
5	19.62	15°	17.16	0.9	2.0	668.7758	222.9252
5	29.43	10°	17.16	0.9	2.0	607.2933	202.4311
5	0	30°	17.16	1.2	2.0	1274.561	424.8536
5	9.81	20°	17.16	1.2	2.0	664.7206	221.5735
5	19.62	15°	17.16	1.2	2.0	618.2221	206.0740
5	29.43	10°	17.16	1.2	2.0	560.2132	186.7377
5	0	30°	17.16	1.5	2.0	1269.193	423.0641
5	9.81	20°	17.16	1.5	2.0	639.8591	213.2864
5	19.62	15°	17.16	1.5	2.0	588.9499	196.3166
5	29.43	10°	17.16	1.5	2.0	532.3414	177.4471

Table-11 Ultimate and Safe Bearing Capacity of Square Footing having Different Sizes at Depth D = 1.0 m and γ = 17.65 kN/m^3

Ultimate Bearing Capacity (γ = 17.65 kN/m^3) at Depth D = 1.0m							
N	**C (kpa)**	**ϕ**	**γ (kN/m^3)**	**B (m)**	**D (m)**	**Qu (kpa)**	**Qs (kpa)**
4	0	30°	17.65	0.6	1.0	655.4778	218.4926
4	9.81	20°	17.65	0.6	1.0	488.4050	162.8017
4	19.62	15°	17.65	0.6	1.0	519.3813	173.1271
4	29.43	10°	17.65	0.6	1.0	499.2339	166.4113
4	0	30°	17.65	0.9	1.0	658.0812	219.3604
4	9.81	20°	17.65	0.9	1.0	452.5726	150.8575
4	19.62	15°	17.65	0.9	1.0	474.4099	158.1366
4	29.43	10°	17.65	0.9	1.0	457.0731	152.3577
4	0	30°	17.65	1.2	1.0	680.9970	226.9990
4	9.81	20°	17.65	1.2	1.0	438.3539	146.1180
4	19.62	15°	17.65	1.2	1.0	453.2869	151.0956
4	29.43	10°	17.65	1.2	1.0	435.6058	145.2019
4	0	30°	17.65	1.5	1.0	712.0378	237.3459
4	9.81	20°	17.65	1.5	1.0	432.7807	144.2602
4	19.62	15°	17.65	1.5	1.0	441.7033	147.2344
4	29.43	10°	17.65	1.5	1.0	423.1125	141.0375

Table-12 Ultimate and Safe Bearing Capacity of Square Footing having Different Sizes at Depth D = 1.5 m and γ = 17.65 kN/m^3

Ultimate Bearing Capacity (γ = 17.65 kN/m^3) at Depth D = 1.5 m							
N	**C (kpa)**	**ϕ**	**γ (kN/m^3)**	**B (m)**	**D (m)**	**Qu (kpa)**	**Qs (kpa)**
4	0	30°	17.65	0.6	1.5	1031.395	343.7982
4	9.81	20°	17.65	0.6	1.5	647.2843	215.7614
4	19.62	15°	17.65	0.6	1.5	644.8997	214.9666
4	29.43	10°	17.65	0.6	1.5	601.1747	200.3916
4	0	30°	17.65	0.9	1.5	983.2167	327.7389
4	9.81	20°	17.65	0.9	1.5	581.7455	193.9152
4	19.62	15°	17.65	0.9	1.5	571.7071	190.5690
4	29.43	10°	17.65	0.9	1.5	532.3355	177.4452
4	0	30°	17.65	1.2	1.5	980.7419	326.9140
4	9.81	20°	17.65	1.2	1.5	552.6735	184.2245
4	19.62	15°	17.65	1.2	1.5	536.4735	178.8245
4	29.43	10°	17.65	1.2	1.5	498.3996	166.1332
4	0	30°	17.65	1.5	1.5	996.5483	332.1828
4	9.81	20°	17.65	1.5	1.5	538.1884	179.3961
4	19.62	15°	17.65	1.5	1.5	516.4236	172.1412
4	29.43	10°	17.65	1.5	1.5	478.4251	159.4750

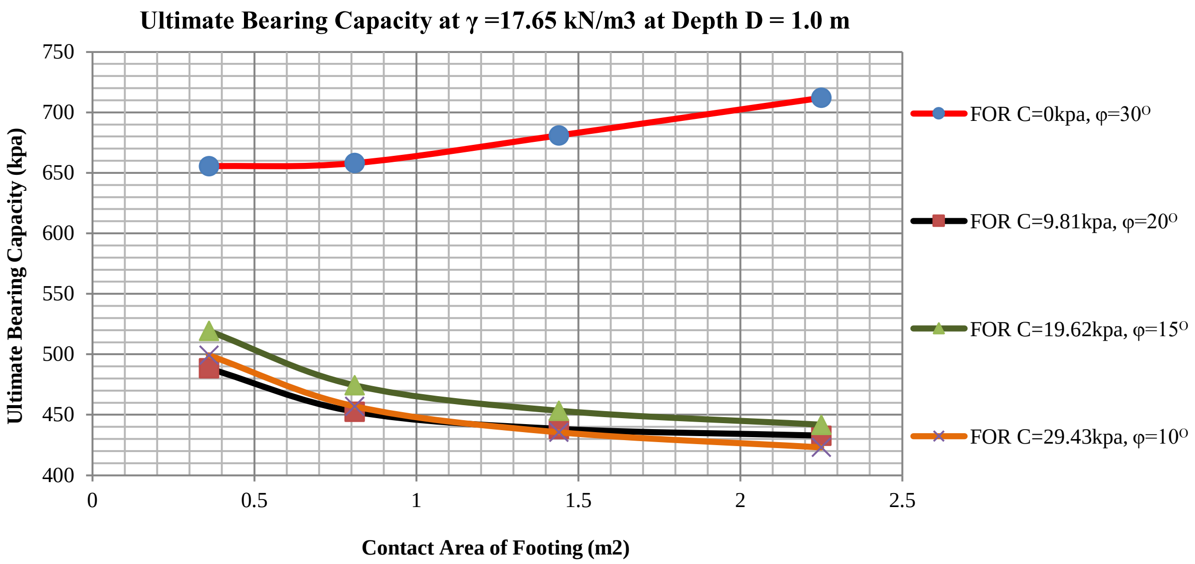

Fig.12 Variation of Ultimate Bearing Capacity with Contact Area of Footing at Depth D = 1.0 m and γ = 17.65 kN/m³

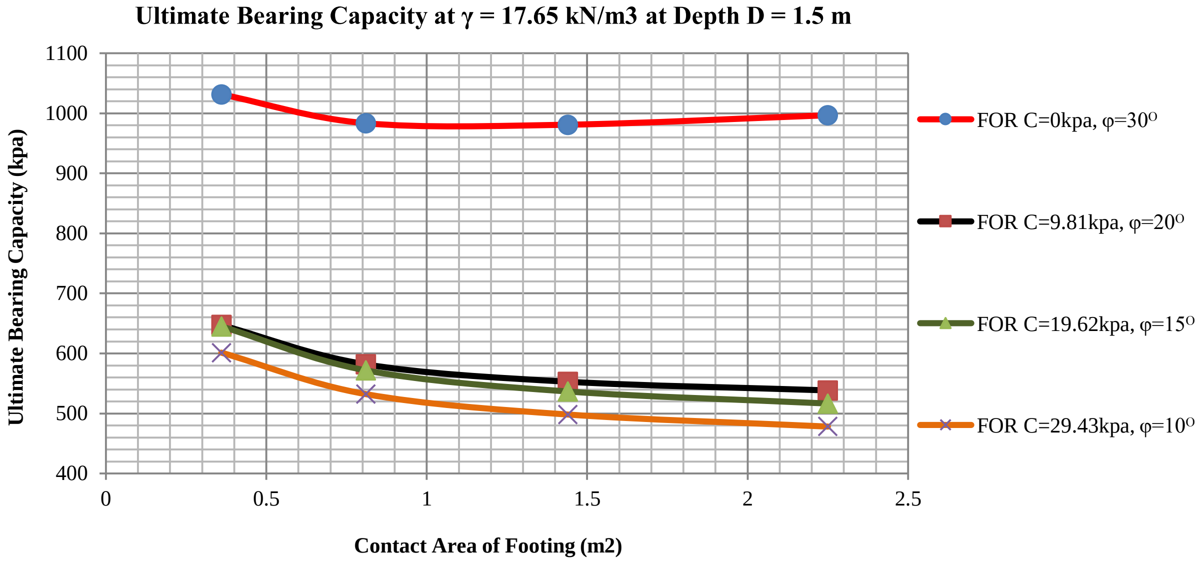

Fig.13 Variation of Ultimate Bearing Capacity with Contact Area of Footing at Depth D = 1.5 m and γ = 17.65 kN/m³

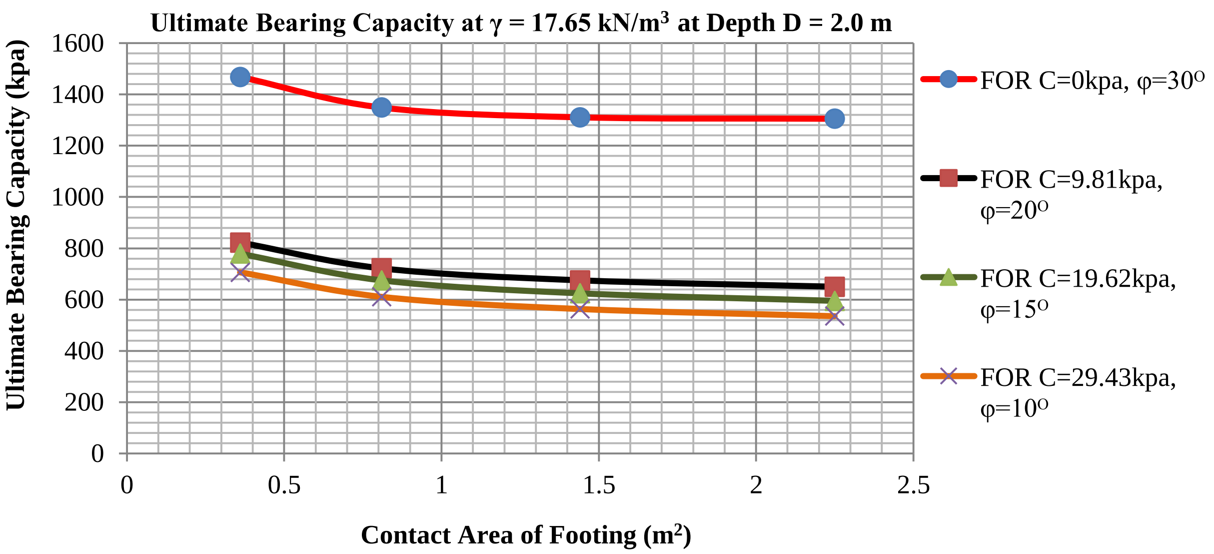

Fig.14 Variation of Ultimate Bearing Capacity with Contact Area of Footing at Depth D = 2.0 m and γ = 17.65 kN/m³

Table-13 Ultimate and Safe Bearing Capacity of Square Footing having Different Sizes at Depth D = 2.0 m and γ = 17.65 kN/m³

Ultimate Bearing Capacity (γ = 17.65 kN/m³) at Depth D = 2.0 m							
N	**C (kpa)**	**ϕ**	**γ (kN/m³)**	**B (m)**	**D (m)**	**Qu (kpa)**	**Qs (kpa)**
4	0	30°	17.65	0.6	2.0	1468.249	489.4164
4	9.81	20°	17.65	0.6	2.0	822.3492	274.1164
4	19.62	15°	17.65	0.6	2.0	779.1633	259.7211
4	29.47	10°	17.65	0.6	2.0	705.8049	235.2683
4	0	30°	17.65	0.9	2.0	1348.977	449.6591
4	9.81	20°	17.65	0.9	2.0	721.7087	240.5696
4	19.62	15°	17.65	0.9	2.0	674.8345	224.9448
4	29.47	10°	17.65	0.9	2.0	610.4451	203.4817
4	0	30°	17.65	1.2	2.0	1310.956	436.9852
4	9.81	20°	17.65	1.2	2.0	675.0859	225.0286
4	19.62	15°	17.65	1.2	2.0	624.0328	208.0109
4	29.47	10°	17.65	1.2	2.0	563.2490	187.7496
4	0	30°	17.65	1.5	2.0	1305.434	435.1447
4	9.81	20°	17.65	1.5	2.0	650.0703	216.6901
4	19.62	15°	17.65	1.5	2.0	594.6420	198.2140
4	29.47	10°	17.65	1.5	2.0	535.3183	178.4394

CONCLUSION

The following conclusions are made from present investigation:

- It is obvious that as the depth of footing increase, ultimate bearing capacity of square footing value increases.
- It can be seen that as the depth of footing increase, the ultimate bearing capacity of square footing increases. The ultimate bearing capacity increases sharply for a cohesionless soil (c = 0) because for cohesionless soil angle of internal friction (ϕ) is more equal to 30° due to which N_C ,Nq ,Nγ ,Sc ,Sq ,Sγ ,dc ,dq and dγ increase which cause a sharp increase in ultimate bearing capacity.
- It can be seen that for the soils having cohesion (c) 9.81 kpa and 19.6 kpa, the ultimate bearing capacity with depth of square footing curves are intersecting with each other, because for soil having c = 9.81 kpa; angle of internal friction (ϕ) is 20° and for soil having c = 19.6 kpa; ϕ is 15° i.e. for value of ϕ is decreasing due to which Sc, Sq, Sγ, dc, dq, dγ, Nc, Nq and Nγ decrease, ultimate bearing capacity decreases.
- It can be seen that ultimate bearing capacity decrease with increase in contact area of footing because as the value of ϕ decrease, the bearing capacity factors, shape factor and depth factor reduces so ultimate bearing capacity decreases.
- It can be seen that for cohesion (c) equals to zero, the bearing capacity value of square footing are more as compare to c-ϕ soil. This occurs because of greater value of bearing capacity factors, shape factor and depth factor for ϕ =30° which corresponding to c = 0 kpa.
- Calculating bearing capacity of square footing by using Microsoft Visual Basic Program is easier and faster. It also reduces the human error. User can determine the parameter which gives most impact toward the value of bearing capacity of square footing.

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