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Software for Design of Shallow Foundation using Matlab

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Abstract

This paper demonstrates programmable calculations of allowable bearing capacity as per (IS: 6403-1981), settlement according to (IS 8009(part-1)-1976), design of R.C.C footing as per (IS: 456-2000) for given load, moments, soil properties using 'MATLAB'. Firstly, the historical background is presented for the determination of allowable bearing capacity of shallow foundations. Secondly, based on a variety of case histories of site investigations, including extensive bore hole data and laboratory testing, an empirical formulation is proposed for the determination of allowable bearing capacity of shallow foundations. Various soil profiles like homogeneous, two layered and multilayer in pure cohesive, pure cohesionless and mixed c- Φ types of soil are considered in software. The software gives the optimum size of foundation with the consideration of various soil parameters for a given soil profiles. Analysis results are helpful to designers for considering allowable bearing capacity, size of footing and settlement of foundation based on IS code considerations. The soil bearing capacity is affected by many factors such as type and strength of soil, foundation width and depth, soil weight in the shear zone, surcharge, shear parameter of soil ('c' and' φ'), type of loading, shape of footing and depth of influence zone below foundation. Settlement depends on soil stiffness below foundation, soil poisson's ratio, depth of incompressible layer and foundation width. Variation in these parameters makes calculations complex. By using software these complex calculations can be optimized with consideration of economical aspects, safety and IS code. The results obtained in this work are compared with renowned books of the field and are found satisfactory.

Keywords: Shear parameter ('c' and' Φ'), Allowable bearing capacity, settlement, design of footing, Matlab.

Introduction

The earth is the ultimate supports for all the structures. The action of the supporting earth or soil /rock affects the stability of the structure. Soil is a natural material, highly variable and affected by numerous factors. Hence, the properties of the soil must be expected to affect the choice of the type of structural foundation requires for a structure. Due to the variety of soil types, soil profiles and multi-layered soil profiles exist in nature, giving probabilistic analysis experimentally and therefore without the aid of modern high-speed computers and software it would be very tedious. by every engineer. One of the reasons behind developing this software is that to have method of one's own choice. It develops in such a way that it provides results as it is been required. A foundation is defined as the supporting base of a structure which forms the interface across which the loads are transmitted to the underlying soil or rock. It transmits the load in such a way that the supporting soil is not undergoing deformations that would cause excessive settlement of the structure. Foundations are classified according to the depth of footing, D compared to the width of the foundation, B. (a) Shallow foundations: are placed at shallow depths i.e. D< B (b) Deep foundations: are placed at greater depths D>B. For reasons of economy, shallow foundations are the first choice of a foundation engineer for a structure. However, the use of shallow foundations may save up to 50% of the structure's foundation cost, which amounts to about 25% to 30% of the total cost. For the design of shallow foundation. The concept of the ultimate bearing capacity of soil, under a shallow foundation, was developed first by Prandtl (1921) [1] and Reissner (1924) [2] using the concept of plastic equilibrium as early as in 1921. This concept later modified and generalized by Terzaghi (1925) [3], Meyerhof (1956) [4], Hansen (1968) [5], De Beer (1970) [6], and Sieffert et al. (2000) [7].

Classical Formulation

Bearing capacity of a shallow foundation

Bearing capacity is the power of soil to safely carry the load or pressure placed on the soil from any structure without undergoing a shear failure with accompanying large settlements.. Foundation design should satisfy two criteria; one deal with ultimate bearing capacity of the soil under the foundation and the other is concern with the limit of soil deformation. The load intensity at failure called ultimate bearing capacity.Each criterion is dependent on the footing geometry and several soil properties. Soil properties are rather difficult to obtain, close scrutiny should be used when interpreting laboratory or in-situ tests. Bearing capacity calculations shall be made on the basis of shear strength parameters φ and c obtained from appropriate shear tests [8] or from plate load test results [9] or from static cone penetration resistance q_c obtained from static cone penetration test [10]. Depending upon the deformations associated with the load and the extent of development of failure surface, different modes of failure may arise. They are general shear failure, local shear failure, punching shear failure.

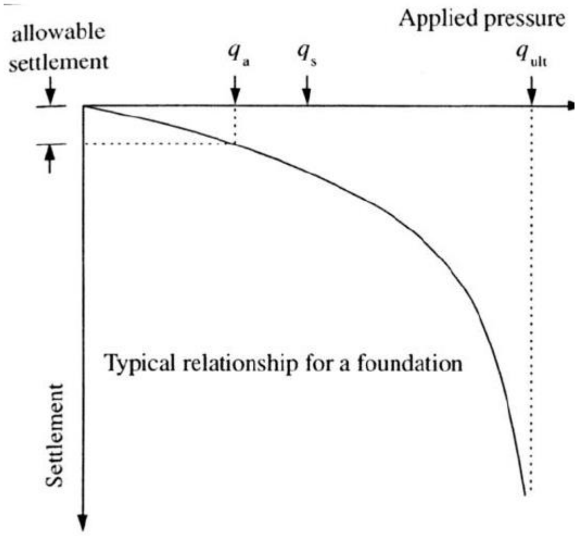


Fig. 1.Concept of Bearing Capacity

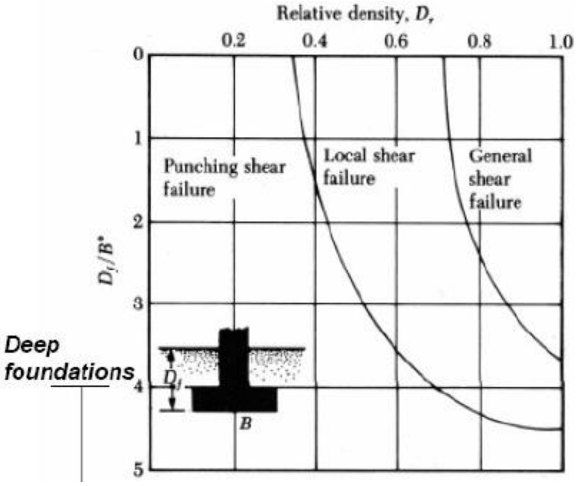


Fig. 2. Modes of failure at different relative densities & depth of foundations.[bbit document or unit 7 skp.pdf]

Using the principles of plastic equilibrium, the ultimate bearing capacity q_u , of a shallow strip footing, with a depth of D, from the surface and with a width of B and length L,, is given by Terzaghi (1967) [11] as ,

In case of general shear failure

$$q_u = cN_c + qN_q + \frac{1}{2}B\gamma N_\gamma \qquad (1)$$

In case of local shear failure

$$q_u = \frac{2}{3}cN_c + qN_q + \frac{1}{2}B\gamma N_\gamma \qquad (2)$$

The first term of (1) represents the shear strength, the second term is the contribution of the surcharge pressure due to the depth of foundation, and the third term represents the contribution of the self-weight.

Where,

(a) Bearing capacity factors

$$N_c = \left(N_q - 1\right)\cot\varphi \qquad (3)$$

$$N_q = \frac{e^{2(\frac{3\pi}{4}-\frac{\varphi}{2})\tan\varphi}}{2\cos^2(45+\frac{\varphi}{2})} \qquad (4)$$

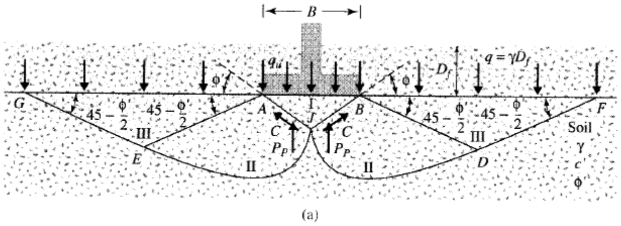


Fig. 3.Terzaghi's bearing capacity Analysis[12]

$$N_\gamma = \frac{1}{2}\tan\varphi\left(\frac{K_p}{\cos^2\varphi} - 1\right) \qquad (5)$$

Bearing Capacity Factors [13-14].

$$N_c = (N_q - 1) \cot\varphi \qquad (6)$$

$$N_q = \exp(\pi \tan\Phi) \tan^2\left(45 + \frac{\Phi}{2}\right) \qquad (7)$$

$$N_\gamma = 2(N_q + 1) \tan\varphi \qquad (8)$$

The modified net ultimate bearing capacity equations for strip footing resting on c-φ soil are as follow.

In case of general shear failure

$$q_{ult} = cN_c s_c d_c i_c + q(N_q - 1) s_q d_q i_q + \frac{1}{2} B\gamma N_\gamma s_\gamma d_\gamma i_\gamma W' \qquad (9)$$

In case of local shear failure

$$q_{ult} = \frac{2}{3} cN_c s_c d_c i_c + q(N_q - 1) s_q d_q i_q + \frac{1}{2} B\gamma N_\gamma s_\gamma d_\gamma i_\gamma W' \qquad (10)$$

Where

s_c, s_q, s_γ=shape factors,

d_c, d_q, d_γ=depth factors,

i_c, i_q , i_γ = inclination factors and

W' is the correction factor for depth of water table consider as per IS:6403.Effect of eccentricity of load is also considered as per IS: 6403.

The net ultimate bearing capacity for cohesionless soil is obtained by (9),(10) considering c=0.The relative density shall be used as a guide to determine the modes of failure as a method of analysis in cohesionless soil.

The net ultimate bearing capacity in cohesive soil is obtained by (11).

$$q_d = cN_c s_c d_c i_c \qquad (11)$$

where N_c =5.14

In the case of two layered cohesive soil system which do not exhibit marked anisotropy the ultimate net bearing capacity of a strip footing shall be determined by (12)

$$q_d = c_{1\,N_c} \qquad (12)$$

N_c may be obtained from(4).

c_1 = Undrained cohesion of the top layer,c_2 = Undrained cohesion of the lower clay layer

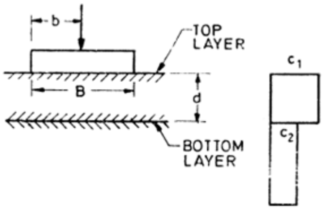


Fig. 4.Footing resting on two layred Cohesive Soil

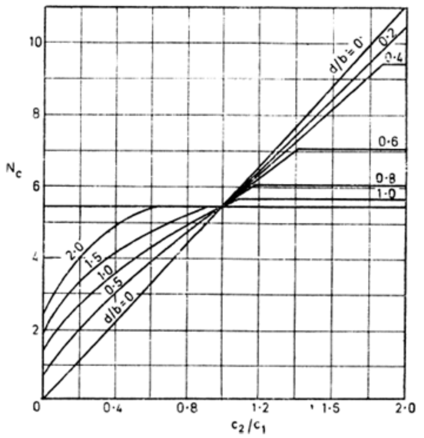


Fig. 5.Bearing capacity factor for two layered cohesive soil deposit[14]

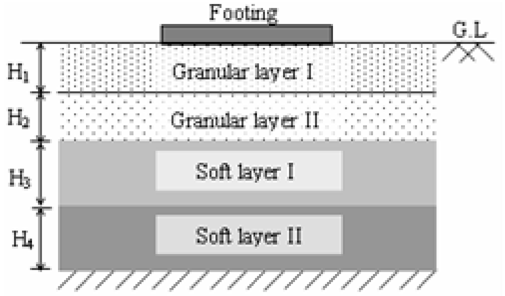


Fig. 6. Footing on multilayer soil deposit [15].

When footing rest on a thin layers of soil, of thickness h_1,h_2,h_3----h_j ,the ultimate bearing capacity of the footing shall be determined by (9) using average value of cohesion, c_{av} and average angle of shearing resistance φ_{av}. The average values are computed over the depth H below the base of the footing [16].

$$H = \sum_{j=1}^{n} h_j = 0.5B \tan\left(\frac{45+\varphi_{av}}{2}\right) \qquad (13)$$

$$c_{av} = \frac{\sum_{j=1}^{n} c_j h_j}{\sum_{j=1}^{n} h_j} \qquad (14)$$

$$\tan\varphi_{av} = \frac{\sum_{j=1}^{n} h_j \tan\varphi_j}{\sum_{j=1}^{n} h_j} \qquad (15)$$

A. Sources of Approximations in classical approach

The Assumptions involved in the derivation and use of the ultimate bearing capacity, q_u may be summarized as follows:

- a) The soil mass is assumed to be purely homogeneous and isotropic, while the soil in nature is extremely heterogeneous and tixotropic, and also the theory is developed only for a planar case, while all footings are 3- dimensional in real behavior.
- b) The ultimate bearing capacity calculations are very sensible to the cohesion 'c' , and 'φ'(shear parameters), are determined in the laboratory, which may not necessarily represent the true conditions prevailing at the site. Values of all soil parameters like internal angle of friction φ ' water content, void ratio, confining pressure, etc are not exactly the same in the soil samples. If values of 'c' & 'φ' obtained from laboratory is high ,the ultimate bearing capacity is higher than actual.
- c) Actually a single value of allowable bearing capacity q_a , is used in practice, to a particular construction site. However, minor variations in sizes, shapes and depths of different foundations at a particular site are observed, and the same q_a value is used in foundation design, through- out the construction site.
- d) The elastic zone has straight boundaries inclined at φ' to the horizontal, and the plastic zone fully develop. Actually when the soil compresses, φ' changes slight downward movement of footing may not develop fully the plastic zones.
- e) The contribution of self-weight can be determined only approximately, by numerical or graphical means, for which no exact formulation is available.
- f) The shear resistance of soil above the base is neglected.

B. Settlement of Shallow Foundation

Settlement is a function of the additional stress imposed on the soil by the foundation. The total settlement S_t of shallow foundation can be expressed as [17]

$$S_t = S_i + S_c + S_s + S_{cr} \qquad (16)$$

where, S_i= immediate or elastic settlement, S_c=primary consolidation settlement, S_s= secondary consolidation settlement, S_{cr}=settlement due to creep. DeBeer and Martens (1957) and DeBeer (1965) proposed the following relationship to estimate the elastic settlement of a foundation[18].

$$S_f = 2.3 \frac{H_i}{C_i} log_{10} \left[\frac{P_{oi}^{-}+\Delta\sigma_{zi}}{P_{oi}^{-}}\right] \qquad (17)$$

$$C = 1.5 \frac{q_{c-i}}{P_{oi}^{-}}$$

where, qc-i= average static cone resistance in ith layer, $\bar{p}_{oi}$=effective overburden pressure at mid height of ith layer, $\Delta\sigma_{zi}$= increase in vertical stress at mid height of ith layer.

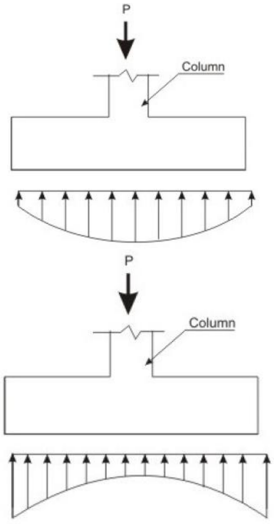
Total settlement of foundation resting on cohesive soils should be [19]

$$s_f = \frac{h_i}{1+e_{oi}} C_{ci} log_{10} \left[\frac{P_{oi}^{-}+\Delta\sigma_{zi}}{P_{oi}^{-}}\right] + pB \frac{(1-\mu^2)}{E} I \qquad (19)$$

Where, C_{ci}=compression index of ith layer, e_{oi}=initial void ratio at mid height of ith layer, $\bar{p}_{oi}$=effective overburden pressure at mid height of ith layer, $\Delta\sigma_{zi}$= increase in vertical stress at mid height of ith layer.

C. Structural Design

Isolated footings are most commonly used footings for R.C.C Columns because of the simplicity and economy. The distribution of base pressure is different for different types of soil. However, for the sake of simplicity the footing is assumed to be a perfectly rigid body, the soil is assumed to behave elastically and the distributions of stress and stain are linear in the soil just below the base of the foundation.



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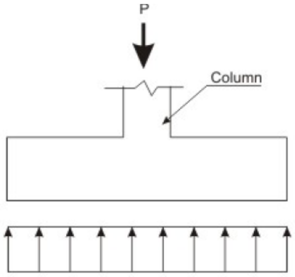
(a) **(b)**



(c)

Fig. 5 Pressure Distribution in soil (a) Pressure distribution in sandy soil (b) Pressure distribution in clayey soil and (c) Assuming uniform pressure in the design

Application of the Software

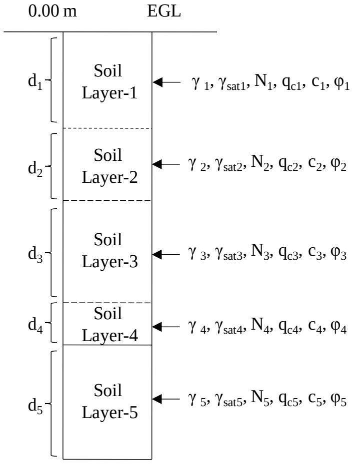


Fig. 6.Bore log details.

The main applications of this software are calculation of allowable bearing capacity (q_a), settlement of footing (S_f), design of R.C.C footing under permissible settlement for different soil profiles with cost of footing. Soil parameters are obtained from bore log details as shown in Fig. 2. Results obtained for various types of soil by this software are summarized in terms of INPUT and OUTPUT files.

Abbreviations: P=Applied load (kN), M_x=Applied moment @ major axis (kN.m), My=Applied moment @ minor axis (kN.m), D_w=Depth of water table (m), γ=Dry density of soil (kN/m^3), γ_{sat}=Saturated density of soil (kN/m^3), φ=Angle of shearing resistance in degree, c=Cohesion of soil (kN/m^2),ID=Density index in percent, N=Standard penetration resistance value, e=Void ratio, q_c=Cone resistance value (kN/m^2), E=Modulus of elasticity in (kN/m^2), C_c=Compression index, m_v=Coefficient of volume compressibility (m^2/kN), L=Length of footing (m), B=Width of footing (m), D_f=Depth of foundation (m), S_f=Settlement of footing (mm) , q_a=Allowable bearing capacity in (kN/m^2), D=Thickness of R.C.C footing (mm), Reinf || to 'L'=Dia. 12 mm bar parallel to length of footing (Nos.), Reinf || to 'B'= Dia. 12 mm bar parallel to width of footing (Nos.)

F. MATLAB

MATLAB, a high-performance language for technical computing is used for programming. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. It is also easy build up set of functions for a particular application. 'Matlab' is used which makes this task easier. Matlab is the powerful mathematical tool widely used in the industry and academics in almost all the streams. The calculation flow control is easy in Matlab

Case-1 Cohesionless soil with general shear failure, column size 300 x 300 mm with f_{ck}=20 N/mm^2,f_y=415 N/mm^2.Table I shows the input data require for the program, and Table II shows the output of the program.

Table I. Case - 1 Input Data

Soil layer	P	M_x	M_y	Depth of soil layer	D_w	γ	γ_{sat}	φ	ID	N
	kN	kN.m	kN.m	m	m	kN/m^3	kN/m^3	degree	%	
1	800	0	0	3.5	2.8	16.1	18.5	33	75	20.00
2				3		-	19.1			23.50
3				3.5		-	19.3			28.50
4				4		-	19.5			29.50
5				4		-	20			35.00

Table II. Case - 1 Output of Program

L/B	L	B	D_f	S_f	q_a	D	Reinf ‖ to ‘L’	Reinf ‖ to ‘B’	Total Cost	Remark
	m	m	m	mm	kN/m^2	mm	Nos.	Nos.	Rs.	
1	1.55	1.55	1.45	33.3	405.60	500	11	11	8895	Recommended size
1.25	1.88	1.50	1.40	28.1	363.99	500	13	10	10634	
1.5	2.10	1.40	1.30	26.9	338.91	525	15	8	11460	
1.75	2.36	1.35	1.25	25.0	326.79	550	17	7	12855	
2	2.70	1.35	1.25	22.2	314.10	600	18	7	15385	

Case-2cohesive soil with, column size 350 x 350 mm with f_{ck}=20 N/mm^2,f_y=415 N/mm^2.Table III shows the input data require for the program, and Table IV shows the output of the program.

Table III. Case - 2 Input Data

Soil layer	P	M_x	M_y	Depth of soil layer	D_w	γ	γ_{sat}	c	e	E	C_c
	kN	kN.m	kN.m	m	m	kN/m^3	kN/m^3	kN/m^2		kN/m^2	
1				5		15.9	17.8		0.67	24000	0.11
2				10		16.2	18.7		0.68	26000	0.11
3	700	0	0	4	1.8	-	19.3	50	0.70	26000	0.12
4				5		-	20.0		0.72	24000	0.12
5				5		-	21.5		0.72	22000	0.13

Table IV. Case - 2 Output of Program

L/B	L	B	D_f	S_f	q_a	D	Reinf ‖ to ‘L’	Reinf ‖ to ‘B’	Total Cost	Remark
	m	m	m	mm	kN/m^2	mm	Nos.	Nos.	Rs.	
1	2.30	2.30	2.20	49.9	166.84	500	17	17	14777	Recommended size
1.25	2.75	2.20	2.10	49.7	150.92	550	17	12	17284	
1.5	3.08	2.05	1.95	50.0	145.75	575	18	10	18399	
1.75	3.33	1.90	1.80	49.5	141.34	600	19	9	19052	
2	3.60	1.80	1.70	49.4	138.24	625	20	8	20143	

Case-3 Cohesionless soil,column size 230 x 450 mm with f_{ck}=20 N/mm^2,f_y=415 N/mm^2.Table V shows the inputs data require for the program, and Table VI shows the output of the program.

Table V. Case - 3 Input Data

Soil layer	P	M_x,	M_y	Depth of soil layer	D_w	φ	γ	ID	γ_{sat}	N
	kN	kN.m	kN.m	m	m	degree	kN/m^3	%	kN/m^3	
1				3.0			15.2	18	-	10
2				4.0		27	-		17.9	13
3	900	100	0	3.5	3.6		-		18.1	15.2
4				2.0			-		18.4	16.35
5				5.0			-		18.6	18.23

Table VI. Case - 3 Output of Program

L/B	L	B	D_f	S_f	q_a	D	Reinf ‖ to ‘L’	Reinf ‖ to ‘B’	Total Cost	Remark
	m	m	m	mm	kN/m^2	mm	Nos.	Nos.	Rs.	
1	3.00	3.00	2.90	42.4	151.92	400	37	39	43554	Recommended size
1.25	3.56	2.85	2.75	36.5	139.06	450	39	31	51867	
1.5	3.97	2.65	2.55	32.8	129.30	500	38	25	57341	
1.75	4.46	2.55	2.45	29.4	124.44	500	39	27	67228	
2	4.90	2.45	2.35	27.0	119.74	575	41	30	72871	

Case-4 Multilayer soil profile, column size 380 x 380 mm with f_{ck}=20 N/mm^2,f_y=415 N/mm^2.Table VII shows the inputs data require for the program, and Table VIII shows the output of the program.

Table VII Case - 4 Input Data

Soil layer	P kN	M_x kN.m	M_y kN.m	Depth of soil layer m	D_w m	γ kN/m^3	γ_{sat} kN/m^3	φ degree	c kN/m^2	e	E kN/m^2	C_c	m_v m^2/kN	q_c kN/m^2
1	800	0	0	2.98	4.2	16.5	-	30	0	-	-	-	-	8000
2				5.00		16.8	19.2	0	60	0.68	26000	0.12	-	-
\3				3.00		-	19.5	31	25	0.62	28000	-	3x10^{-4}	-
4				3.00		-	19.8	32	0	-	-	-	-	10000
5				2.50		-	20.1	28	0	-	-	-	-	11000

Table VIII. Case - 4 Output of Program

L/B	L m	B m	D_f mm	S_f mm	q_a kN/m^2	D mm	Reinf || to 'L' Nos.	Reinf || to 'B' Nos.	Total Cost Rs.	Remark
1	3.65	3.65	3.55	49.5	327.11	650	24	24	40585	Recommended size
1.25	4.19	3.35	3.25	49.9	286.44	700	24	18	44134	
1.5	4.80	3.20	3.10	49.3	268.39	750	26	15	50007	
1.75	5.16	2.95	2.85	49.8	259.62	775	28	30	51058	
2	5.60	2.80	2.70	49.7	240.65	800	30	12	54089	

Case-5 Cohesionless soil profile, column size 230 x 450 mm with f_{ck}=20 N/mm^2,f_y=415 N/mm^2.Table IX shows the inputs data require for the program, and Table X shows the output of the program.

Table IX Case - IX Input Data

Soil layer	P kN	M_x kN.m	M_y kN.m	Depth of soil layer m	D_w m	γ kN/m^3	γ_{sat} kN/m^3	φ degree	q_c kN/m^2	ID %
1	600	60	40	4	3	16.2	18.5	32	8000	50
2				4.5		-	19		9500	
3				3		-	19.4		10500	
4				2.5		-	19.8		11000	
5				5		-	20.1		13000	

Table X. Case - 4 Output of Program

L/B	L m	B m	D_f mm	S_f mm	q_a kN/m^2	D mm	Reinf || to 'L' Nos.	Reinf || to 'B' Nos.	Total Cost Rs.	Remark
1	2.28	2.28	2.05	6.7	264.90	375	16	21	21320	Recommended
1.25	2.85	2.28	2.05	7.4	248.25	400	20	18	27773	
1.5	3.42	2.28	2.05	7.9	249.48	450	22	17	36669	
1.75	4.00	2.28	2.05	8.3	250.35	475	25	21	45459	
2	4.57	2.28	2.05	8.5	251.01	500	27	25	54784	

Conclusion

From study on all types of soil profiles and soil parameters, different load conditions the following conclusions are drawn:

1. Principal factors that influence the bearing capacities are type and strength of soil, foundation width and depth, soil weight in the shear zone.
2. Net safe Bearing capacity decreases with increase in length to width ratio.
3. Bearing capacity of cohesive soil is proportional to soil cohesion 'c' if the effective friction angle 'φ' is zero.
4. For soil whose properties do not change with stress level, settlement is proportional to foundation width.
5. The total settlement of foundations on granular soils is small as compared to cohesive soil.
6. The settlement is generally influenced by loading intensity on the foundation, size and shape of footing, depth of embedment, in situ state of stress and relative density.

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