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Determination of Size of Footings

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Introduction

The bearing capacity or allowable pressure of soil depends on the shape and size of footing as well as the soil properties. There are different methods to determine the bearing capacity from the soil properties. Knowing the values of cohesion and angle of internal friction of soil, bearing capacity can be determined. The equation for bearing capacity includes, in addition, various shape factors and depth factors. Hence for the given load and soil properties, the width of foundation has to be determined only by trial and error procedure. In the present study, this is achieved using computer programmes and design charts are provided to make the computation easy. The method to calculate the required width from settlement criterion is also discussed.

Literature Survey

Analyses of bearing capacity have been made by various investigators assuming the soil to behave like an ideally plastic material. The significant among them are Terzaghi (1943), Meyerhof (1953), Hansen (1970) and Vesic (1973) to name a few.

According to Terzaghi, ultimate bearing capacity in case of general shear failure is,

$$Q_u = CN_c + q\,(N_q - 1) + 0.5B\gamma\,N_\gamma \qquad (1)$$

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and in case of local shear failure,

$$Q'u = \frac{2}{3} CN_c' q(N_q' - 1) + 0.5B\gamma \; N'_\gamma \tag{2}$$

The values of N_c, N_q and N_γ are calculated using Vesic's equations,

$$N_q = e^{\pi \tan\phi} \tan^2 (45 + \phi/2) \tag{3}$$

$$N_c = (N_q - 1) \cot\phi \tag{4}$$

$$N_\gamma = 2(N_q + 1) \tan\phi \tag{5}$$

N'_c' N'_q and $N'\gamma$ are the factors using the modified values of c and ϕ as suggested by Terzaghi.

The ultimate bearing capacity obtained from the above equation is to be modified to take into account the shape of footing, depth of footing, inclination of load and effect of water table. Hence in the case of general shear failure,

$$Q_u = CN_c \, S_c \, d_c \, i_c + qN_q \, S_q \, d_q \, i_q + 0.5 \, B\gamma \, N_\gamma \, S_\gamma \, d_\gamma \, i_\gamma \, w' \tag{6}$$

Shape Factors (IS 6403-1981)

	S_c	S_q	S_γ
(*i*) Continuous strip	1.0	1.0	1.0
(*ii*) Rectangle	$1 + \frac{0.2B}{L}$	$1 + \frac{0.2B}{L}$	$1 - \frac{0.4B}{L}$
(*iii*) Square	1.3	1.2	0.8
(*iv*) Circle	1.3	1.2	0.6

Depth Factors (Meyerhof, 1953)

$$d_c = 1 + \frac{0.2 D_f}{B} \tan (45 + \phi/2) \tag{7}$$

For $\phi < 10°$,

$$d_q = d_\gamma = 1 \tag{8}$$

For $\phi > 10°$,

$$d_q = d_\gamma = 1 + \frac{0.1 D_f}{B} \tan (45 + \phi/2) \tag{9}$$

Inclination Factors (Meyerhof, 1953)

The inclination factors shall be,

$$I_c = i_q = (1 - \alpha/90)^2 \tag{10}$$

$$i_\gamma = (1-\alpha/\phi)^2 \tag{11}$$

where α is the inclination of the load with vertical.

Effect of Water Table

If the water table remains at/or below the depth of $(D_f + B)$, $w' = 1$. If it is located at a depth of D_f or above, $w' = 0.5$. When the water table is in between the above two, w' can be obtained by interpolation.

It is assumed in this study that load is acting vertically and depth of water table is far below the footing level.

Safe Bearing Capacity

The ultimate bearing capacity obtained has to be divided by a suitable factor of safety to obtain the safe bearing capacity. In this investigation a factor of safety of 3.0 has been used throughout.

Pressure Distribution Beneath Foundation

The contact pressure depends on the rigidity of the footing and the type of soil (Faber 1933, Skopek 1961). If the footing is flexible, the distribution of contact pressure is uniform irrespective of the type of soil. If it is rigid, the distribution depends on the type of foundation soil. Since the footings are neither completely flexible nor rigid, the actual contact pressure distribution is intermediate between that due to rigid and flexible conditions. However, for practical purposes, usually it is assumed to be uniform. In the present analysis also, it is assumed to be uniform.

Settlement of Foundations

The vertical displacement due to the loads is necessary to evaluate the stability of the foundation. Settlement of the foundation consists of generally three parts (Bowles, 1988).

(*i*) Immediate settlement

(*ii*) Consolidation settlement and

(*iii*) Settlement due to secondary compression.

Settlement due to consolidation alone is considered in the present study.

Computation of Settlement

The consolidation settlement can be calculated using the coefficient of volume compressibility (m_v), which is the change in volume per unit volume per unit increase of pressure.

$$\Delta H = m_v \, \sigma_v H \tag{12}$$

ΔH — consolidation settlement

m_v — average coefficient of volume compressibility for the effective pressure increment in the particular layer under consideration

σ_z — average effective vertical stress imposed by the foundation load.

H — thickness of the compressible layer under consideration.

Vertical Stress Distribution

Determination of the distribution of stresses within the relevant zone is necessary to predict the settlements. Boussinesq derived an equation to find out the stress increase at a depth 'Z' due to the load 'Q'. Westergaard considered the case of non-isotropic soils (Tomlinson, 1986). Newmark (1935) integrated Boussinesq's equation and derived an expression to find out the stress under the corner of a uniformly loaded rectangular area.

$$\sigma_z = \frac{q_1}{4\pi}\left[\frac{2mn(m^2+n^2+1)^{1/2}}{m^2+n^2+m^2n^2+1}\;\frac{(m^2+n^2+2)}{(m^2+n^2+1)} + \tan^{-1}\frac{2mn\,(m^2+n^2+1)^{1/2}}{m^2+n^2-m^2\,n^2+1}\right] \tag{13}$$

where, $m = a1/Z$, $n = b1/Z$

'$a1$' and '$b1$' are the sides of the rectangle.

Bearing Capacity Criterion

The soil must be capable of carrying loads without shear failure. The evaluation of the limiting shear resistance or ultimate bearing capacity forms the main part of computation. Based on trial and error procedure, the dimension of the footings for various loading and soil conditions have been arrived in such a way that the resulting pressure on the soil due to the foundation is equal to the safe bearing capacity of the soil.

A computer programme was developed and used to obtain the dimensions of the footing required for various combinations of axial load (Q), cohesion (c) and angle of internal friction (ϕ) for a depth of foundation D_f of $1m$, factor of safety of 3 and unit weight of soil (γ) of $1.9t/m^3$. For changes in D_f and factor of safety, suitable multiplication factors are presented. The change in dimensions due to the change in unit weight of soil normally met in practice is found to be insignificant as shown in Table 1 and hence neglected. For example, when $c = 2.5t/\text{m}^2$, $\phi = 5°$, $L/B = 1$ and $Q = 40t$, the value of B is $2.40m$ for a value of $\gamma = 1.6t/m^3$, it is $2.39m$ for value of $\gamma = 1.8t/m^3$ and the value is $2.38m$ when $\gamma = 2.0t/m^3$. When Q is $200t$ the value of B remains same i.e., $5.3m$ for all these values of γ.

TABLE 1

Variation of Width with Unit Weight of Soil

c (t/m^2)	ϕ (o)	Q (t)	L/B	γ (t/m^3)	B (m)
2.50	5.00	40.00	1.00	1.60	2.40
2.50	5.00	40.00	1.00	1.80	2.39
2.50	5.00	40.00	1.00	2.00	2.38
2.50	5.00	40.00	2.00	1.60	1.83
2.50	5.00	40.00	2.00	1.80	1.82
2.50	5.00	40.00	2.00	2.00	1.81
2.50	5.00	40.00	3.00	1.60	1.51
2.50	5.00	40.00	3.00	1.80	1.50
2.50	5.00	40.00	3.00	2.00	1.49
2.50	5.00	200.00	1.00	1.60	5.30
2.50	5.00	200.00	1.00	1.80	5.30
2.50	5.00	200.00	1.00	2.00	5.30
2.50	5.00	200.00	2.00	1.60	4.15
2.50	5.00	200.00	2.00	1.80	4.12
2.50	5.00	200.00	2.00	2.00	4.10
2.50	5.00	200.00	3.00	1.60	3.44
2.50	5.00	200.00	3.00	1.80	3.42
2.50	5.00	200.00	3.00	2.00	3.39
2.50	30.00	40.00	1.00	1.60	0.84
2.50	30.00	40.00	1.00	1.80	0.82
2.50	30.00	40.00	1.00	2.00	0.81
2.50	30.00	200.00	2.00	1.60	1.45
2.50	30.00	200.00	2.00	1.80	1.42
2.50	30.00	200.00	2.00	2.00	1.39
2.50	30.00	200.00	3.00	1.60	1.19
2.50	30.00	200.00	3.00	1.80	1.17
2.50	30.00	200.00	3.00	2.00	1.14
10.00	5.00	40.00	1.00	1.60	1.16
10.00	5.00	40.00	1.00	1.80	1.16
10.00	5.00	40.00	1.00	2.00	1.16
10.00	5.00	40.00	2.00	1.60	0.87
10.00	5.00	40.00	2.00	1.80	0.87
10.00	5.00	40.00	2.00	2.00	0.87
10.00	5.00	40.00	3.00	1.60	0.70
10.00	5.00	40.00	3.00	1.80	0.70

(Contd.)

TABLE 1 (*Contd.*)

10.00	5.00	40.00	3.00	2.00	0.70
10.00	5.00	200.00	1.00	1.60	2.70
10.00	5.00	200.00	1.00	1.80	2.70
10.00	5.00	200.00	1.00	2.00	2.70
10.00	5.00	200.00	2.00	1.60	2.06
10.00	5.00	200.00	2.00	1.80	2.06
10.00	5.00	200.00	2.00	2.00	2.06
10.00	5.00	200.00	3.00	1.60	1.69
10.00	5.00	200.00	3.00	1.80	1.69
10.00	5.00	200.00	3.00	2.00	1.69

Design Parameters

The range of values assumed in the present study for various parameters cover the possible ranges met in practice and are as follows.

Cohesion $2.5t/m^2$ to $20t/m^2$; angle of internal friction 5° to 30° and axial load for each column $40t$ to $200t$. Charts are prepared for total column loads upto $800t$. In the present study L/B values upto 15 have been considered to cover isolated footings, two column-combined footings and strip footings.

Procedure

In brief, the procedure for computation of B is as follows. Assuming the values for B and L/B, the ultimate bearing capacity can be calculated using equation 6 for given values of c and ϕ. The actual pressure on the soil due to the footing is computed for the given axial loads and the assumed dimensions of the footing. If the safe bearing capacity does not equal the actual pressure on the soil, the procedure is repeated with modified value of B (trial and adjustment), till the computed safe bearing-apacity is equal to the actual pressure.

Discussion of Results

Figure 1 presents the variation of B with respect to ϕ and c for different axial loads when L/B is unity. As expected, the value of B (since it is a case of $L/B = 1$) increases with increasing column loads. It decreases with increase in ϕ and c. For a given value of c, say, for, $c = 10t/m^2$ the reduction in B with increase in ϕ for a given load is seen to be nearly linear. But for a given value of ϕ, say, for, $\phi = 15°$, the reduction in B with c for a given load is nonlinear and pronounced over lower values of c. For example, in Fig. 1*b*, for a load of $50t$, the width required is about 1.95/metres when

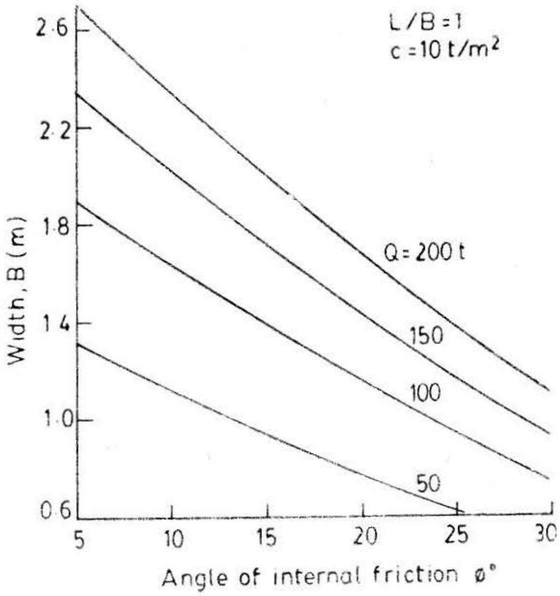

FIGURE 1a Variation of B With ϕ for Different Values of Q.

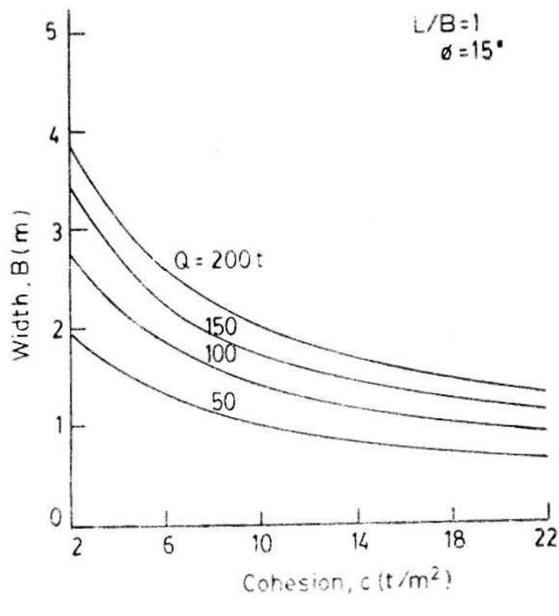

FIGURE 1b Variation of B With c for Different Values of Q.

$c = 2t/m^2$; it is about 1.3 metres when $c = 6t/m^2$ and 1.00 metre when $c = 10t/m^2$. The reductions in width requirements are 33% and 23% for the same increase in c, namely, $4t/m^2$. The extent of reduction further decreases when the value of c is higher. The reduction in B directly represents a reduction in cost. It can be seen that for a given increase of c, the decrease in width required is more pronounced at lower values of ϕ, especially at higher loads. For example for a Q of $180t$, if c increases from $2.5t/m^2$ to $5t/m^2$ (Fig. 2), B required decreases from 5.00 m to 3.6 m when $\phi = 5°$; when $\phi = 30°$, the respective B values are 1.74 m and 1.40m.

Hence it can be stated that more care should be exercised in evaluating the values of c and ϕ in their lower ranges since they significantly affect the cost.

Figures 2 to 9 report the widths required for different axial loads for a wide combination of c and ϕ assuming L/B as unity. They exhibit the expected trend namely, decrease in B with increase in ϕ and/or c. All these values are computed keeping D_f as one metre and factor of safety as 3 with the unit weight of soil being $1.9t/m^3$.

Since the B values are for L/B = 1m $D_f = 1m$, $\gamma = 1.9t/m^3$ and $FS = 3$, they need to be modified when these parameters differ. Table 2 gives the multiplication factors to be applied to modify the B values for different values of depth of foundation for different combinations of c, ϕ and Q. Tables 3, 4, 5 and 6 report the multiplication factors for different L/B ratios

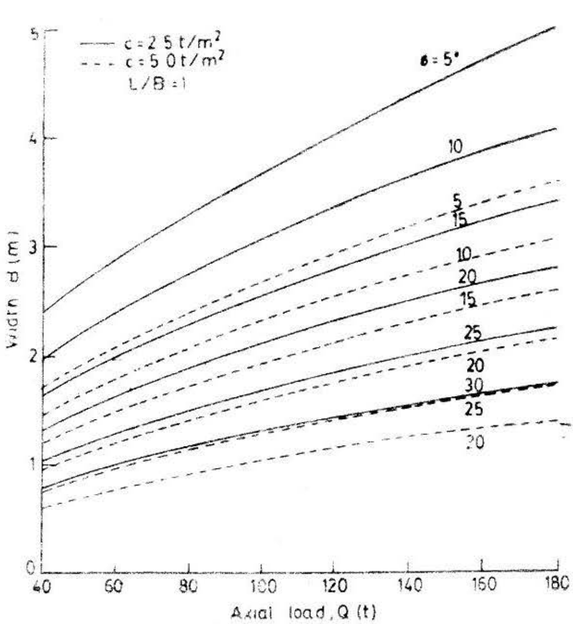

FIGURE 2 Variation of B With Q for Different Values of ϕ.

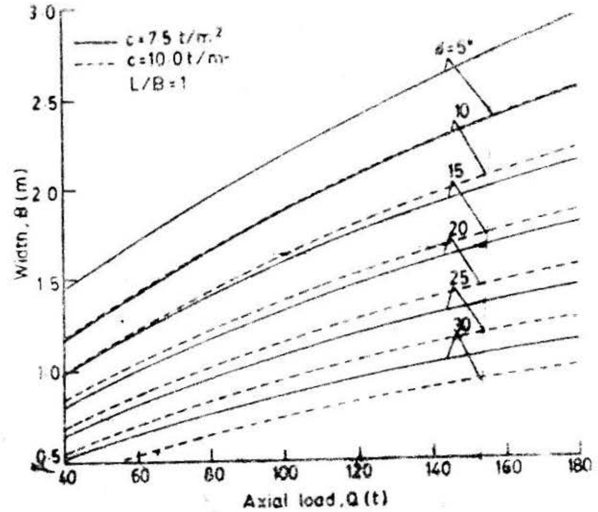

FIGURE 3 Variation of B With Q for Different Values of ϕ.

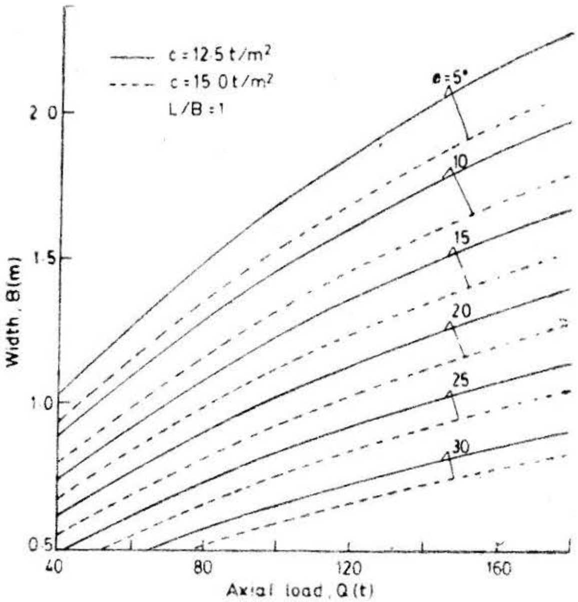

FIGURE 4 Variation of B With Q for Different Values of ϕ

and factors of safety for different combinations of D_f. Figures 10 to 13 present these factors in the graphical form. The widths B obtained earlier (for $L/B = 1$, $D_f = 1$ and factor of safety $= 3$) are to be multiplied by these multiplication factors whenever the L/B value is more than one, or D_f is more than one metre, and/or the factor of safety is other than 3. It can be

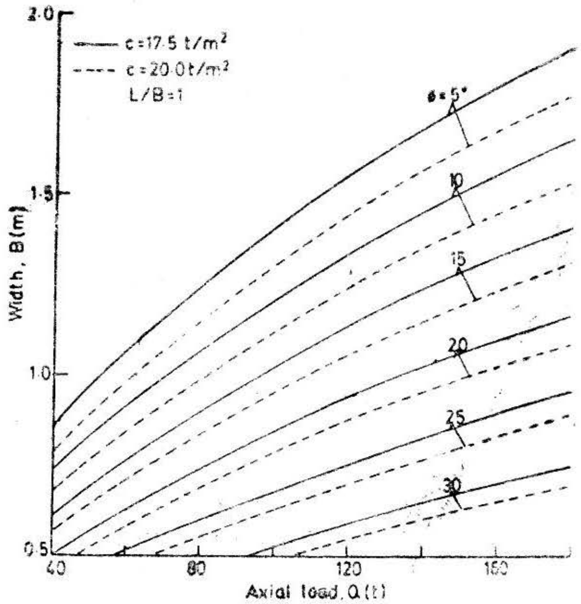

FIGURE 5 Variation of B with Q for Different Values of ϕ.

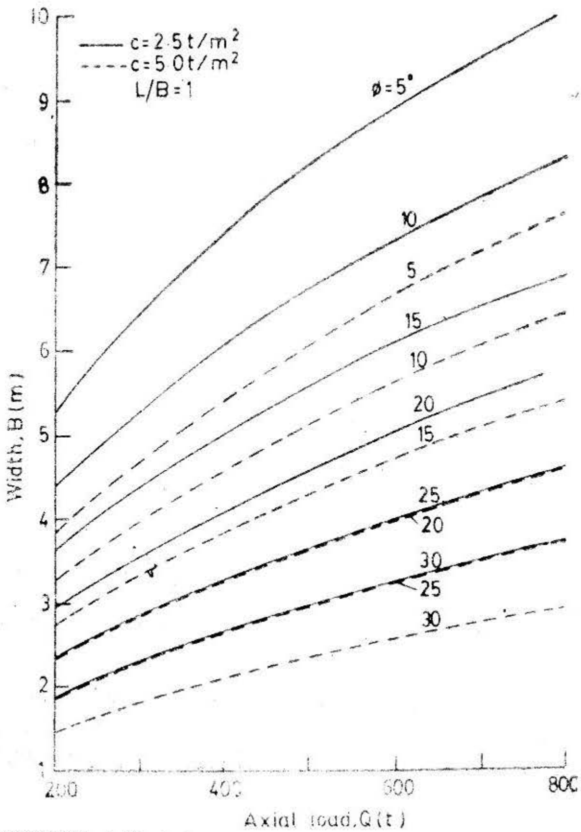

FIGURE 6 Variation of B with Q for Different Values of ϕ.

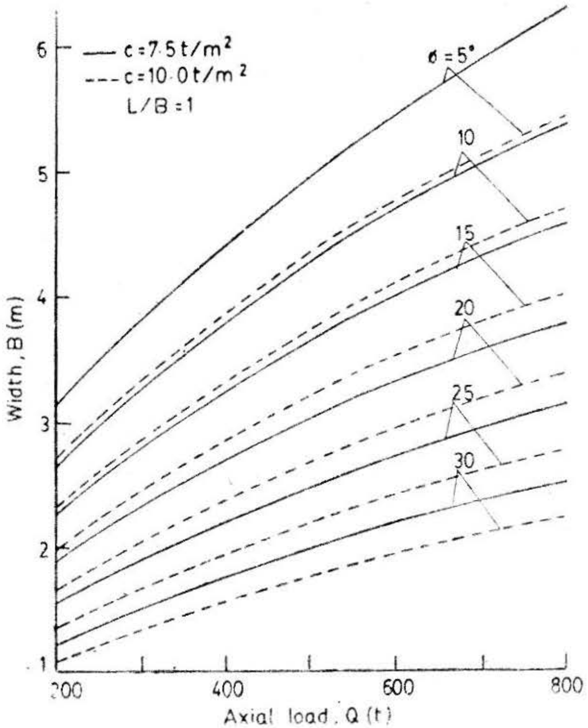

FIGURE 7 Variation of B with Q for Different Values of ϕ

seen from figures 10 and 11 that the multiplication factors decrease with increase of D_f and the decrease is more significant for lower values of axial loads. For example in Fig. 10 when $c = 2.5t/m^2$, $L/B = 1$, $D_f = 3m$ and $\phi = 30°$ the reduction in multiplication factor is about 40% for a value of $Q = 40t$ and is only 20% when the value of Q is $800t$. Multiplication factor reduces with L/B also. Figs. 12 and 13 show the variation of multiplication factor with L/B for different values of FS. The reduction is nonlinear and more pronounced for L/B values between 1 and 5 and beyond that the reduction is less and linear. For example in Fig. 12 when $D_f = 1m$ for all values of FS, the multiplication factor reduces by about 50% as L/B increases from 1 to 5 and the same is about 70% when L/B increases from 1 to 15.

As discussed earlier, it was found that the effect of variation of unit weight, within ranges normally encountered in practice, upon B is insignificant. Hence no multiplication factors are suggested with respect to variations in unit weight.

Multiplication factors are given for total loads of $40t$, $200t$, $400t$ and $800t$; c values $2.5t/m^2$ and $20t/m^2$; ϕ values 5° and 30°; L/B values from 1 to 15; D_f values from 1 to $4m$ and FS from 1 to 4. For intermediate values, the

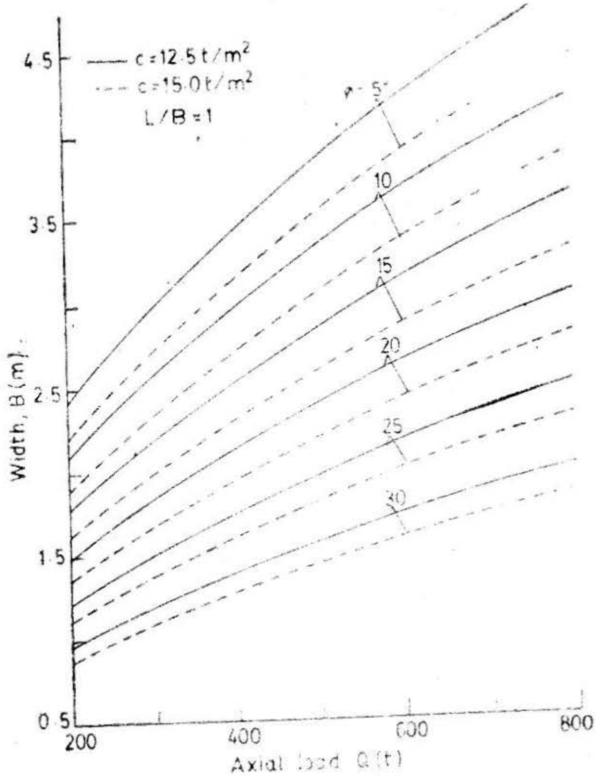

FIGURE 8 Variation of B with Q for Different Values of ϕ.

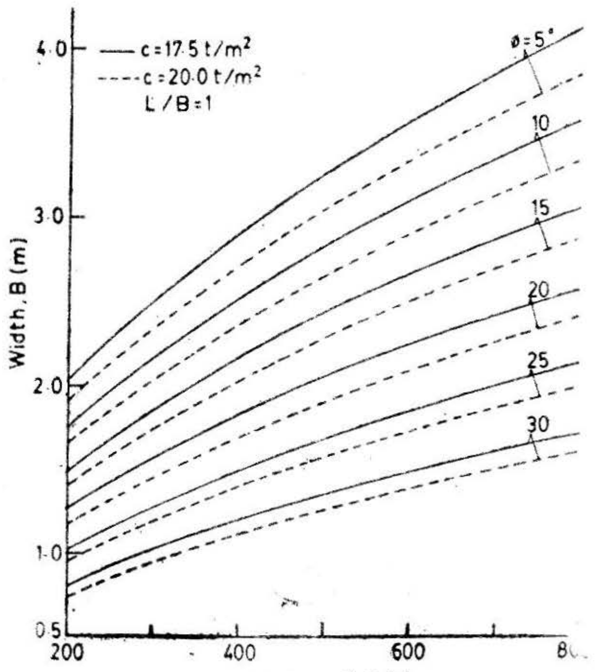

FIGURE 9 Variation of B with Q for Different Values of ϕ.

TABLE 2

Multiplication Factors for Different Values of D_f

c t/m²	φ (o)	Q = 40t, D_f in metres 1	2	3	4	Q = 200t, D_f in meters 1	2	3	4	Q = 400t, D_f in metres 1	2	3	4	Q = 800t, D_f in metres 1	2	3	4
2.5	5	1.0	0.93	0.88	0.82	1.0	0.96	0.92	0.89	1.0	0.99	0.95	0.92	1.0	0.98	0.95	0.92
	15	1.0	0.87	0.77	0.68	1.0	0.91	0.84	0.77	1.0	0.93	0.86	0.80	1.0	0.94	0.88	0.83
	30	1.0	0.77	—	—	1.0	0.85	0.72	0.62	1.0	0.87	0.76	0.67	1.0	0.89	0.80	0.72
10.0	5	1.0	0.91	0.83	0.77	1.0	0.96	0.92	0.88	1.0	0.97	0.93	0.90	1.0	0.97	0.95	0.93
	15	1.0	0.86	0.74	0.64	1.0	0.92	0.85	0.79	1.0	0.94	0.88	0.83	1.0	0.95	0.91	0.86
	30	—	—	—	—	1.0	0.84	0.71	0.61	1.0	0.88	0.77	0.68	1.0	0.90	0.81	0.74
20.0	5	1.0	0.88	0.78	0.70	1.0	0.94	0.89	0.84	1.0	0.96	0.92	0.89	1.0	0.97	0.94	0.91
	15					1.0	0.91	0.83	0.75	1.0	0.93	0.87	0.81	1.0	0.95	0.90	0.85
	30					1.0	0.82	0.67	—	1.0	0.86	0.74	0.64	1.0	0.89	0.80	0.71

TABLE 3

Multiplication Factors for Different Values of FS for L/B from 1 to 15 and $D_f = 1M$

L/B	Multiplication Factors			
	Factor of Safety			
	1	2	3	4
1	0.58	0.82	1.00	1.15
2	0.44	0.63	0.77	0.88
3	0.37	0.52	0.64	0.75
4	0.32	0.46	0.56	0.65
5	0.29	0.41	0.51	0.58
6	0.26	0.38	0.47	0.54
7	0.24	0.35	0.43	0.49
8	0.23	0.33	0.41	0.47
9	0.22	0.31	0.38	0.45
10	0.20	0.29	0.37	0.43
11	0.20	0.28	0.35	0.39
12	0.19	0.27	0.33	0.38
13	0.18	0.26	0.32	0.37
14	0.17	0.25	0.31	0.36
15	0.17	0.24	0.30	0.35

multiplication factors can be obtained by linear interpolation without loss of accuracy.

Settlement Criterion

Even if the foundation is safe from bearing capacity considerations, it should not undergo settlements in excess of the stipulated values during its life time.

The dimensions of footings are estimated in such a way that actual pressure on soil due to the foundation is less than or equal to the allowable pressure calculated based on the permissible settlement.

TABLE 4

Multiplication Factors for Different Values of FS for L/B from 1 to 15 and D_f=2M

	Multiplication Factors			
	Factor of Safety			
L/B	1	2	3	4
1	0.56	0.79	0.97	1.09
2	0.42	0.61	0.75	0.86
3	0.35	0.50	0.62	0.72
4	0.30	0.44	0.54	0.63
5	0.27	0.39	0.49	0.56
6	0.25	0.36	0.44	0.52
7	0.23	0.33	0.41	0.47
8	0.21	0.31	0.39	0.45
9	0.20	0.29	0.37	0.43
10	0.19	0.28	0.35	0.40
11	0.18	0.26	0.33	0.37
12	0.17	0.25	0.32	0.37
13	0.17	0.24	0.30	0.36
14	0.16	0.23	0.29	0.34
15	0.15	0.23	0.28	0.33

Equation 13 is used to calculate the stress increase due to foundation load and equation 12 is used to estimate the settlement. The value of permissible settlement is taken as 75mm for raft foundation and 50mm for other types of shallow foundations.

Procedure

The computational procedure can be summarised as follows. The compressible medium is divided into layers of 0.5m thickness and the total settlement is taken as the algebraic sum of the settlements of individual layers. If the settlement so computed does not agree with the permissible value, the assumed B is modified and the entire procedure is repeated till the calculated settlement agrees with the stipulated permissible settlement.

TABLE 5

Multiplication Factors for Different Values of FS for L/B from 1 to 15 and D_f = 3M

	Multiplication Factors			
	Factor of Safety			
L/B	1	2	3	4
1	0.54	0.76	0.94	1.07
2	0.41	0.58	0.72	0.84
3	0.33	0.48	0.60	0.67
4	0.29	0.42	0.52	0.61
5	0.26	0.37	0.47	0.54
6	0.23	0.34	0.43	0.50
7	0.22	0.32	0.39	0.46
8	0.20	0.30	0.37	0.43
9	0.19	0.28	0.35	0.41
10	0.18	0.26	0.33	0.37
11	0.17	0.25	0.31	0.36
12	0.16	0.24	0.30	0.35
13	0.15	0.23	0.29	0.34
14	0.15	0.22	0.28	0.33
15	0.14	0.21	0.27	0.31

Discussion of Results

Figure 14 gives the width required for different combinations of m_v and axial loads for permissible settlement values of 50mm as well as 75mm. These values are for L/B ratio = 1.As expected B can be seen to increase with Q and m_v. Since the plots in figure 14 are linear, it is possible to suggest the following relations.

(*i*) m_v and permissible settlement remaining the same,

$$\frac{Q_1}{Q_2} = \frac{B1}{B2} \tag{17}$$

B1 — width of foundation corresponding to an axial load Q1

TABLE 6

Multiplication Factors for Different Values of FS for L/B from 1 to 15 and D_f = 4M

L/B	Multiplication Factors			
	Factor of Safety			
	1	2	3	4
1	0.52	0.74	0.89	1.05
2	0.39	0.56	0.70	0.81
3	0.32	0.46	0.57	0.66
4	0.27	0.40	0.50	0.56
5	0.24	0.36	0.45	0.52
6	0.22	0.33	0.41	0.46
7	0.20	0.30	0.38	0.44
8	0.19	0.28	0.35	0.41
9	0.18	0.26	0.33	0.39
10	0.17	0.25	0.31	0.36
11	0.16	0.24	0.30	0.35
12	0.15	0.23	0.29	0.34
13	0.14	0.22	0.27	0.32
14	0.14	0.21	0.26	0.31
15	0.13	0.20	0.25	0.30

B2 — width of foundation corresponding to an axial load Q2

(*ii*) Axial load and permissible settlement remaining the same,

$$\frac{m_{v1}}{m_{v2}} = \frac{B1}{B2} \qquad (18)$$

B1 — width of foundation corresponding to the coefficient of volume compressibility of m_{v1}.

B2 — width of foundation corresponding tot he coefficient of volume compressibility of m_{v2}.

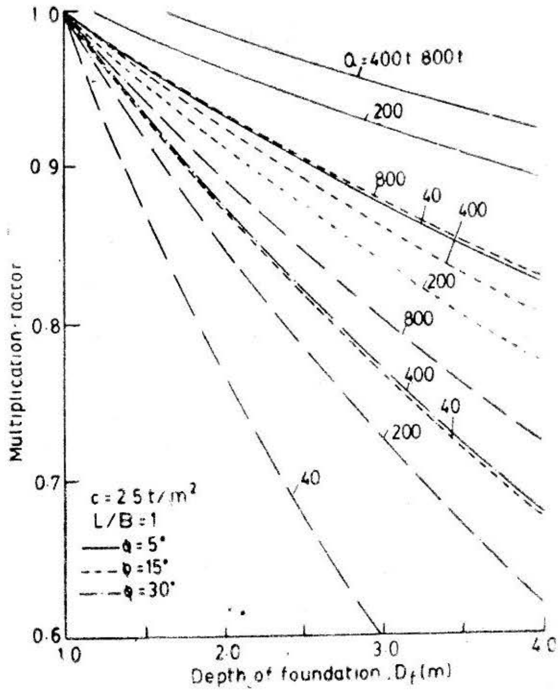

FIGURE 10 Multiplication Factors for Different Values of ϕ and D_f.

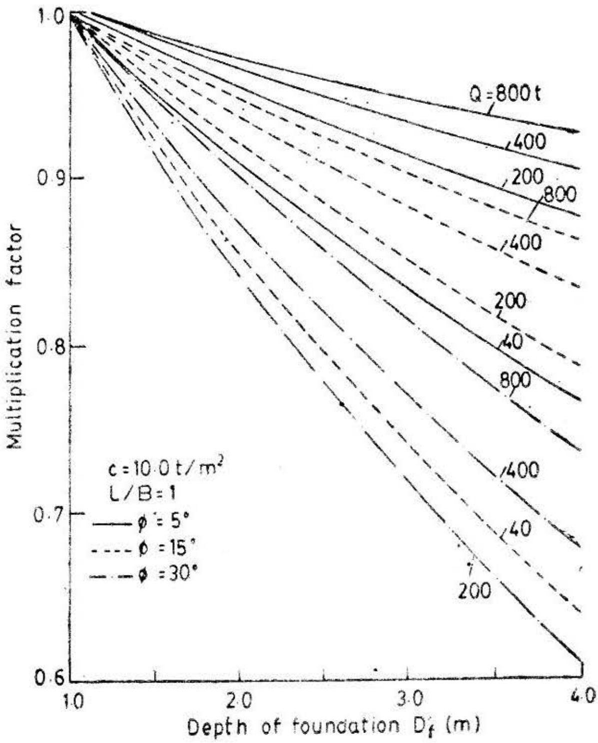

FIGURE 11 Multiplication Factors for Different Values of ϕ and D_f

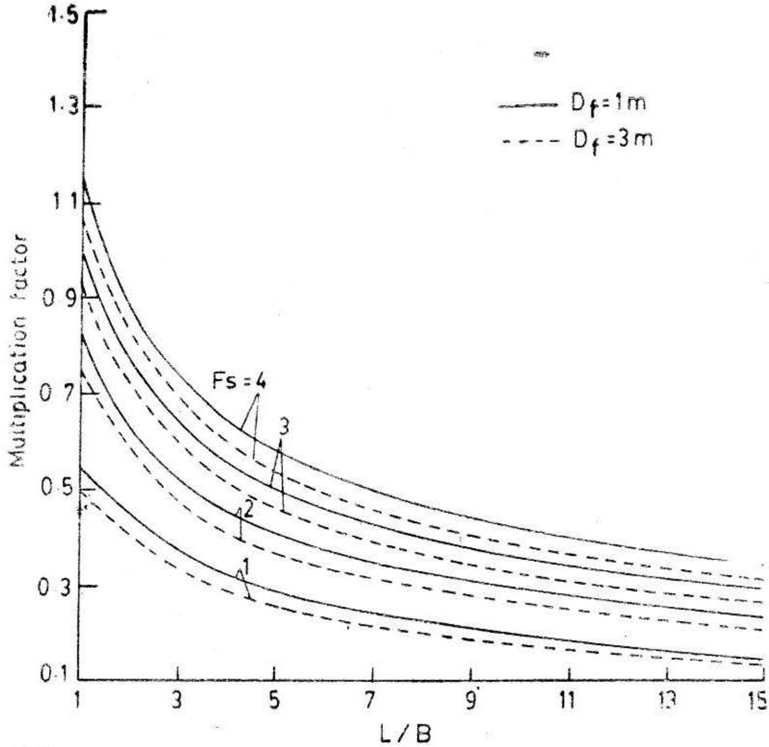

FIGURE 12 Multiplication F ctors for Different Values of FS and L/B

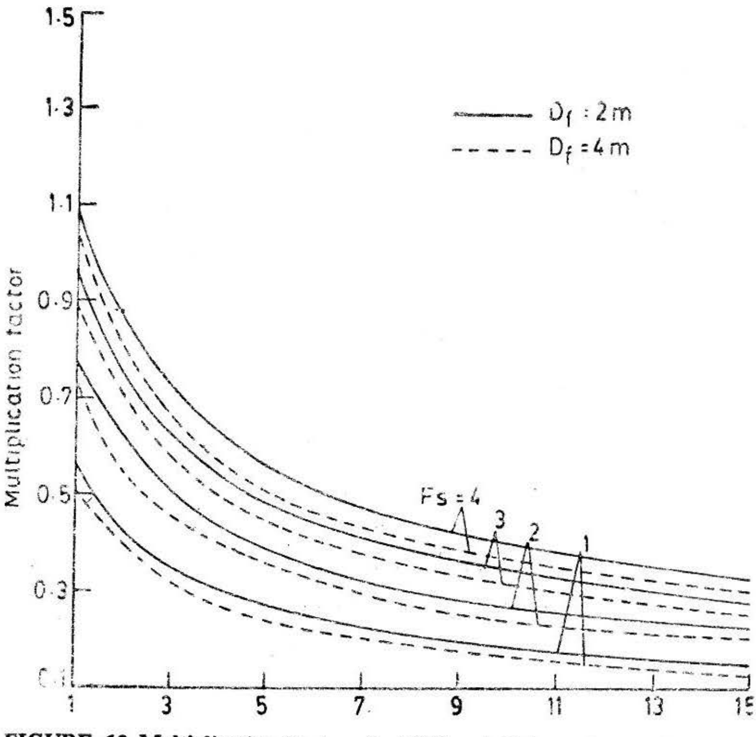

FIGURE 13 Multiplication Factors for Different Values of FS and L/B

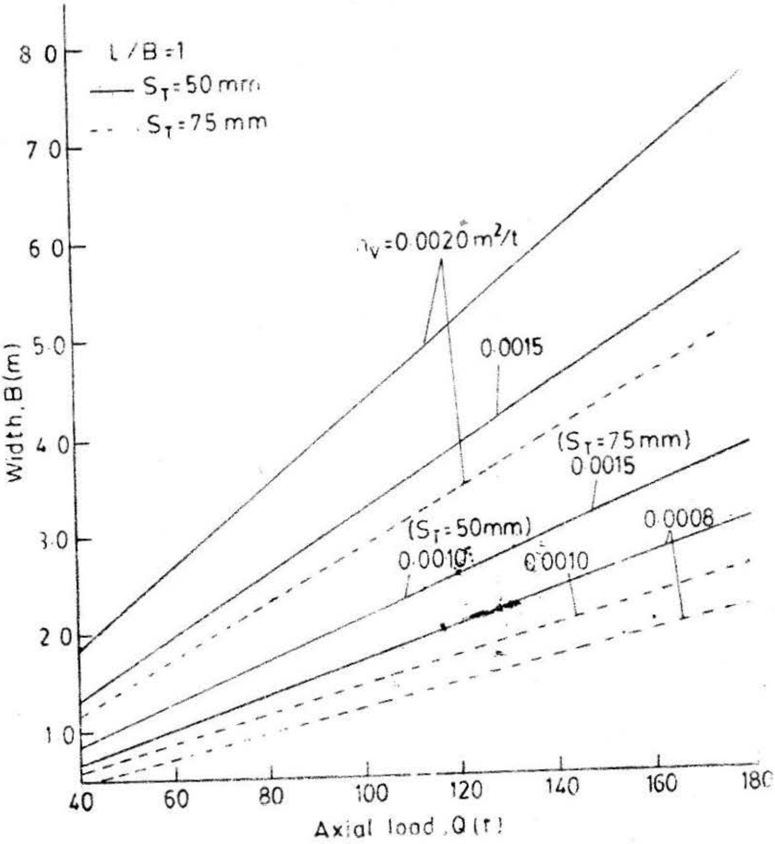

FIGURE 14 Variation of B with Q for Different Values of m_v.

The width of foundation obtained as described above should be compared with that obtained from bearing capacity criteria and the higher value is to be adopted. The variation of B can be expressed as,

$$B = f(Q, m_v, S_T)$$

Based on the figures, it is possible to suggest an equation of the form,

$$B = \frac{1.085\ Qm_v}{S_T} \text{ for square footings} \tag{19}$$

where, B — width of footing

Q — total axial load

m_v — coefficient of volume compressibility

and S_T — permissible total settlement

TABLE 7

Multiplication Factors when Settlement Governs

L/B	Multiplication factors to be applied to the value of "B"
1	1
2	0.63
3	0.47
4	0.36
5	0.29
6	0.25
7	0.21
9	0.17
11	0.14
13	0.12
15	0.10

Since the plots give B for L/B = 1, it is necessary to apply multiplication factors when L/B is other than unity. These factors have been reported in Table 7.

Illustrative Example

To calculate the width of foundation under the following conditions,

$c = 2.5 t/m^2$, $\phi = 5°$, $Q = 100t$, $m_v = 0.0008 m^2/t$, $D_f = 1.5$m,

$S_T = 65$mm, $FS = 2.5$ and $L/B = 2$.

(*i*) From Fig. 2 for $c = 2.5$t/m², $\phi = 5°$ and $Q = 100$t, width = 3.70m.

(*ii*) From Fig. 10, multiplication factor for $D_f = 1.5$m, $c = 2.5$t/m² and $\phi = 5°$ is 0.965 for $Q = 40$t and for $Q = 200$t, it is 0.985. Hence multiplication factor to be applied for 100t is,

$$0.965 + \frac{(0.985-0.965)\times(100-40)}{(200-40)} = 0.9725$$

(*iii*) From Fig. 12, multiplication factor to be applied for factor of safety 2.5, $D_f = 1$m and $L/B = 2$ is 0.70. From Fig 13, multiplication factor to be applied for factor of safety 2.5, $D_f = 2$m and $L/B = 2$ is 0.68.

Hence the multiplication factor for $D_f = 1.5$ is the average of the above values i.e. 0.69.

(*iv*) The corrected width based on bearing capacity criteria is $3.7 \times 0.9725 \times 0.69 = 2.48$ m.

(*v*) From Fig. 14, the width of foundation required is 1.74m (when $Q = 100$t, $S_T = 50$ mm, $L/B = 1$ and $m_v = 0.0008 \text{m}^2/\text{t}$). Multiplication factor required for $L/B = 2$ is 0.63 (from Table 7). Multiplication factor for $S_T = 65$mm is $50/65 = 0.769$. Hence the width required from settlement consideration is $1.74 \times 0.63 \times 0.769 = 0.842$m.

(*vi*) The width of foundation required based on both bearing capacity and settlement criteria is 2.48m (that is the higher value).

Conclusions

Determination of the width of foundation involves shape factors such as S_c, S_q and S_γ which themselves depend upon the value of B. Hence the value of B cannot be determined directly. Its value can be found only by trial and error method. To arriave at the width, design charts have been provided. The procedure for calculating the width of shallow foundations based on the bearing capacity and settlement criteria has been presented.

Design charts are prepared based on the assumption that $L/B = 1$, $D_f = 1$m, $\gamma = 1.9$ t/m^3, $S_T = 50$mm and $FS = 3$. For values other than those mentioned above, necessary multiplication factors have been obtained and presented. For footings governed by settlement considerations, an equation has been suggested to determine the width required. An example has been presented to illustrate the usage of charts.

References

BOWLES, J.E. (1988), Foundation Analysis and Design, 4th edition, McGraw-Hill, Kogakusha Ltd., Tokyo.

FABER, O. (1933), Pressure Distribution Under Bases and Stability of Foundations, *The Structural Engineer*, Vol. 11, No. 3, p. 113.

HANSEN, J.B. (1970), A Revised and Extended Formula for Bearing Capacity, Danish Geotechnical Institute Bulletin No. 28, Copenhagen.

IS. 6403-1981, Indian Standard Code of Practice for Determination of Bearing Capacity of Shallow Foundations (First Revision). Indian Standards Institute, New Delhi.

MEYERHOF, G.G. (1953), The Bearing Capacity of Foundations Under Eccentric and Inclined Loads, 3*rd ICSMFE*, Vol. 1, pp. 440-445.

NEWMARK, N.M. (1935), Simplified Computation of Stresses in Elastic Foundations, Univ. of Illinois, reprinted 1964.

SKOPEK, J. (1961), The Influence of Foundation Depth on Stress Distribution, *5th ICSMFE*, Vol. 1, p. 815.

TERZAGHI, K. (1943), Theoretical Soil Mechanics, John Wiley and Sons, New York.

TOMLINSON, M.J. (1986), Foundation Design and Construction, English Language Book Society, Longman.

VESIC, A.S. (1973), Analysis of Ultimate Loads of Shallow Foundations, *JSMFD ASCE*, Vol. 99, SM 1, pp. 45-73.

NOMENCLATURE

B, B_1, B_2	—Width of footing
c	—Cohesion of soil
$c' = \frac{2}{3} c$	—Modified cohesion in case of local shear failure
C_c	—Compression index
D_f	—Depth of foundation
d_c, d_q, d_γ	—Depth factors
H	—Thickness of compressible medium
i_c, i_q, i_γ	—Inclination factors
L	—Length of footing
m_v	—Coefficient of volume change of soil
q	—Overburden weight of soil
q_1	—Intensity of load per unit area
q_a	—Allowable pressure based on settlement criterion alone
q_s	—Safe bearing capacity of soil or safe bearing capacity/ allowable pressure based on both criteria
Q_u	—Ultimate bearing capacity of soil
Q, $Q1$ $Q2$	—Axial load on each column
r	—Horizontal distance of the po'nt (from the line of action of the load) where the vertical stress is to be-etermned
S_c, S_q, S_γ	—Shape factors
S_T	—Total settlement

w'	—Correction factor for water table
X	—L/B ratio
Z	—Depth at which the vertical stress due to foundation load is to be determined
γ	—Unit weight of soil
ϕ	—Angle of internal friction of soil
ϕ'	—Modified value of angle of internal friction in case of local shear failure ($\tan\phi' = 2/3 \tan\phi$)
μ	—Poisson's ratio
σ_z	—Vertical stress imposed by the foundation load
α	—Inclination of the load to the vertical
ΔH	—Settlement due to consolidation