Bearing Capacity of Shallow Foundations on Slopes

by

A. Siva Reddy*

G. Mogaliah**

Introduction

Foundations are sometimes built on sloping sites or adjacent to the top edge of a slope or a cutting. The problem of ultimate bearing capacity of foundations on slopes was studied by Meyerhof (1957). It is known that certain natural soil deposits exhibit anisotropy and nonhomogeneity in shear strength to a great degree (Bishop 1966, Lo 1965 and Ward et al 1959), The study made by Meyerhof (1957) is for soils which are homogeneous and isotropic. The studies of Lo (1965), Livneh (1967) and Hunter and Schuster (1968) on stability of slopes and Siva Reddy and Srinivasan (1970) on bearing capacity of foundations in soils having anisotropy and nonhomogeneity indicate that effect of anisotropy and nonhomogeneity is significant. It is, therefore, important to know how far these strength variations influence the ultimate bearing capacity of foundations on slopes. In the present investigation this has been studied taking cohesion to be anisotropic and to be increasing linearly with depth and using the method of characteristics (Sokolovsky 1965).

Assumptions

1. The soil is rigid plastic at failure and anisotropic with respect to cohesion. The cohesion for any direction (Casagrande and Carrillo 1944, Lo 1965 and Livneh and Komornik (1967) is :

$$c = c_H \, [1+(k-1)\sin^2\psi] \qquad \dots \quad (1)$$

where c = cohesion corresponding to any value of ψ,

ψ = angle made with the horizontal, by the bisector of the angle between the failure planes at a point $= \theta_i - 45^0 + \phi/2$, ϕ = angle of internal friction, θ_i = inclination of a $(\psi + \mu)$ — family slip line to the x-axis (see Figure 1), $\mu = 45^\circ - \phi/2$ c_H = cohesion in horizontal direction, corresponding to $\psi = 0$, and k = coefficient of anisotropy, = the ratio of cohesion in vertical direction to that in horizontal direction.

It may be noted from Figure 1 that $\bar{\psi}$ is the inclination of the major principal stress direction to the x-axis. $\bar{\psi}$ equals ψ for an isotropic medium.

*Professror, Department of Civil Engineering, Indian Institute of Science, Bangalore.

**Lecturer, Department of Civil Engineering, University Visvesvaraya College of Engineering, Bangalore.

The paper is open for discussion till March 1976.

2. The cohesion in a given direction increases linearly with depth below top of slope. This variation is expressed by the equation.

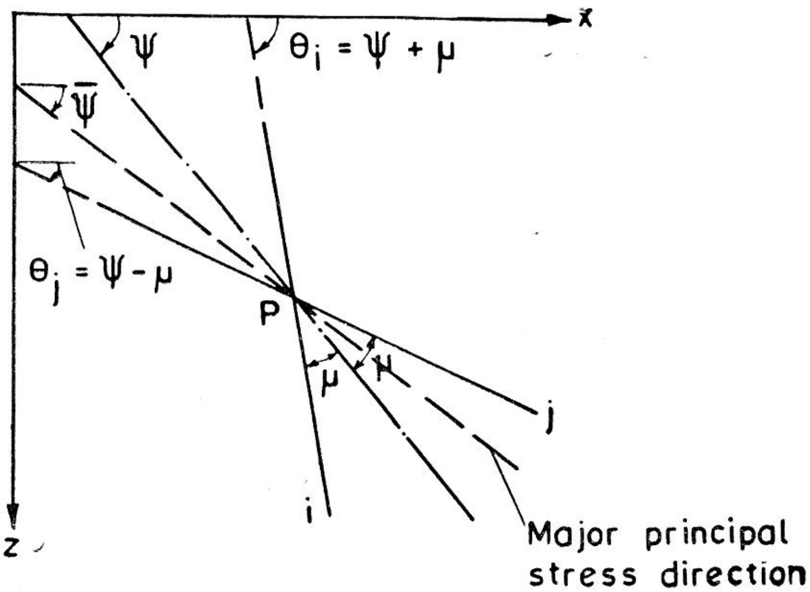

FIGURE 1. Orientation of slip lines at a point

$$c_V = c_{Vs} + \alpha\,(D + Z) \qquad \ldots(2)$$

where c_V = cohesion in vertical direction at any point, c_{Vs} = cohesion in vertical direction, at top of slope, α = rate of increase of c_V with z, D = depth of foundation, and Z = Z-coordinate of the point considered for a foundation on face of a slope and on top of slope (Figure 2).

3. The rupture mechanisms are as shown in Figure 2, wherein the line OA, making an angle β with the horizontal is the equivalent free surface (Meyerhof 1957).

4. At the instant of failure, a wedge of soil OO′L which is in elastic state (Figure 2) is formed beneath the foundation and sloping sides of this wedge are inclined at angles of $45°+\varphi/2$ to the foundation base (Meyerhof 1957). The effect of active earth pressure on the foundation shaft is neglected as the foundation considered herein is a shallow foundation.

Analysis

The variations of shear strength with direction as well as depth below ground surface, are the same as those assumed by Siva Reddy and Srinivasan (1970). Hence, the expressions for the stresses as well as relationships along the slip lines at a point, are the same as those that have been obtained by them.

In order to find the normal and tangential stresses along the equivalent free surface OA, the equilibrium of the mass of soil above OA (Figure 2) is considered.

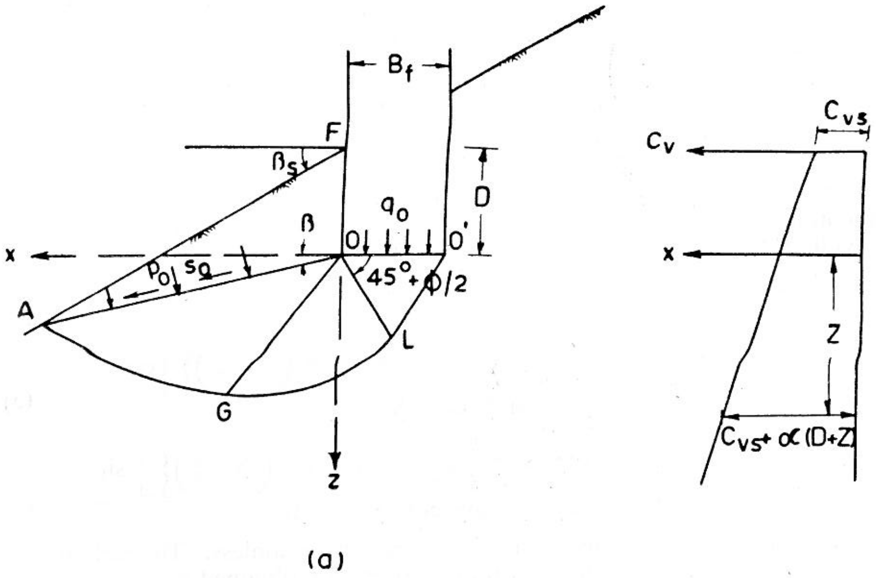

FIGURE 2. (a) Shallow Foundation on face of slope

Foundatian on Face of a Slope

The forces acting on the soil mass OAF (Figure 2 a) for a strip foundation on face of a slope are the weight of the soil mass, W, and the resultant forces P_o and S_o acting on the inclined surface OA. The weight, W, of the soil mass is

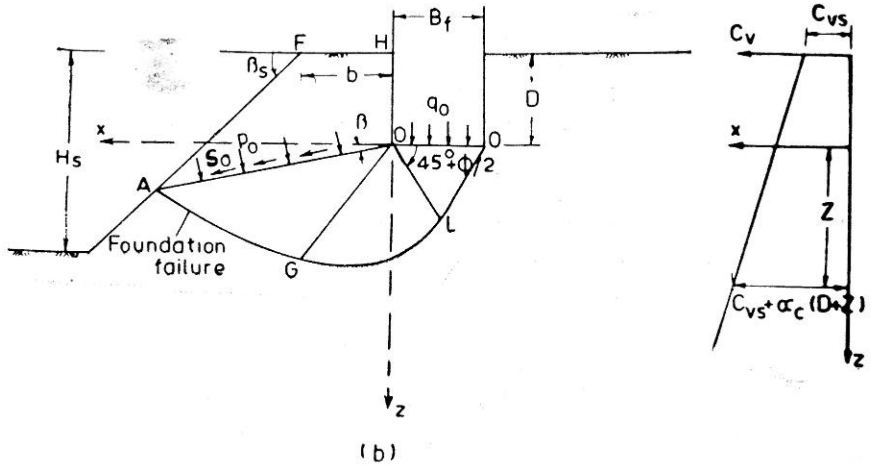

FIGURE 2. (b) Shallow Foundation on top of slope

$$W = \frac{\gamma D^2}{2} \cot\beta_s \left[1 + \cot\beta_s \sin\beta \left\{ \cos\beta + \sin\beta \cot(\beta_s - \beta) \right\} \right] \quad ...(3)$$

By resolving the forces in the directions normal and tangential to OA, the following expressions are obtained for P_o and S_o :

$$P_o = W \cos\beta, \; S_o = W \sin\beta \quad \ldots (4)$$

where γ unit weight of the soil mass, β_s = Inclination of the slope with the horizontal (Figure 2), and D = depth of foundation.

Assuming the forces P_o and S_o to be uniformly distributed along OA, the nondimensional expressions for the stresses P'_o and s'_o are obtained by dividing the stresses by a characteristic stress $\sigma_o = c_{Vs}$, and the distances by a characteristic length, $l = \frac{c_{Vs}}{\gamma}$ and are given by

$$p'_o = \frac{\frac{1}{2}\frac{\gamma l}{c_{Vs}} D'\left[1+\cot\beta_s \sin\beta \left\{\cos\beta+\sin\beta \cot\left(\beta_s-\beta\right)\right\}\right]\cos\beta}{\cos\beta + \sin\beta \cot(\beta_s - \beta)} \quad \ldots (5)$$

$$s'_o = \frac{\frac{1}{2}\frac{\gamma l}{c_{Vs}} D'\left[1+\cot\beta_s \sin\beta \left\{\cos\beta+\sin\beta \cot\left(\beta_s-\beta\right)\right\}\right]\sin\beta}{\cos\beta + \sin\beta \cot(\beta_s - \beta)} \quad \ldots (6)$$

In this paper all quantities with primes are dimensionless. Throughout the paper nondimensional stresses and distances are obtained by dividing the stresses and distances by the characteristic stress c_{Vs} and the characteristic length $l = \frac{c_{Vs}}{\gamma}$.

Foundation on top of a Slope

In this case, the equilibrium of the soil mass OAFH (Figure 2 b) is considered for evaluating the normal and tangential stresses on OA. For this case the nondimensional stresses p'_o and s'_o are

$$p'_o = \frac{\frac{\gamma l}{2c_{Vs}}\cos\beta}{(b'+D'\cot\beta_s)\left[\cos\beta+\sin\beta\cot(\beta_s-\beta)\right]}\left[D'(2b'+D\cot\beta_s) + (b'+D'\cot\beta_s)^2\sin\beta\left\{\cos\beta+\sin\beta\cot(\beta_s-\beta)\right\}\right] \quad \ldots (7)$$

$$s'_o = \frac{\frac{\gamma l}{2c_{Vs}}\sin\beta}{(b'+D')\cot\beta_s\left[\cos\beta+\sin\beta\cot(\beta_s-\beta)\right]}\left[D'(2b'+D'\cot\beta_s) + (b'+D'\cot\beta_s)^2\sin\beta\left\{\cos\beta+\sin\beta\cot(\beta_s-\beta)\right\}\right] \quad \ldots (8)$$

Soils having Internal Friction

At a point on the equivalent free surface the angle λ_f between the failure plane and the equivalent free surface is determined using the Mohr's circle of rupture at the point (Figure 3 a). It is seen from this figure that

$$\cos(2\lambda_f + \varphi) = \frac{s_o \cos\varphi}{c + p_1 \tan\varphi} \quad \ldots (9)$$

and

$$p_1 = \frac{c + p_1 \tan\varphi}{\cos\varphi}\left[\sin(2\lambda_f + \varphi) - \sin\varphi\right] + p_o \quad \ldots (10)$$

where c=cohesion which is anisotropic, and increases linearly with depth as defined by Equations (1) and (2). The angle between the major principal stress and the x-axis, may then be obtained for points along OA from the following relationship (Figure 3 b) as

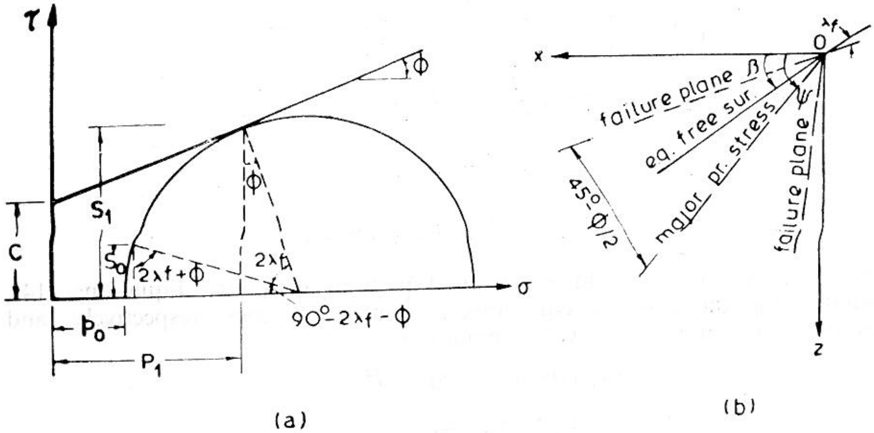

FIGURE 3 (a) Mohr's circle at any point on OA for c-ϕ soils
(b) Relationship between ψ and other angles for c-ϕ soils

$$\psi = 45° - \frac{\varphi}{2} + \beta - \lambda_f \quad \text{... (11)}$$

Substituting in Equation (9) for p_1, λ_f and c from Equations (10) and (11) and (1), the following nondimensional expression is obtained after simplification :

$$\frac{\cos(2\lambda_f+\varphi)}{\cos\varphi - \tan\varphi\,[\sin(2\lambda_f+\varphi)-\sin\varphi]} - \frac{s'_o}{\frac{1}{k}[1+\beta_c(D'+Z')][1+(k-1)\sin^2(45°-\frac{\varphi}{2}+\beta-\lambda_f)]+p'_o\tan\varphi} = 0 \quad (12)$$

where $\beta_c = \frac{\alpha l}{c_{vs}}$ The value of λ_f may be determined by solving Equation (12). It will be seen from Equation (12) that when the second term is equal to zero, the angle λ_f is equal to $(45° - \frac{\varphi}{2})$ and when it is equal to 1, the angle λ_f is zero.

After determining the values of λ_f, the values of ψ at several points along OA can be determined from Equation (11). The next step is to find σ which is defined as

$$\sigma = \frac{(\sigma_x + \sigma_z)}{2} + H \quad \text{...(13)}$$

where $H = c\cot\varphi$. For this purpose, the equilibrium of an elemental wedge on one side by the equivalent free surface is considered.

Resolving the forces in horizontal and vertical directions, respectively, the following equations are obtained.

$$\left.\begin{aligned} p_o \sin\beta - s_o \cos\beta &= \sigma_x \sin\beta - \tau_{xz} \cos\beta \\ p_o \cos\beta + s_o \sin\beta &= \sigma_z \cos\beta - \tau_{xz} \sin\beta \end{aligned}\right\} \quad \ldots (14)$$

Since the same types of anisotropy and variation of cohesion with depth as those assumed by Siva Reddy and Srinivasan (1970) are considered, the expressions for σ_x, σ_z and τ_{xz} at any point in the zone of rupture, are the same as those derived in their paper. They are :

$$\left.\begin{aligned} \sigma_x &= \sigma\,[1 + \sin\varphi \cos 2\psi] - H - \tfrac{1}{2} \frac{\partial c}{\partial \psi} \cos\varphi \sin 2\psi \\ \sigma_z &= \sigma\,[1 - \sin\varphi \cos 2\psi] - H + \tfrac{1}{2} \frac{\partial c}{\partial \psi} \cos\varphi \sin 2\psi \\ \tau_{xz} &= \sigma \sin\varphi \sin 2\psi + \tfrac{1}{2} \frac{\partial c}{\partial \psi} \cos\varphi \cos 2\psi \end{aligned}\right\} \quad \ldots (15)$$

Substituting for σ_x, σ_z and τ_{xz} from Equations (15) into Equations (14), multiplying, the resulting equations by $\sin\beta$ and $\cos\beta$, respectively, and adding and simplifying, give the equation

$$p_o = \sigma - \sigma \sin\varphi \cos 2(\psi - \beta) - H + \tfrac{1}{2} \frac{\partial c}{\partial \psi} \cos\varphi \sin 2(\psi - \beta)$$

Using dimensionless variables, the above equation gives

$$\sigma' = \frac{p'_o + H' - \tfrac{1}{2} \frac{\partial c'}{\partial \psi} \cos\varphi \sin 2(\psi - \beta)}{1 - \sin\varphi \cos 2(\psi - \beta)} \quad \ldots (16)$$

where $H' = c' \cot\varphi$.

For several points along OA, with known values of z', the values of ψ and σ' are determined using Equations (11), (12) and (16). The next step is the successive numerical integration of the equations along the characteristics, starting from the known boundary OA. The equations along the two families of slip lines are (Siva Reddy and Srinivasan 1970) :

Along the $(\psi + \mu)$ — family

$$\frac{dz'}{dx'} = \tan(\psi + \mu), \quad \frac{d\xi}{dx'} + A_1 \frac{d\psi}{dx'} = A_3 \quad \ldots (17)$$

and along the $(\psi - \mu)$ — family

$$\frac{dz'}{dx'} = \tan(\psi - \mu), \quad \frac{d\eta}{dx'} + A_2 \frac{d\psi}{dx'} = A_4 \quad \ldots (18)$$

where $\xi, \eta = \frac{\cot\varphi}{2} \log_e \sigma' \pm \psi$

$$A_1, A_2 = -\frac{\cot\varphi}{2\sigma'} \frac{1}{c_{Vs}} \left(\cot\varphi \frac{\partial c}{\partial \psi} \mp \tfrac{1}{2} \frac{\partial^2 c}{\partial \psi^2} \right),$$

$$A_3, A_4 = \pm \frac{\gamma l}{c_{Vs}} \frac{\cos(\psi + \mu)}{2\sigma' \sin\varphi \cos(\psi \pm \mu)} + \frac{\cot\varphi}{2\sigma'}$$

$$\left[\pm f_2 \beta_c \frac{\cos(\psi \mp \mu)}{\sin\varphi \cos(\psi \pm \mu)} \mp \frac{f}{2} \beta_c \tan(\psi \pm \mu)\right],$$

$$f_2 = \frac{1 + (k-1)\sin^2\psi}{k} \text{ and } f = \frac{k-1}{k} \sin 2\psi$$

From equations (17) and (18), the quantities x', z', ξ and η at a point of intersection of the characteristics are

$$x' = \frac{x'_A \tan(\psi_A - \mu) - z'_A - x'_B \tan(\psi_B + \mu) + z'_B}{\tan(\psi_A - \mu) - \tan(\psi_B + \mu)} \quad \ldots (19)$$

$$z' = z_B' + (x' - x_B') \tan(\psi_B + \mu) \quad \ldots (20)$$

$$\psi = \frac{1}{(A_1 - A_2 + 2)} [\xi_B + A_1\psi_B + A_3(x' - x'_B) - \eta_A - A_2\psi_A - A_4(x' - x'_A)] \quad \ldots (21)$$

$$\xi = \xi_B + A_1(\psi_B - \psi) + A_3(x' - x'_B) \quad \ldots (22)$$

$$\eta = \eta_A + A_2(\psi_A - \psi) + A_4(x' - x'_A) \quad \ldots (23)$$

in which, quantities with subscript A refer to the point A which is on a slip line of the $(\psi - \mu)$—family and quantities with subscript B refer to the point B which is on a silp line of the $(\psi + \mu)$—family.

The above equations are applicable for the points in the rupture zone between OA and OL (Figure 2). For determining the points of intersection of the characteristics with OL, the two conditions

$$z' = m' x' \text{ and } \tau'_n = -(\sigma'_n + H') \tan\varphi \quad \ldots (24)$$

with the following equations are used :

$$x' = \frac{z'_1 - x'_1 \tan(\psi_1 - \mu)}{m' - \tan(\psi_1 - \mu)} \quad \ldots (25)$$

$$\eta = \eta_1 - A_2(\psi - \psi_1) + A_4(x - x'_1) \quad \ldots (26)$$

$$\text{and } \xi = \eta + 2\psi \quad \ldots (27)$$

where m' = slope of the line OL, τ'_n, σ'_n = the dimensionless tangential and normal stresses on OL and the quantities with the subscript 1 refer to the last point determined on the $(\psi - \mu)$—family slip line.

After determining the required quantities along OL, the ultimate bearing capacity is calculated by considering the equilibrium of the wedge OLO′.

Soils with φ equal to zero

For this case in order to find λ_f at any point OA, the Mohr's rupture circle at that point is used. It is given by

$$\frac{s'_o}{s'_1} = \cos 2\lambda_f \quad \ldots (28)$$

where s'_f = nondimensional shear stress on the failure plane and is equal to the non-dimensional cohesion corresponding to failure direction.

The angle ψ may then be obtained for points along OA as

$$\psi = 45° + \beta - \lambda_f \quad \ldots (29)$$

From Equations (1), (2) and (29)

$$s'_1 = c' = [1 + \beta_c(D' + z')][1 + (k - 1)\sin^2(45° + \beta - \lambda_f)]/k \quad \ldots (30)$$

Substitution for s'_1 from Equation (30) into Equation (28), gives

$$s'_o - [1 + \beta_c(D' + z')][1 + (k - 1)\sin^2(45° + \beta - \lambda_f)] \frac{\cos 2\lambda_f}{k} = 0 \ldots (31)$$

By solving the above equation, the value of λ_f is obtained. From the above equation it is seen that when shear stress $s'_o = 0$, the angle λ_f is equal to 45° and when $s'_o = s'_1$ the angle λ_f is zero.

The expressions for σ_x, σ_z and τ_{xz} are

$$\left.\begin{aligned} \sigma_x &= p - \tfrac{1}{2}\frac{\partial c}{\partial \psi}\sin 2\psi + c\cos 2\psi \\ \sigma_z &= p + \tfrac{1}{2}\frac{\partial c}{\partial \psi}\sin 2\psi - c\cos 2\psi \\ \tau_{xz} &= \tfrac{1}{2}\frac{\partial c}{\partial \psi}\cos 2\psi + c\sin 2\psi \end{aligned}\right\} \quad \ldots (32)$$

where $p = \dfrac{\sigma_x + \sigma_z}{2}$

In order to obtain p, the expressions for σ_x, σ_z and τ_{xz} from equations (32) are substituted into Equation (14). Then multiplying the resulting equations by $\sin\beta$ and $\cos\beta$ respectively, and adding them and on further simplification using dimensionless variables the following expression is obtained :

$$p' = p'_o - \tfrac{1}{2}\frac{\partial c'}{\partial \psi}\sin 2(\psi - \beta) + c'\cos 2(\psi - \beta) \quad \ldots (33)$$

The values of ψ and p' may be determined at several points along OA from Equatsons (29), (31) and (33) . Using the equations, along the $(\psi+\mu)$ —family

$$\frac{dz'}{dx'} = \tan\left(\psi + \frac{\pi}{4}\right) \text{ and } \frac{d\xi}{dx'} + E_1\frac{d\psi}{dx'} = E_2 \quad \ldots (34)$$

and along the $(\psi-\mu)$—family

$$\frac{dz'}{dx'} = \tan\left(\psi - \frac{\pi}{4}\right) \text{ and } \frac{d\eta}{dx'} - E_1\frac{d\psi}{dx'} = E_3 \quad \ldots (35)$$

where $E_1 = \tfrac{1}{2}(1+\beta_c z')\left(\dfrac{f_1}{2} + 2f_2\right) - 1,$

$$E_2 = \tfrac{1}{2}\left[\left(1 - \frac{f\beta_c}{2}\right)\tan(\psi + \pi/4) + f_1\beta_c\right],$$

$$E_3 = \tfrac{1}{2}\left[\left(1 + \frac{f\beta_c}{2}\right)\tan\left(\psi - \frac{\pi}{4}\right) - f_1\beta_c\right]$$

and $f_1 = \dfrac{k-1}{k}\, 2\cos 2\psi,$

the expressions for quantities x', z', ξ and η at a point of intersection of the characteristics are obtained as

$$x' = \frac{x'_A \tan\left(\psi_A - \frac{\pi}{4}\right) - z'_A - x'_B \tan\left(\psi_B + \frac{\pi}{4}\right) + z'_B}{\tan\left(\psi_A - \frac{\pi}{4}\right) \tan - \left(\psi_B + \frac{\pi}{4}\right)}$$

$$z' = z'_B + (x' - x'_B)\tan\left(\psi_B + \frac{\pi}{4}\right)$$

$$\psi = \frac{1}{2E_1 + 2}\left[\xi_B + E_1\psi_B + E_2(x' - x_B') - \eta_A + E_1\psi_A - E_3(x' - x'_A)\right] \quad \ldots (36)$$

$$\xi = \xi_B + E_1(\psi_B - \psi) + E_2(x' - x'_B)$$
$$\eta = \eta_A - E_1(\psi_A - \psi) + E_3(x' - x'_A)$$

For determining the points of intersection of the characteristics of the $(\psi - \mu)$—family with the line OL, the following equations are used :

$$x' = \frac{z'_1 - x'_1 \tan\left(\psi_1 - \frac{\pi}{4}\right)}{m' - \tan\left(\psi_1 - \frac{\pi}{4}\right)}, \; z' = m'x'$$
$$\eta = \eta_1 + E_1(\psi - \psi_1) + E_3(x' - x'_1), \; \xi = \eta + 2\psi \qquad \dots (37)$$

Results and Discussion

The ultimate bearing capacity is expressed as

$$q'_o = N_c + p'_o N_q + \tfrac{1}{2} \frac{\gamma l}{c_{Vs}} B'_f N_\gamma \qquad \dots (38)$$

Bearing capacity factors N_c, N_q and N_γ as defined by Equation (38) are obtained for values of $\varphi = 0°, 10°, 20°$ and $30°$ and for values of β_s ranging from 15° to 75°. These factors are also obtained as functions of the assumed values of β, D', b', k and β_c. For all the calculations a fine mesh size that gives sufficiently accurate results is used. The bearing capacity factors are determined as explained below.

The values of p'_o and s'_o are first determined for assumed values of β, D', β_s and b' using Equations (5) and (6); and (7) and (8) for foundations on face of a slope and top of a slope, respectively. The ultimate bearing capacity q_{cq}, due to cohesion and surcharge is then determined by using $\frac{\gamma l}{c_{Vs}}$ to be equal to zero below the equivalent free surface, and it is given by

$$q'_{cq} = N_c + p'_o N_q \qquad \dots (39)$$

Next, the value of ultimate bearing capacity due to cohesion only is determined by equating p'_o and s'_o along the equivalent free surface to zero, for β and D' assumed in obtaining q_{cq}. This gives the value of N_c. Using values of N_c thus obtained, the values of N_q are calculated from Equation (39).

After obtaining N_c and N_q, the ultimate bearing capacity, q'_o, due to all components is next determined assuming $\frac{\gamma l}{c_{Vs}} = 1$, for same values of β and D' assumed in obtaining q_{cq}. The values N_γ are then determined using the equation

$$q_c - q_{cq} = \tfrac{1}{2} \gamma B'_f N_\gamma \qquad \dots (40)$$

The values of N_c, N_q and N_γ for different values of the parameters are presented in Figures 4 through 8.

In order to show the influence of k and β_c clearly, the values N_c for $\varphi = 0°$ are plotted for $b' = 0$ and 4 and for extreme values of k and β_c in

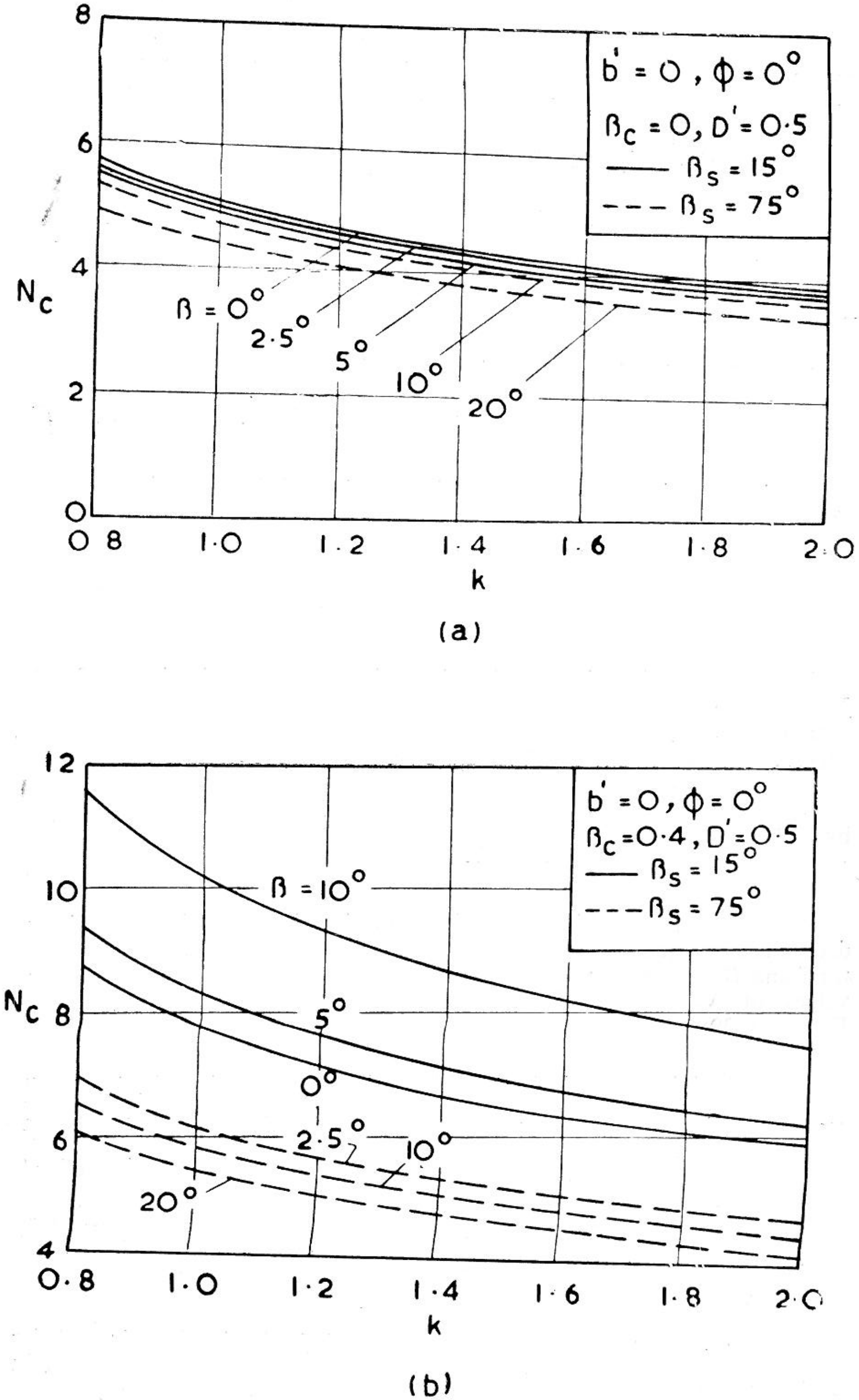

FIGURE 4 : Influence of k on N_c for $\phi = 0$ and $b' = 0$

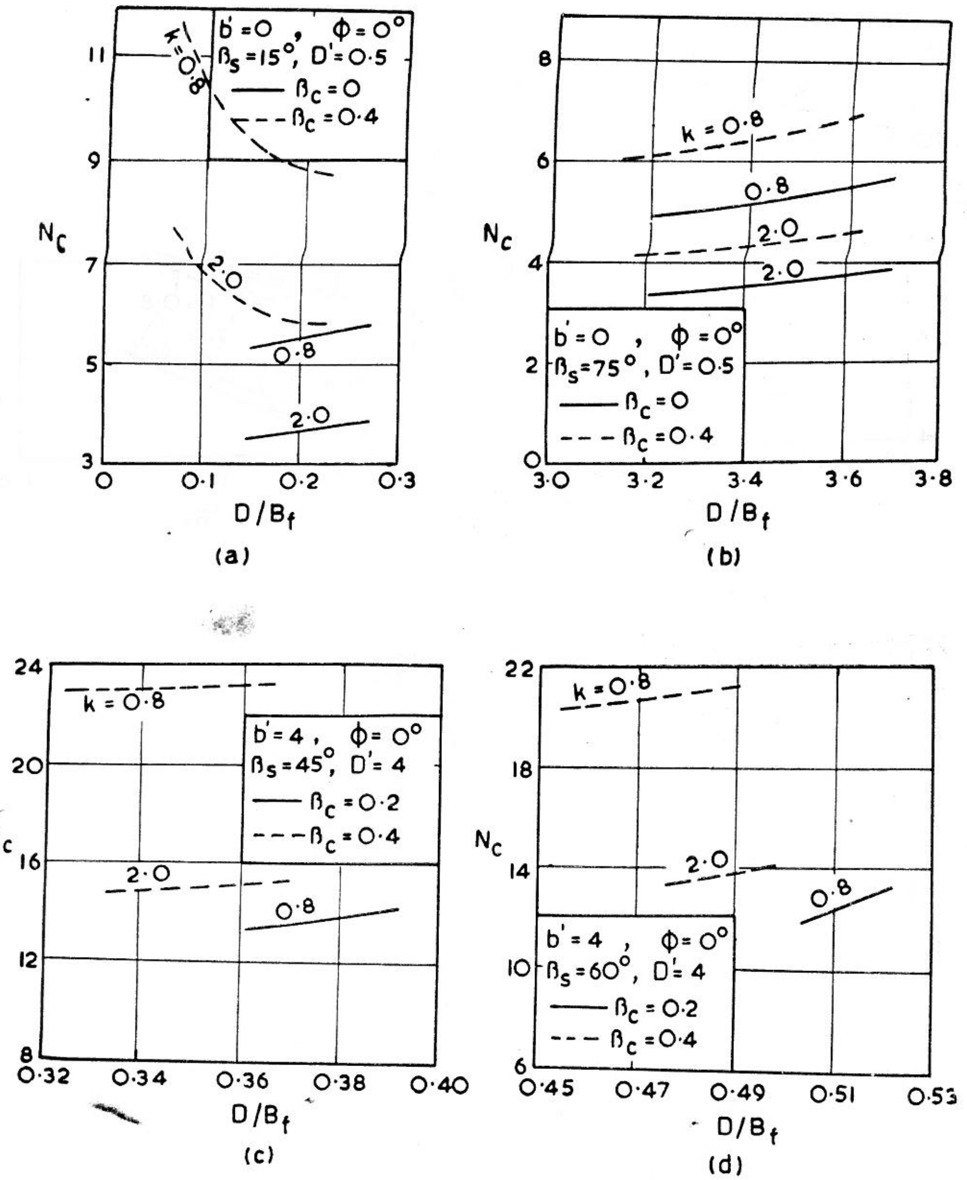

FIGURE 5 : N_c Vs D/B_f relationship for $\phi = 0°$

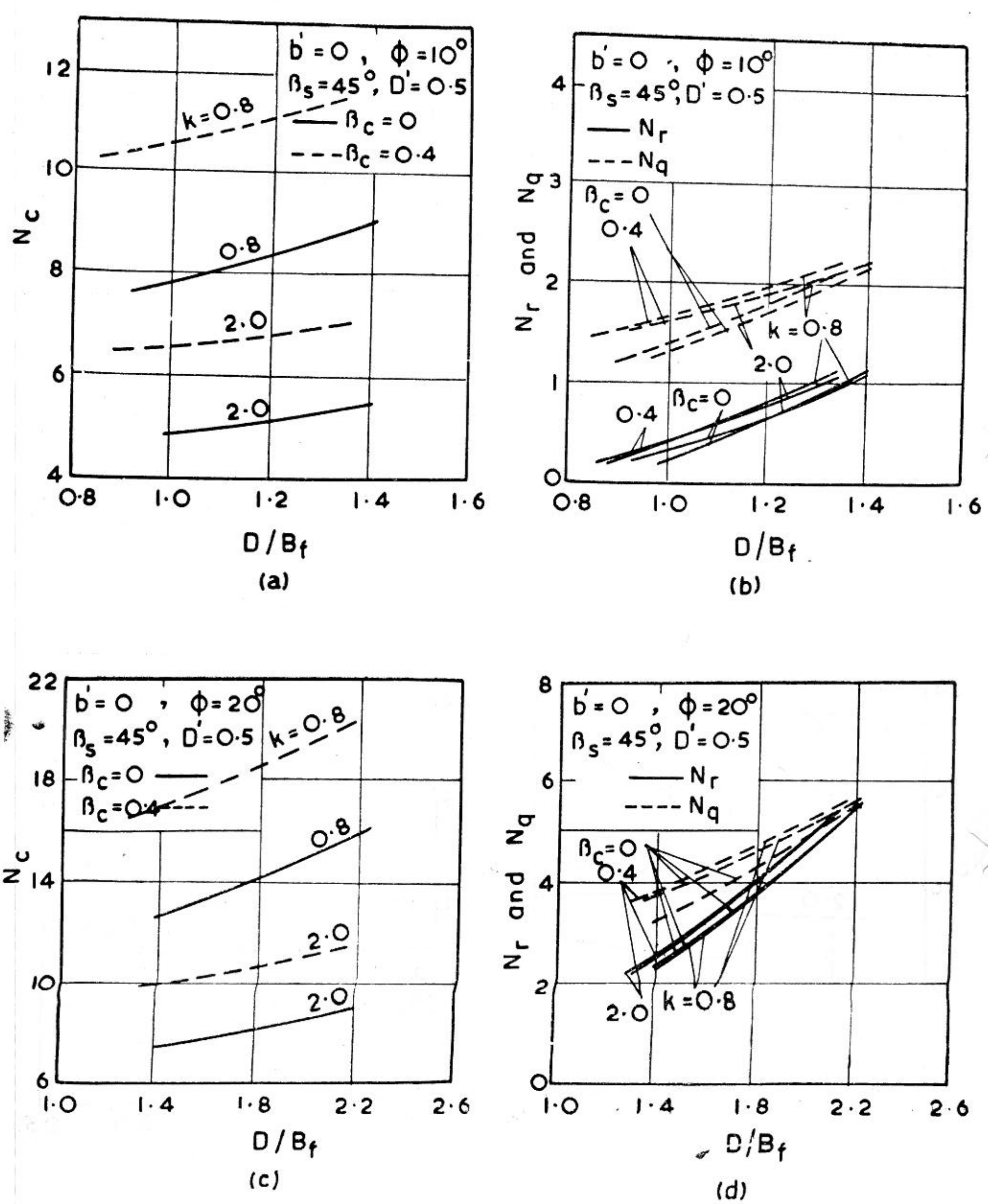

FIGURE 6 : Variation of N_c, N_γ and N_q with D/B_f for $\phi = 10°$ and $20°$

Figures 4 and 5 and N_c, N_q and N_γ in Figures 6 to 8 for $\varphi = 10°$, 20° and 30°, and $b' = 0$ and 6. From these figures it is seen that for given values of $\frac{D}{B_f}$ (or β) and β_c, when k changes from 0.8 to 2, N_c decreases considerably. For $\varphi = 0°$, $b' = 0$, and $D' = 0.5$, as k changes from 0.8 to 2, $\beta_s = 15°$ and $\frac{D}{B_f} = 0.2$, the reduction in N_c is about 34 per cent for $\beta_c = 0$ and 0.4. The corresponding reductions for $\beta_s = 75°$ and $\frac{D}{B_f} = 3.4$ are 32 and 33 per cent for $\beta_c = 0$ and 0.4, respectively. For $b' = 4$, $D' = 4$ and $\beta_s = 60°$, as k varies from 0.8 to 2, N_c decreases by about 36 percent for $\frac{D}{B_f} = 0.48$ and $\beta_c = 0.4$. *For* $\varphi = 30°$ *and* $b' = 0$ *as* k *increases* from 0.8 to 2, when $\beta_s = 45°$, $D' = 0.5$ and $\frac{D}{B_f} = 2.8$, the reductions in N_c are about 46 and 47 per cent for $\beta_c = 0$ and 0.4, respectively. The corresponding values for $b' = 6$ and $\frac{D}{B_f} = 0.4$ are 47 and 48 per cent. It is also seen from these figures that for given values of $\frac{D}{B_f}$ and k as β_c changes from 0 to 0.4, N_c increases substantially, whereas N_γ and N_q are little affected. For $\varphi = 0°$, $b' = 0$, $D' = 0.5$, $\beta_s = 15°$ and $\frac{D}{B_f} = 0.2$, when β_c changes from 0.0 to 0.4, the increase in N_c is about 60 per cent for $k = 0.8$ and 2. The corresponding values for $\beta_s = 75°$ and $\frac{D}{B_f} = 3.4$ are 25 and 24 per cent for $k = 0.8$ and 2, respectively. For $\varphi = 30°$ and $b' = 0$ as β_c increases from 0 to 0.4, N_c increases, when $\beta_s = 45°$ and $\frac{D}{B_f} = 2.8$ by about 31 and 29 per cent for $k = 0.8$ and 2, respectively. The corresponding values for $b' = 6$ and $\frac{D}{B_f} = 0.4$ are 154 and 86 per cent.

The values of N_c corresponding to $k = 1$ and $\beta_c = 0$ obtained in the present investigation are compared with those of Meyerhof (1951, 1957) in Table I. It is seen from this table that the present N_c values are, in general, in good agreement with the values given by Meyerhof. In order to compare other bearing capacity factors the values of $N_{\gamma q}$ corresponding to $k = 1$ and $\beta_c = 0$ are calculated from the equation

$$q_o = \tfrac{1}{2}\,\gamma B_f\, N_{\gamma q} = p_o\, N_q + \frac{\gamma B_f}{2}\, N_\gamma$$

These values are compared with the results of Meyerhof (1957) in Table II. It is observed from this table that the values of $N_{\gamma q}$ obtained in the present investigation are higher than Meyerhof's values.

Conclusions

On the basis of the numerical results presented the following general conclusions are drawn.

For given slope and spacing on the top of slope, the value of N_c is considerably affected by anisotropy and nonhomogeneity. The effect of nonhomogeneity is more in case of small slope angles and φ.

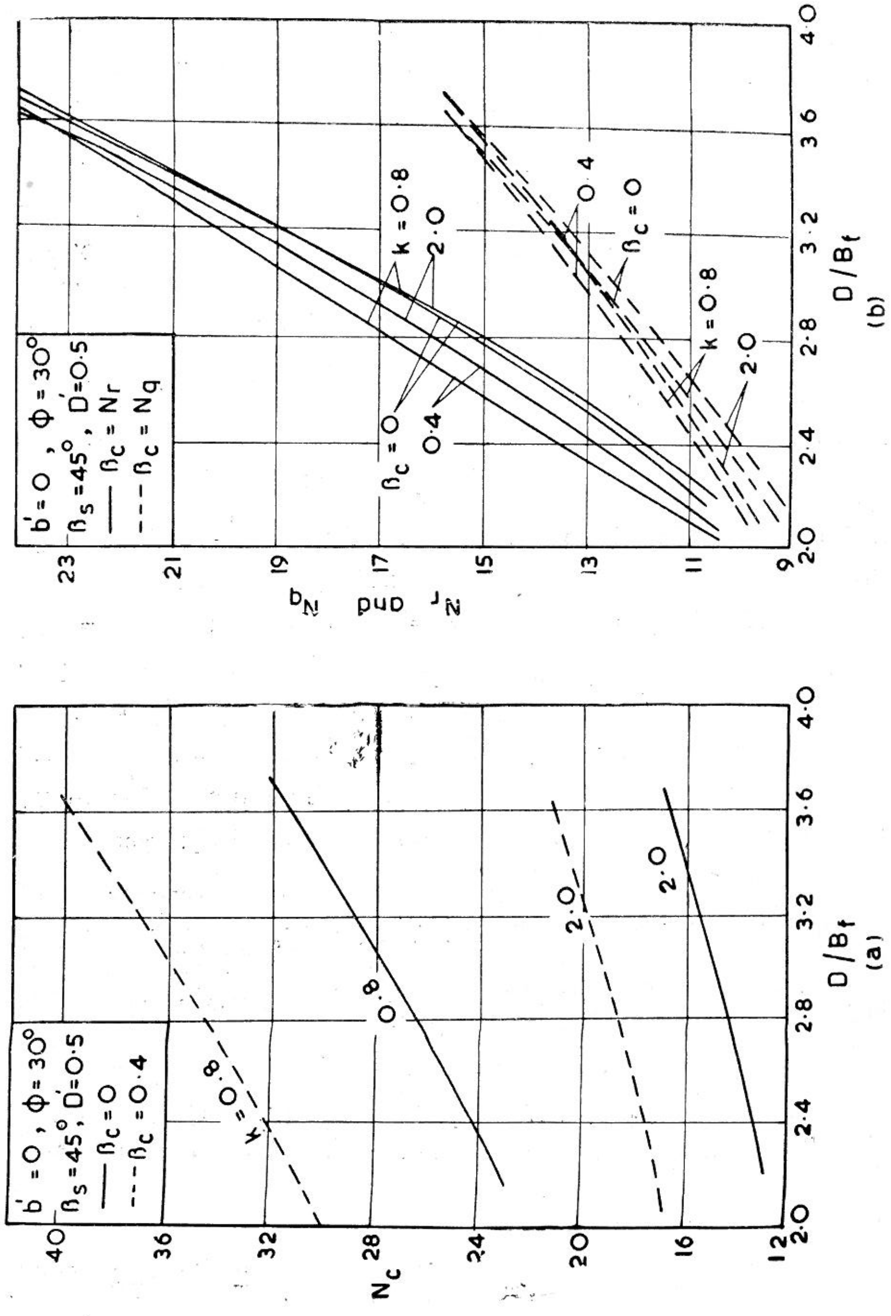

FIGURE 7 : Variation of N_c, N_γ and N_q with D/B_f for $\phi = 30°$ and $b' = 0$

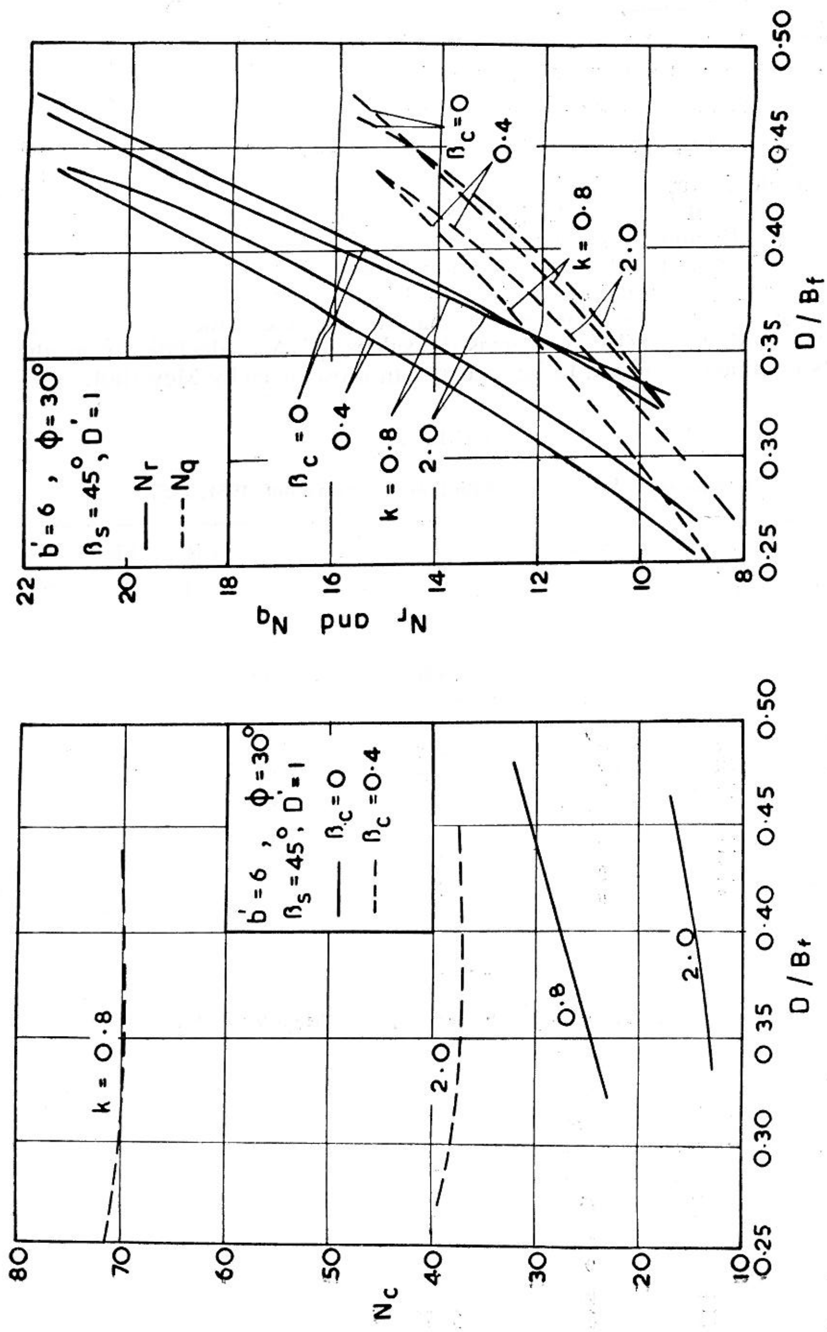

FIGURE 8 : Variation of Nc, $N\gamma$ and Nq with D/Bf for $\phi = 30°$ and $b' = 6$

It is observed that for low values of slope angles and φ, as $\frac{D}{B_f}$ decreases, the value of N_c increases for β_c greater than zero. This increase is more for higher rate of increase of cohesion with depth. For given values of k, β_c, $\frac{D}{B_f}$ and φ, the bearing capacity factors N_c, N_q and N_γ decrease as slope angle increases. It is observed that these factors increase with increase in b'. It is found that, for $\varphi = 0°$, the variation in the value of N_q is small and it is around unity. The error introduced in q'_o by assuming N_q equal to 1.0 is quite small and hence for practical purposes it may be taken to be equal to one for $\varphi = 0°$ case. For the case of isotropic and homogeneous slopes, the present analysis gives the same values of N_c as those of Meyerhof (1957) whereas the values of N_q calculated from the results obtained are found to be higher than those given by Meyerhof.

TABLE I

Comparison of N_c Values with those of Meyerhof (1951, 1957)

ϕ, in degrees	β_s, in degrees	$\frac{b}{B_f}$	$\frac{D}{B_f}$	Present Analysis ($k = 1$, $\beta_c = 0$) N_c	Meyerhof (1951, 1957) N_c
(1)	(2)	(3)	(4)	(5)	(6)
0	15	0	0.230	5.04	5.08
0	45	0	0.648	4.41	4.48
0	30	0.80	0.102	5.03	5.10
0	60	0.97	0.121	5.03	4.90
10	15	0	0	7.11	7.10
20	15	0	0	11.78	11.80
30	15	0	0	21.82	21.90
30	30	0	0	15.68	15.70
30	45	0	0	11.14	11.20

TABLE II

Comparison of $N_{\gamma q}$ Values with those of Meyerhof (1957)

ϕ, in degrees	β_s, in degrees	$\frac{b}{B_f}$	$\frac{D}{B_f}$	Present Analysis ($k = 1$, $\beta_c = 0$) $N_{\gamma q}$	Meyerhof (1957) $N_{\gamma q}$
(1)	(2)	(3)	(4)	(5)	(6)
30	15	0	0	13.76	10.0
30	30	0	0	5.01	3.10
30	15	0	0.681	33.60	30.0
30	15	0	0.308	20.10	17.0
30	15	1.42	0.236	28.10	24.50

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