Dimensioning of Footings on Cohesionless Soils

by

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Introduction

A footing on cohesionless soil is so dimensioned that the load from the superstructure is transmitted to the foundation soil without causing :

(*i*) A break into ground (bearing capacity failure)

(*ii*) Excessive settlements.

It is specified in the Indian Standards (IS : 6403) that the factor of safety against bearing capacity failure is 2.5 and the permissible settlement for ordinary structures on cohesionless soils is generally 40 mm. Thus, the allowable bearing capacity of strip footings on cohesioless soil is the lower of q_s and q_a given by:

$$q_s = \frac{q(N_q - 1) + \frac{1}{2}B\gamma N\gamma W'}{2.5} \quad ...(1)$$

$$q_a = 0.554\,(N-3)\;W'\left(\frac{B+30}{2B}\right)^2 \quad ...(2)$$

The bearing capcity factors, N_q and $N\gamma$ in Equation (1) can be read from Figure 1 of IS: 6403, if N is known ; correction coefficient for water-table, W', is given in Figure 3 of the same code (IS : 6403). If considered necessary, the bearing capacity factors may be corrected for depth of footing, using the correction coefficients provided in section 5.7.3 of IS: 6403. Further, it is to be noted that if the footing is rectangular of circular, the coefficients in Equation (1) will be different; but the form of the equation remains the same.

Economic Design of Footings

Economy in footing design is achieved by arriving at the minimum dimensions for the width, depth and thickness of the footing. As the allowable bearing capacity depends upon the width and depth of footing, one has

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This paper (modified) was received on 1 January 1974. It is open for discussion up to January 1975.

to make several trial and error attempts in order to arrive at the maximum allowable bearing pressure and minimum required width and depth of footing. When the width of fooling is a minimum, the bending moment caused by the soil reaction is also a minimum. Therefore, if the width is minimised, automatically the thickness also gets minimised. Thus, one has to find by trial and error, the desirable values of depth and width of footing for a given load by maximising the allowable bearing pressure, thereby minimising the width of footing. No guide lines or systematic procedures are available for finding the economic size of footings. This paper aims at providing such a procedure.

Basis of the suggested Procedure

The variation of q_s and q_a with depth and width of footing was studied for various combinations of γ, N, allowable settlement and depth to water-table. The results of these studies are not reproduced in detail due to want of space. However, the results for one typical case, when $\gamma = 0.0016$ kg/cc, $N = 10$ and depth to water-table is 2 m, is shown in Figure 1. In Figures 1(*b*) to 1(*d*) the allowable bearing pressure, (minimum of q_s and q_a), is marked in firm line. It may be seen that this pressure for a fixed depth of footing (D_f) is a maximum for a particular width. This observation is found to be true for all usual values of the variables and coincides with the observation of Taylor (1948), who investigated this aspect for surface footings on dry sands. This observation means that maximum advantage will be abtained, if the width corresponding to the peak value of allowable bearing pressure is adopted. A curve constructed by connecting the peak points obtained for different D_f values, provides the relationship between the maximum possible net allowable bearing pressure and width of footing. By plotting the three points obtained from Figures 1(*b*) to 1(*d*) and joining them by a smooth curve, the portion BC, of the curve ABCD in Figure 1(*e*) is obtained. The required D_f values taken from Figures 1(*b*) to 1(*d*) are marked on this curve. The full curve ABCD, is obtained by noting that :

(*i*) in the region CD, settlement controls and it is advantageous to keep D_f as low as is permissible, i.e., $D_f = 80$ cm ;

(*ii*) In the region AB, bearing capacity failure controls; further, as the allowable bearing pressure increases with D_f and for a shallow foundation, the maximum value of D_f is B, the most desirable values are $D_f = B$.

Therefore, in the region where settlement controls, the line follows the q_a line for $D_f = 80$ cm and in the region where bearing capacity failure controls, the line follows the points for $D_f = B$. Thus, the full curve ABCD in Figure 1(*e*) is obtained. The maximum net allowable load per unit length can now be computed as the product of the maximum net allowable bearing pressure and the corresponding width of footing.

In any given problem, the net load is known in advance and not the bearing pressure. Therefore, to facilitate fixing the economical size of footings, charts connecting the maximum allowable load with B and

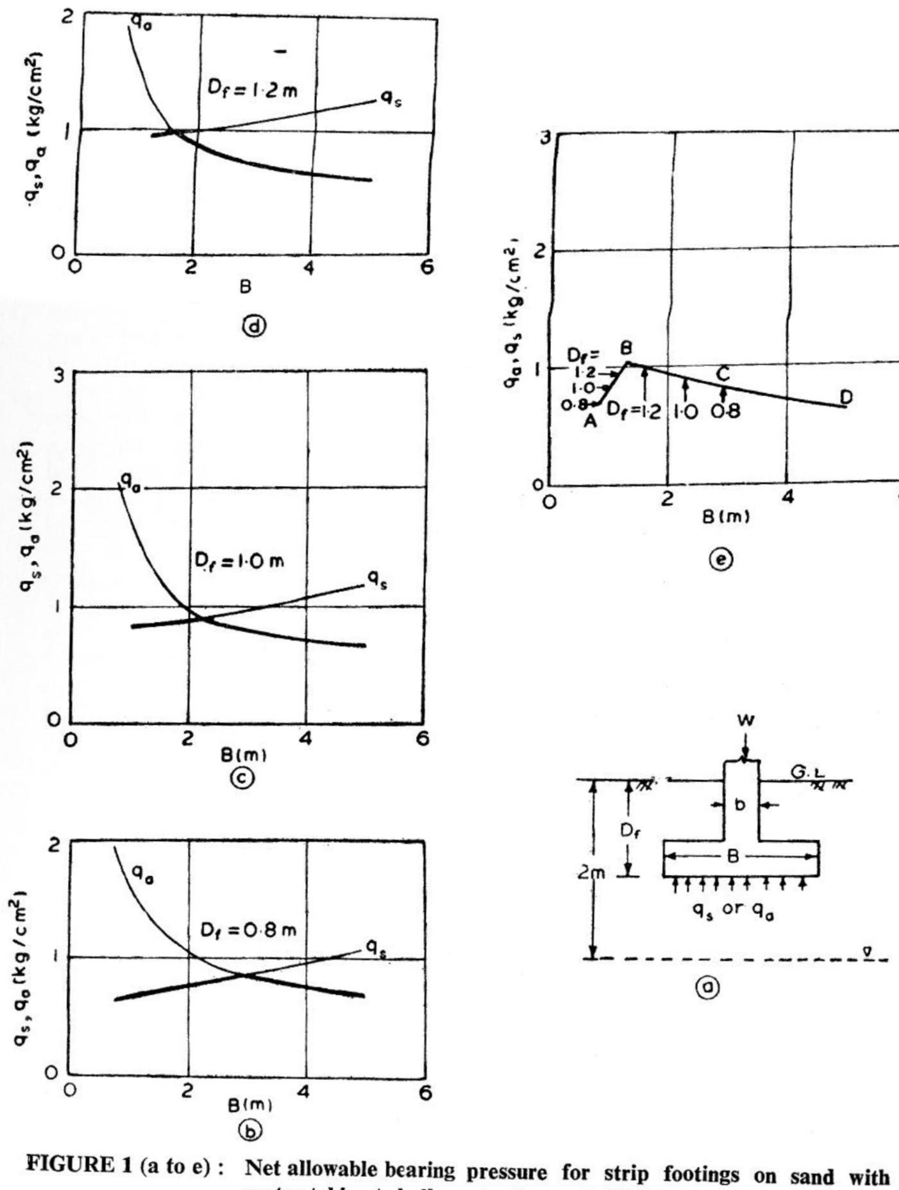

FIGURE 1 (a to e) : **Net allowable bearing pressure for strip footings on sand with water-table at shallow depth. γ=0.0016 kg/cc, allowable settlement=40 mm, N=10, water-table at 2 m below ground level.**

the corresponding D_f are to be made available. Such a chart can be prepared for given values of γ, N, depth to water-table and allowable settlement by the following steps :

(*i*) Assume a minimum value for B.

(*ii*) Starting from a low value of D_f, find the minimum D_f which will give the maximum net allowable bearing pressure. It is to be noted that D_f must not be increased beyond the limit for shallow foundations, namely, $D_f = B$.

(*iii*) Compute the maximum net allowable load per unit length from the maximum net allowable bearing pressure and the corresponding B.

(*iv*) Repeat steps (*ii*) and (*iii*), for increasing values of B till the desired maximum value of B is reached.

Charts

Based on the method suggested in the previous section, a set of charts for strip footings, if $\gamma = 0.0016$ kg/cc and allowable settlement$=40$ mm, are prepared and presented in Figures 2 to 4. The charts give the net load, Q, for different values of B, N and depth to water-table. The Q values shown are the maximum possible values for the given γ, allowable settlement, N, depth to water-table and B. The required D_f for obtaining these maximum possible Q values are also given in the same charts.

These charts can be used for fixing the most desirable values of B and D_f as explained in Appendix I. They have been prepared for the most common values of γ and allowable settlement, namely, 0.0016 kg/cc and 40 mm, respectively. If some other values of γ and/or allowable settlement are applicable, based on the principles stated above, a curve connecting Q and B and another curve connecting B and required D_f have to be obtained for the known values of γ, N, allowable settlement and depth to water-table, similar to the curves shown in Figures 2 to 4. Then, these curves can be used to read the required B and D_f, if Q is known.

The procedure suggested here can be adopted for rectangular, square and circular footings also by using the appropriate equation instead of Equation (1).

Concluding Remarks

The conventional procedure for arriving at the dimensions of spread footings is explained briefly. It is shown, that for arriving at an economical footing, it is necessary to attempt several trials. It is also shown that the net allowable bearing pressure must be maximised to arrive at an economical footing. An analysis is made for a particular case, $N = 10$, $\gamma = 0.0016$ kg/cc, allowable settlement$=40$ mm and depth to water-table$=2$ m. It is seen from this analysis that a curve connecting maximum possible net allowable load per unit length of foundation with the width of foundation can be prepared for known values of γ, N, allowable settlement and depth to water-table. A corresponding curve connecting width and required depth of foundation can also be prepared. From these curves, for the known load per unit length of foundation, the desirable values of width and depth of foundation can be read.

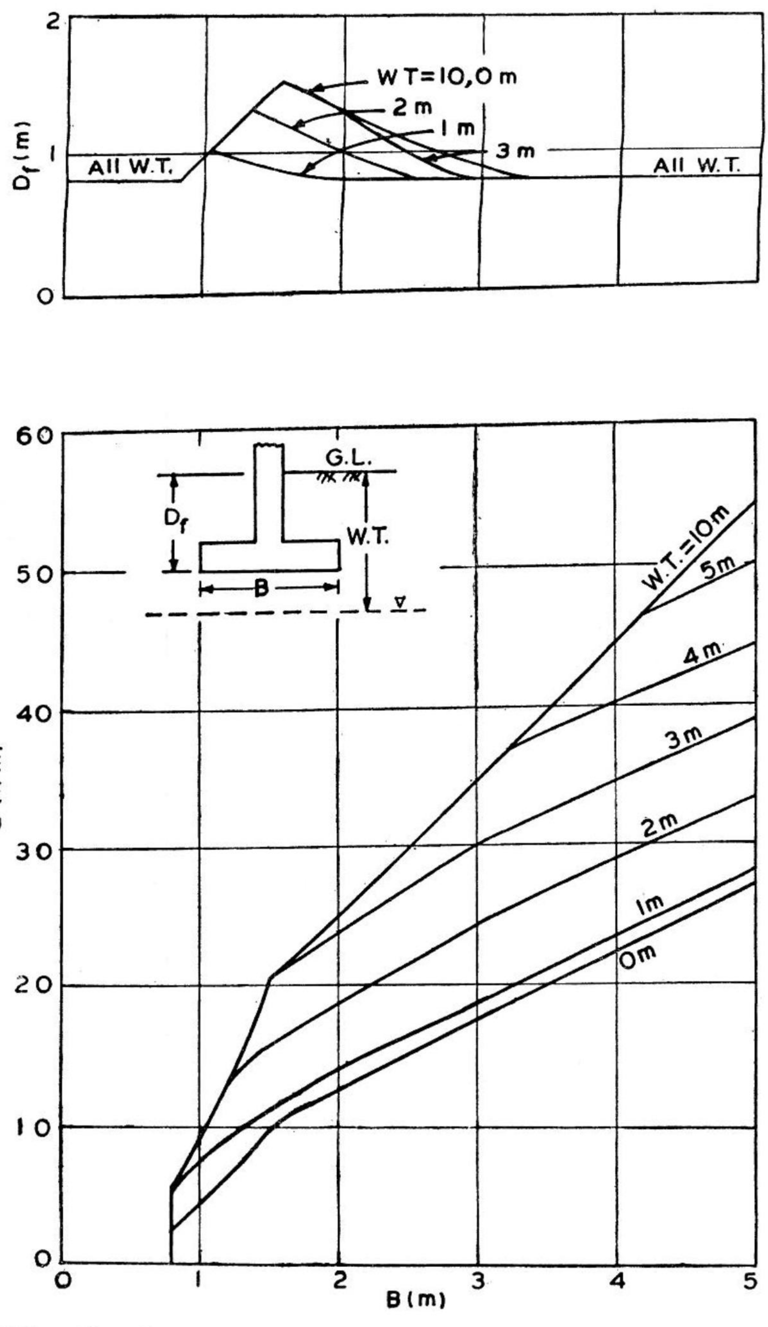

FIGURE 2 : Chart for net allowable load per metre length of strip footings on sand. $\gamma = 0.0016$ kg/cc, allowable settlement = 40 mm, N = 10.

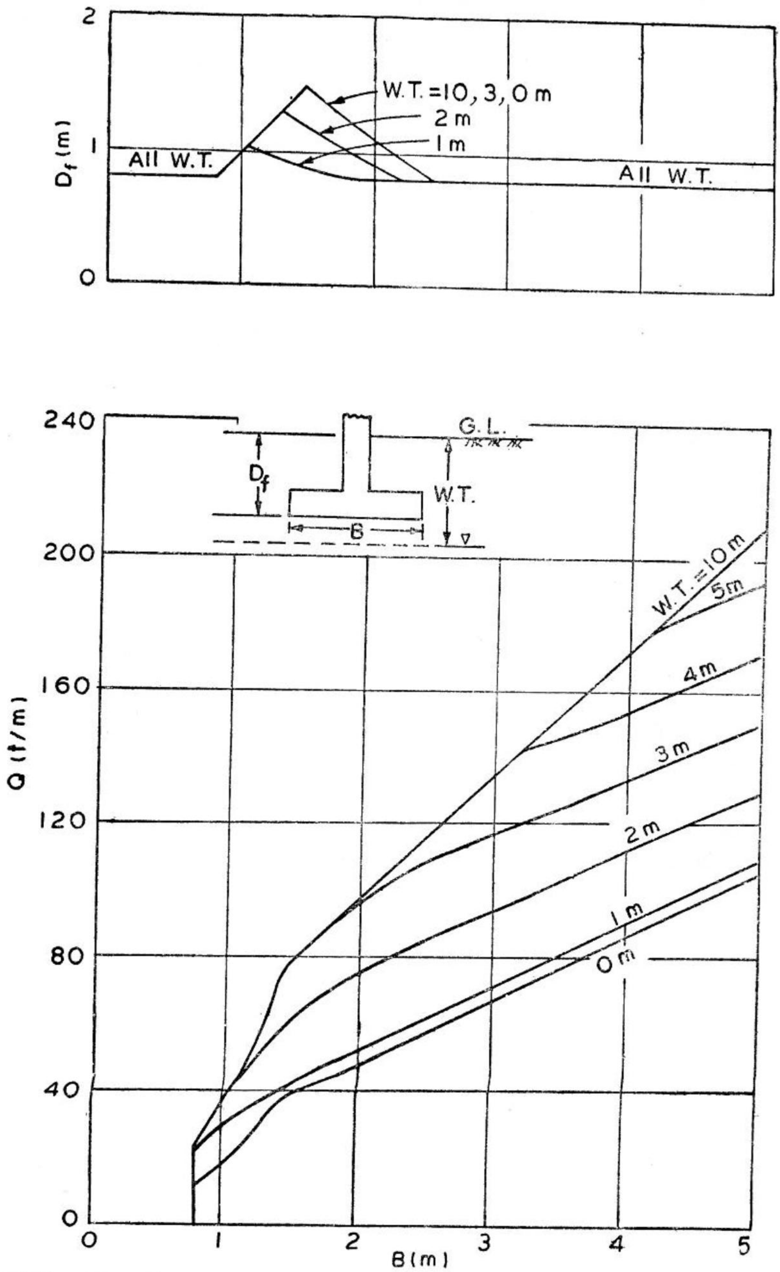

FIGURE 3 : Chart for net allowable load per metre length of strip footings on sand. $\gamma = 0.0016$ kg/cc, allowable settlement = 40 mm, N = 30.

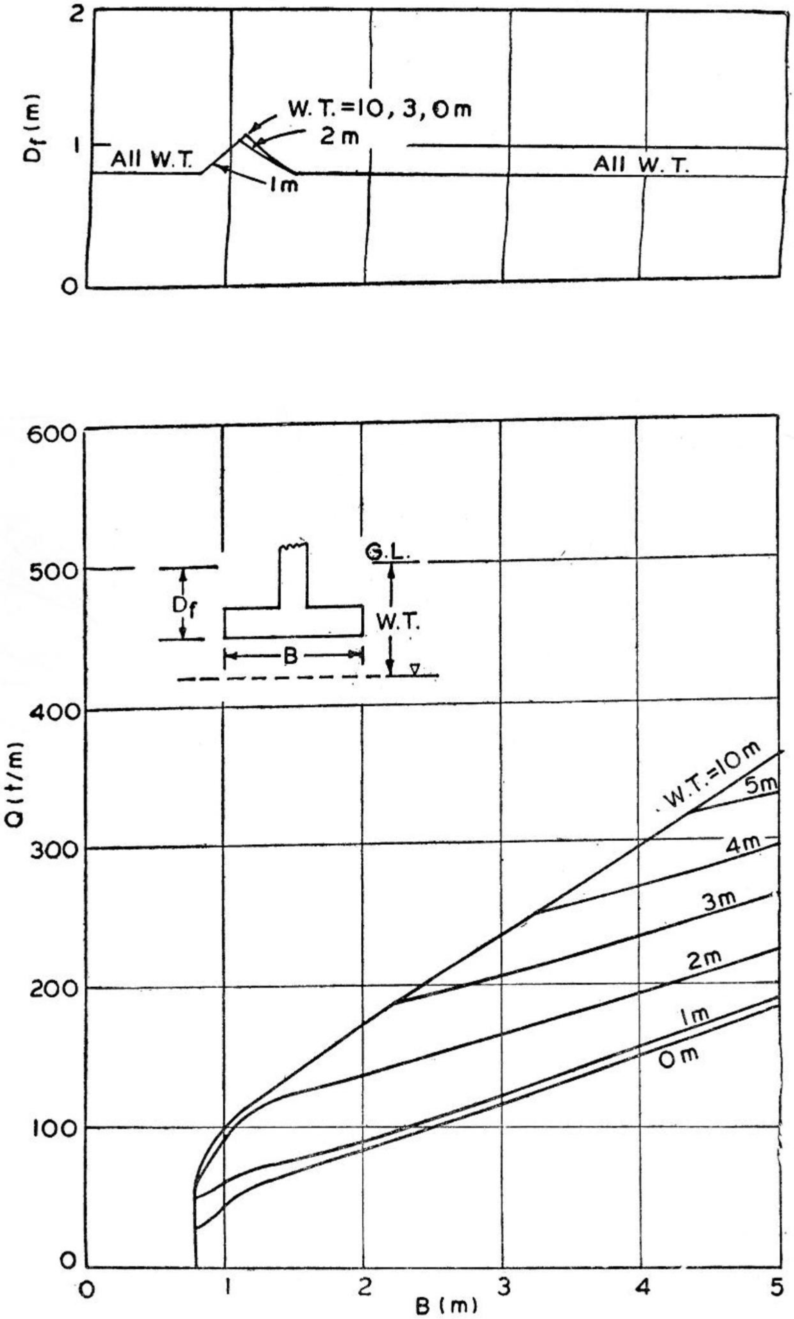

FIGURE 4 : Chart for net allowable load per metre length of strip footings on sand. $\gamma = 0.0016$ kg/cc, allowable settlement = 40 mm, N = 50.

A set of design charts for strip footings for $N=10$, 30 and 50 were prepared and presented. These give the variation of Q with B for different values of depth to water-table. These have been prepared for the usual values of γ and allowable settlement, namely, 0.0016 kg/cc and 40 mm, respectively. A perusal of these charts brings out the following important observations :

(*i*) Contrary to popular belief, for large loads, the depth of foundation need be only the minimum permissible value, namely, 80 cm, and no useful purpose is served by taking the foundation deeper.

(*ii*) Only for medium loads, it is advantageous to take the foundation below 80 cm.

If γ and allowable settlement are different from the values adopted for the charts in Figures 2 to 4, curves can be prepared as indicated in this article and made use of, for economical design of foundations. If the footing is rectangular, square or circular, the same procedure can be adopted by using the relevant equation instead of Equations (1) and (2).

The procedure suggested here will lead to fixing the most economical size of footing and thereby effect savings. It is expected that in large scale construction activities, the savings will be substantial.

Notations

b = Width of Wall, cm

B = Width of Footing, cm

D_f = Depth of Footing, cm

N = Standard Penetration Value

N_q, N_γ = Bearing Capacity Factors

q = Effective Surcharge, kg/sq cm

q_a = Net Soil Pressure for a Specified Settlement of 40 mm, kg/sq cm

q_s = Net Safe Bearing Capacity, kg/sq cm

Q = Net Allowable Load per metre length, t/m

W = Net Load from the Structure, kg

W' = Correction Coefficient for Water-table

γ = Unit Weight of Soil, kg/cc

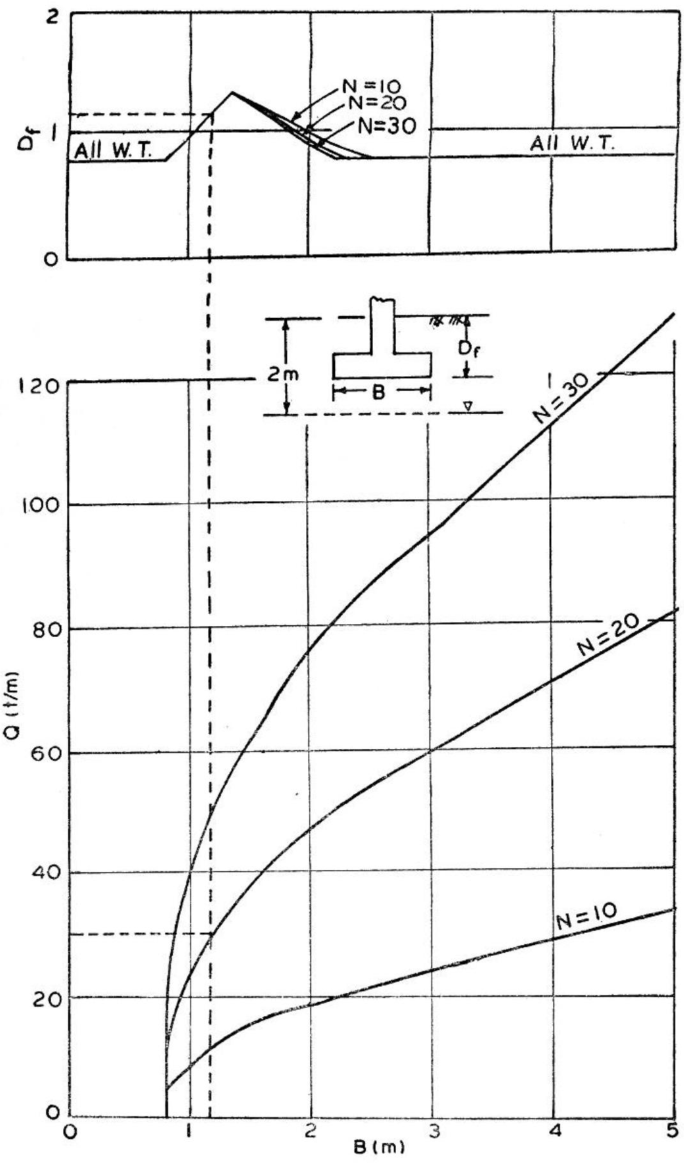

FIGURE 5 : Chart for worked out example.

APPENDIX I

Worked out Example

Data

Load from superstructure $=Q=30$ t/m

$N=20$ $\gamma_d=0.0016$ kg/cc

Permissible settlement $=40$ mm

Depth to water-table $=2$ m

Find the economical dimensions for the strip footing.

Procedure

The relevant lines for the water-table at 2 m below ground level are reproduced in Figure 5, from Figures 2 and 3. An interpolation is effected for $N=20$ from these curves. For the known Q, the required B and D_f are read as shown in the figure. The values read are :

$B=115$ cm $D_f=115$ cm

These values are rounded off to $B=120$ cm and $D_f=120$ cm. While rounding off, the values to the right of the point in the curves must be chosen. Thus, for points on the right side of the peak in the curve connecting B and D_f, the rounding off will lead to lower D_f values.

References

"*Indian Standard Code of Practice for Determination of Allowable Bearing Pressure on shallow Foundations*" IS : 6403—1971.

TAYLOR, D.W. (1948) : "*Fundamentals of Soil Mechanics.*" John Wiley and Sons, Inc., New York.