COMPUTER PACKAGE
ON
ANALYSIS AND DESIGN OF CONTINUOUS FOOTING

A DISSERTATION

Submitted in partial fulfilment of the
requirements for the award of the degree
of
MASTER OF ENGINEERING
in
CIVIL ENGINEERING
(With Specialization in Computer Aided Design)

By

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MARCH, 1999

CANDIDATE'S DECLARATION

I hereby declare that the work which is presented in the dissertation entitled **"COMPUTER PACKAGE ON ANALYSIS AND DESIGN OF CONTINUOUS FOOTINGS"**, in partial fulfillment of the requirements for the award of degree of **Master of Engineering** with specialization in **Computer Aided Design** submitted in the **Department of Civil Engineering, University of Roorkee, Roorkee** is an authentic record of my own original work carried out from October 1998 to March 1999, under the guidance of **Dr. G. Ramasamy**, Professor, Department of Civil Engineering, University of Roorkee.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree or diploma.

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CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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ACKNOWLEDGEMENT

I feel immense pleasure in expressing my profound sense of deep respect, sincere gratitude to **Dr. G. Ramasamy**, Professor, Department of Civil Engineering, University of Roorkee, for his rational guidance, invaluable suggestions and constant encouragement during all the stages of this work. He has displayed unique tolerance and understanding at every step of progress and encouraged me incessantly. It was very pleasant and inspiring experience for me to work under his guidance.

I am also thankful to my friends, CAD Lab staff and Civil Engineering Library staff for their co-operation.

Finally no word of thanks can be great enough I can offer to my parents who have been constant source of inspiration and encouragement throughout the completion of this dissertation.

(BINOD KUMAR)

ABSTRACT

A computer package on the design of continuous footing based on the provision of Indian Standard Code has been developed in C language with graphic features which can be run in any PC system. The analysis of footing is carried out by finite difference method which is a powerful tool of numerical methods. This method provides adequate flexibility to account for stiffness variations of beam and soil along the footing length.

The features of this package include :

(i) Although the package is developed for analysis and design of continuous footing, but it can advantageously be used to analyse and design of isolated footings and combined footings also.

(ii) Limit state design method has been adopted keeping the economy in mind.

(iii) Options to choose grade of concrete, grade of steel, and to revise the design at various stage has been given to user to avoid the repetition of whole data feeding from initial stage of program.

(iv) The user is guided by appropriate knowledge base on codal provisions and practices at various stages.

(v) Footing design has been carried out by following the recommendations of Indian Standard Code of concrete. Graphical output on the screen enables the user to have a better understanding about the design dimension of member.

(vi) Plan and sections of the footing and reinforcement detailing has been depicted using graphics.

Using the program, a few numerical problems have been solved and the parametric results are presented to bring out the following :

(i) Role of stiffness variations of soil and loading conditions on the final design of footing members.

(ii) Role of varying grade of concrete and steel on the final design of footing.

(iii) Role of varying no. of nodes on the final design of footing.

(iv) Role of varying the bearing capacity of soil on final design of footing.

The results show that the package developed can lead to not only faster analysis and efficient design but also can educate the user on various codal provisions and practices on the design of continuous footing.

NOTATIONS

A	Area
A_{st}	Total area of reinforcement
A_{sv}	Total cross-sectional area of stirrup legs or bent up bars within distance S_v
A_w	Area of web reinforcement
B	Width of foundation
b_o	Circumference of critical section for two way shear
D	Overall depth of section
DL	Dead load
d_{eff}	Effective depth
d_{ps}	Effective depth required from punching shear consideration
d_{bm}	Effective depth required from Bending moment consideration
d_{bs}	Effective depth required for Bending shear
E_c	Modulus of elasticity of concrete
E_s	Modulus of elasticity of steel
f_{ck}	Characteristic compressive strength of concrete
f_y	Characteristic strength of steel
h	Spacing of nodes

I	Moment of Inertia
L_o	Anchorage length
L	Length of footing
LL	Live load
l	Length of column
L_d	Development length
M	Bending moment
M_u	Factored bending moment
n	Number of nodes
P	Axial load
P_u	Factored axial load
S_v	Spacing of stirrups
V	Shear force
w	Upward soil pressure
W_u	Upward factored soil pressure
W	Total load
W_L	Wind load
X_u	Neutral axis depth
X_{um}	Neutral axis for balanced section
Y	Deflection of nodal points
τ_{bd}	Average bond stress
τ_v	Nominal stress in concrete
τ_c	Shear stress in concrete
$\tau_{c\ max}$	Maximum shear stress in concrete with shear reinforcement
ϕ	Diameter of bar

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CHAPTER - 1

INTRODUCTION

1.1 GENERAL

Continuous beam foundation may be required where a number of columns are laid in a line. Such situations are commonly encountered in industrial buildings, warehouses, godowns etc. Such a combined beam foundation bridges over weak pockets in the soil and prevents excessive differential settlement between adjacent columns. These foundations provide the added advantage of supporting directly the panel walls of the ground floor of multistoreyed framed buildings.

1.2 USUAL METHODS OF ANALYSIS AND DESIGN

In conventional method of analysis, the soil pressure distribution underneath the footing is generally taken as uniform or linearly varying. Alternatively, Hetenyi's closed form solutions for infinite beam on elastic foundation subjected to concentrated load or moment is adopted (Bowles, 1984) using the principle of super position, the resultant bending moment and shear force at any particularly section of the footing is obtained.

The above method fails to serve the purpose when sectional properties of the footings viz width, depth and moment of inertia vary along the lengths of footing. Further the above method cannot take care of varying compressibility along the length of footing. A few situations can arise when problems involve complexities as non-homogeneous soil, nonlinear material behaviour, variation in material properties and the discontinuities etc., and the same can be taken into account in analysis and design of structures if numerical methods like finite difference method and finite element methods are adopted. Finite difference approach provides adequate flexibility to account for stiffness variations of beam and the soil along the length of footing.

The design of the footing is carried out based on the provisions in the Indian Standard Code 456-1978 using limit state method. Limit state method proves to be more economical. The data required for design are the grades of steel and concrete and the diameter of bars to be used as tension as well as compression reinforcement. The use of shear reinforcement has also been practiced. However the use of shear reinforcement can be avoided by providing adequate depth to resist shear.

1.3 NEED OF PRESENT WORK

The use of the numerical methods for the solution of problems in engineering has become quite common because of the availability of high speed digital computers. Many times revision of analysis, design and drawings are inevitable due to the need of trying alternative designs to affect economy which leads to enormous amount of mechanical type of work. In such cases, a program for analysis and design with graphics facilities relieves the design engineer from hard, routine task.

The computer package enables the designer to quickly revise the design and also check varying alternatives. Hence this work has been taken up as a little step in this direction and an attempt has been made to develop a package for analysis and design of continuous footing foundations.

1.4 OBJECTIVES OF THE COMPUTER PACKAGE

The following objectives have been taken into consideration while formulating this work :

a. Providing a complete analysis and design package for R.C.C. continuous footing foundation.

b. All the design criteria will follow recommendations of IS 456-1978 code of practice for reinforced concrete.

c. Providing an interactive package for design and drafting in order to enable the user incorporate these options.

d. An estimate of quantities to arrive at cost analysis.

e. To carry out parametric study on various aspects of footing design.

f. To provide design drawing to the user.

1.5 OUTLINE OF THESIS WORK

Chapter 1 : This chapter gives general introduction of the problem and objectives of computer package and it's scope.

Chapter 2 : This chapter deals with method of analysis of continuous footings using Winkler's model approach

Chapter 3 : It deals with design procedure and steps involved in the design. Also important provisions as per IS code 456-1978 have been discussed.

Chapter 4 : The salient feature of the package has been discussed.

Chapter 5 : To demonstrate the utility of package few examples have been solved using the package and the results are presented. The results are discussed to bring out the influence of various parameters on the behaviour of footing.

Chapter 6 : Important conclusions have been drawn based on the work presented.

Chapter 7 : This chapter covers limitations of the package and further scope of work in this area.

CHAPTER-2

ANALYSIS OF FOOTING USING FINITE DIFFERENCE METHOD

2.1 GENERAL

The known methods of analysis are the conventional method, soil line method, Hetenyi's closed form solutions for beam on elastic foundation (Bowles, 1984) finite difference method and finite element method. The first three methods of analysis are still widely used if computing is to be done manually. The last two numerical methods viz Finite Difference Method and Finite Element Method are used where high speed digital computers are available. These two methods can be programmed on computer to be used for analysis of any type of continuous footings. These numerical methods are the most accurate and versatile in their use and are also capable of handling complex problem.

2.2 CONVENTIONAL METHOD OF ANALYSIS

The conventional method is based on the assumptions that the footing is infinitely stiff and the subgrade reaction has a straight line distribution.

Following are the steps of design by conventional method :

1. Determine the total column loads :

   $$\Sigma P = P_1 + P_2 + P_3 + \ldots.. \qquad (2.1)$$

   and the location of the line of action of the resultant ΣP. If any column is subjected to any concentrated moment, the effect of moment should be taken into account. The length of footing is chosen in such a way that the line of action of the resultant loads coincides with the c.g. of the footing. The breadth of the footing is chosen based on the allowable soil pressure consideration.

2. Soil pressure distribution per unit length of the footing is determined.
3. Shear force diagram is drawn.
4. Bending moment distribution is drawn along the length of footing.
5. The footing is designed as continuous beam to resist punching shear, one way shear (bending shear) and moment.

2.3 FINITE DIFFERENCE APPROACH

The finite difference method is a very simple and powerful tool of numerical methods. This method seeks to convert differential equations governing a physical phenomenon into a difference equation.

The analysis of continuous footing with this method involves the following procedures :

The footing along it's length is divided into a number of nodes. Finite difference equation corresponding to the differential equation for bending is applied at nodal points of footing. This gives flexibility of varying the parameters like stiffness of soil and footing from node to node. Closer the spacing of nodes, more accurate will be the result. But too closer of spacing of nodes would mean solving a set of very large number of simultaneous equations, costing upon the computer's memory space. Therefore, an optimum spacing of nodes will give fairly accurate results in this form of nodal shear force, bending moment and deflection values.

2.4 WINKLER'S MODEL FOR CONTINUOUS FOOTING

Winkler's foundation (Fig. 2.1) is an approximate model for the analysis of foundation system. It assumes that footing is placed on a bed consisting of a series of closely spaced elastic springs. The springs are assumed to take tension as well as compression. Here the spring constant is related to modulus of subgrade reaction of the soil. This method assumes that soil behaves elastically. This method depicts a simplified model of actual soil behaviour.

According to Winkler's model, the ratio between the soil pressure and the corresponding settlement is termed as modulus of subgrade reaction :

$$K_s = q/\delta \qquad (2.2)$$

where,

K_s = Modulus of subgrade reaction

q = Intensity of soil pressure

δ = Average settlement corresponding to pressure of 'q'

value of K_s for a given soil is dependent on the size of footing. This is due to the fact that for a given value of q, the depth of stress influence (Fig. 2.2) increases with width and hence the settlement increases. Thus with increase in size of footing, K_s value for a soil decreases. Empirical values of K_{s_1} for different soil types as given by Terzaghi (1955) and adopted in IS:2950-PART-1 for a plate size of 30cm x 30cm are given in Table 1 and Table 2 in following page.

Table 1 : Value of Ks_1 (KN/m^3) for granular soil

Relative Density N-Value	Loose < 10	Medium 10-30	Dense 30 and above
Limiting values for K_{s_1}	7200 - 22000	22000-108000	108000-360000
K_{s_1} for dry soil (proposed)	15000	47000	180000
K_{s_1} for submerged	9000	29000	108000

Table 2 : Value of K_{s_1} (KN/m^3) for cohesive soil

Consistency	Stiff	Very stiff	Hard
Unconfined compressive strength q_u (KN/m^3)	100 - 200	200-400	400 and above
K_{s_1} value	27000	54000	108000

2.4.1 Corrections to Modulus of Subgrade Reaction Value

The values of modulus of subgrade reaction (Fig. 2.3) as obtained from plate load test or table 1 should be corrected for the effect of size as well as length of footing.

2.4.1.1 Correction for size of footing

Larger the size of footing, deeper the zone of influence and larger will be the settlement, the effect of size on K_s must be evaluated.

As per Terzaghi, correction in the case of clay soil

$$Ks' = \frac{B_p}{B} Ks_1 \tag{2.3}$$

correction in the case of cohesionless soil

$$Ks' = Ks_1 \left[\frac{B_p (B + 0.3)}{B (B_p + 0.3)} \right]^2 \tag{2.4}$$

where B_p = size of square plate

B = width of footing in meters

Ks' = corrected value of modulus of subgrade reaction

Ks_1 = modulus of subgrade reaction as for a plate of 0.3 m x 0.3 m

2.4.1.2 Beam correction or correction for shape

The value of Ks' obtained should be corrected as below for beam action in the case of clays when size of footing is rectangular.

$$Ks = Ks' \left[\frac{m + 0.5}{1.5\ m} \right] \tag{2.5}$$

where $m = L/B$

L = Length of footing

Beam correction is not applied in case of sands.

Therefore in sand $Ks = Ks'$

2.5 DEVELOPMENT OF FINITE DIFFERENCE ALGORITHM FOR CONTINUOUS FOOTING PROBLEM

For the development of finite difference equations and programming logic, in which footing is divided into 'n' number of equally spaced nodes and loaded with a number of columns is considered (Fig. 2.1a)

n = Number of nodes

E = Modulus of elasticity of footing material

L = Length of footing

B = Width of footing

I_i = Moment of inertia of the footing cross section at ith node

X_j = Distance of jth column from left end of the footing

P_j = Axial column load at jth column

Bm_j = Bending moment at jth column point

N = Number of columns

The footing is divided into (n-1) equal parts each of length h, by n number of equally spaced nodes such that

$$h = L/(n-1) \tag{2.6}$$

Assuming a stepped base pressure distribution (Fig. 2.1c), the values of nodal spring reactions are

$$R_1 = 1/2 \ Ks_1 \ B \ h \ y_1$$

$$R_2 \text{ to } R_{n-1} = Ks_i \ B \ h \ y_i$$

$$R_n = 0.5 \ Ks_n \ B \ h \ y_n$$

Differential equation for moment is

$$\frac{d^2y}{dx^2} = - M/EI \tag{2.7}$$

Using central differences, the corresponding finite difference equation is given by

$$\frac{1}{h^2}\left[y_{i-1} - 2y_i + y_{i+1}\right] = -\frac{M_i}{EI_i} \tag{2.8}$$

Applying equation (2.8) at node 2

$$\frac{EI_2}{h^2}\left[y_1 - 2y_2 + y_3\right] = - M_2 \tag{2.9}$$

or $$\frac{EI_2}{n^2}\left[y_1 - 2y_2 + y_3\right] = - 1/2\ Ks_1\ B\ h^2 y_1 \tag{2.10}$$

Rearranging and assuming $E/h^2 = C$ (const)

$$y_1\ (CI_2 + BKs_1\ h^2/2) - 2CI_2 y_2 + CI_2 y_3 = 0 \tag{2.10a}$$

Similarly at node 3

$$\frac{EI_3}{h^2}\left[y_2 - 2y_3 + y_4\right] = - (R_1\ 2h + R_2 h - P_1(2h-X_1) + Bm_1)$$

i.e. $$BKs_1\ h^2 y_1 + (CI_3 + BKs_2\ h^2)y_2 - 2CI_3 y_3 + CI_3 y_4 = P_1(2h-X_1) - Bm_1) \tag{2.11}$$

Finite difference equation for ith node,

$$BKs_i\ h/2\ (i-1)\ h\ y_i + BKs_2\ h^2(i-2)y_2 + \ldots + BKs_i\ h(i-j)\ h\ y_j + \ldots BKs_{i-2} h2hy_{i-2}$$

$$+ (CI_i + (Ks_{i-1})Bh^2)\ y_{i-1}) - 2\ C\ I_i y_i + CI_i\ y_{i+1} = P_i\ ((i-1)h - X_1) +$$

$$P_2\ ((i-1)h - X_2) + \ldots\ldots\ldots\ BM_1 - BM_2\ \ldots\ldots - BM_K \tag{2.12}$$

(n-2) no. of equations can be obtained by writing the equation at each of the node from 2nd to (n-1)th node.

Remaining two equations are obtained when the two equilibrium conditions $\Sigma M=0$ and $\Sigma V=0$ are applied.

$\Sigma M = 0$, Taking moment about right end of footing

$R_1(n-1)h + R_2(n-2)h + ... + R_i(n-i)h + ...$

$$= \sum_{i=1}^{N} P_i(L-X_i) - BM_i$$

$$BKs_1 y_1 (n-1)\, h^2/2 + BKs_2 y_2\, h^2(n-2) + ..,.. + BKs_i y_1 h^2(n-i) + ...$$

$$+ BKs_{n-1} y_{n-1}\, h^2 = \sum_{i=1}^{N} P_i(L-X_i) - BM_i \qquad (2.13)$$

$\Sigma V = 0$, gives

$$R_1 + R_2 + R_3 + ... + R_n = P_1 + P_2 + P_3 + ... + P_n \qquad (2.14)$$

$$\text{or} \quad BKs_1\, h/2\, y_1 + BKs_2\, h\, y_2 + BKs_3\, h\, y_3 + ...BKs_n\, h/2\, y_n = \sum_{i=1}^{N} P_i \qquad (2.14a)$$

All the above n simultaneous equations can be written in the matrix form as

$$[\,A\,]\ [\,Y\,] = [\,K\,] \qquad (2.15)$$

solving these simultaneous equations using matrix method of inversion and multiplication we obtain the nodal deflections.

Knowing deflections, nodal spring reaction can be calculated. Now the structure becomes determinate and we can draw a stepped shear force diagram.

Consequently moments at nodal points are calculated by substituting the calculated deflections in following equation :

$$M_i = -\frac{EI_i}{h^2}\left[y_{i-1} - 2\,y_i + y_{i+1}\right] \qquad (2.16)$$

2.6 FEATURES OF FINITE DIFFERENCE METHOD

1. Method is simple
2. Even complex problem involving varying moment of inertia, varying subgrade modulus and column moments can be handled.
3. Suitable for computer implementation and easily programmable.
4. Acceptable accuracy is obtained for most of the practical purposes.
5. Method is not recommended for solutions of differential equation involving higher than fourth order derivative.

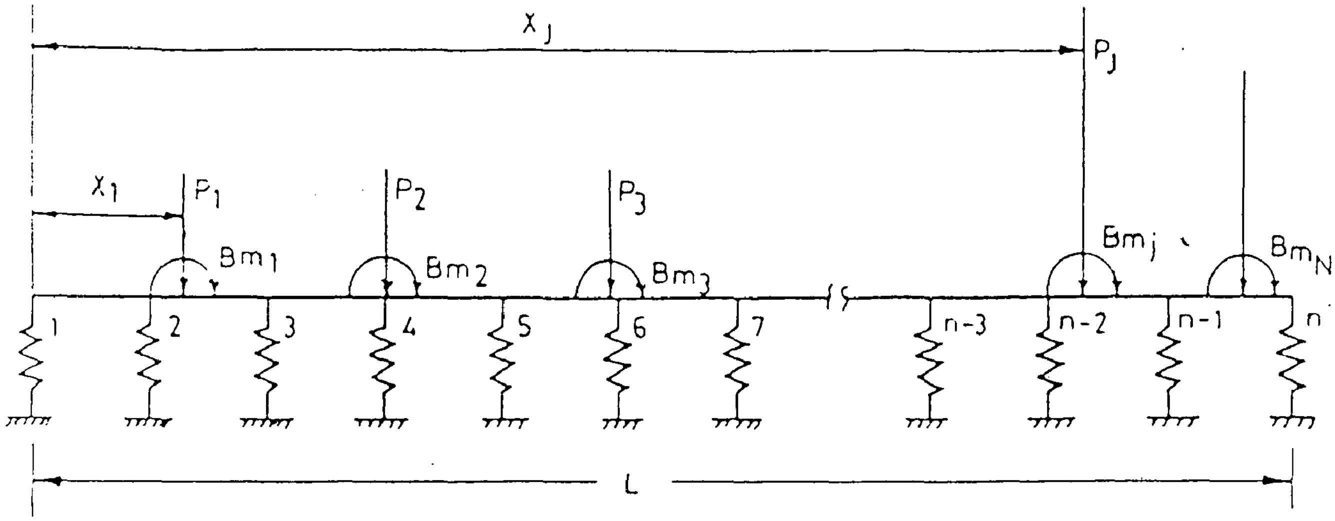


Fig. 2.1(a) Winkler's Foundation Model

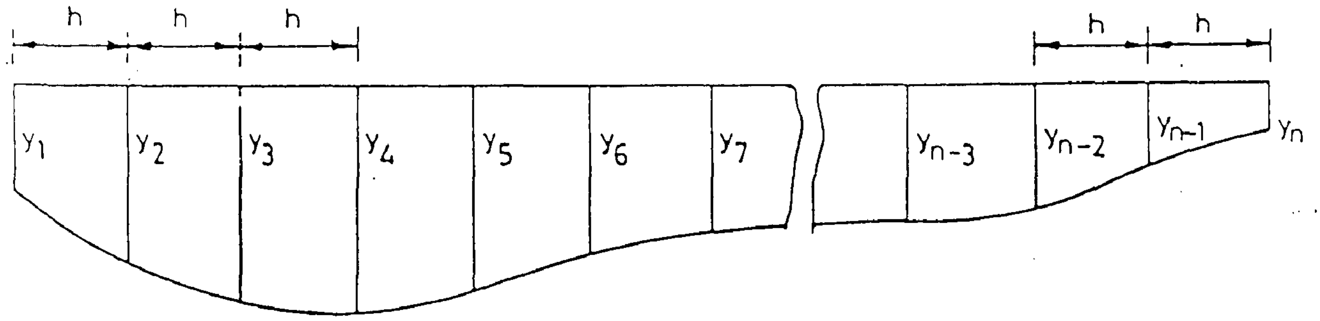


Fig. 2.1(b) Defected Shape

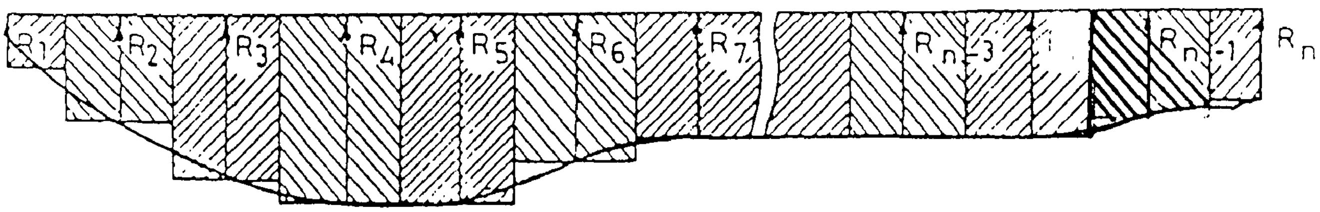


Fig. 2.1(c) Stepped base pressure distribution

Fig. 2.1 Winkler's model for continuous footing

Limit State of Serviceability :

This state correponds to development of excessive deformation. The limit state of serviceability may corrspond to

(a) deflection

(b) cracking

(c) vibration

While determining the deformation, service loads are used, that is, load factors are not included. The deformation is of significance under service loads rather than at collapse.

The limit state concept of reinforced concrete structures takes into account the probalistical and structural variation in the material properties, loads and safety factors.

3.2 SOIL PRESSURE DISTRIBUTION UNDER FOOTING

3.2.1 Soil Pressure Distribution in Conventional Analysis

A footing is assumed to act as rigid body which is in equilibrium under the action of applied forces. As the soil is assumed to behave elastically and stress strain distribution in the soil immediately underneath the base is linear. Soil pressure distributed is assumed to be uniform under the base of footing. However it varies linearly under some condition of soil. Soil pressure in case of sand and clay considerably differs as shown in (Fig. 3.1).

3.2.2 Soil Pressure Distribution in Finite Difference Method

Contrary to soil pressure distribution assumed in conventional analysis, the soil pressure distribution (Fig. 3.1d) in this approach varies considerably throughout the length of footing. For a long continuous footing it is not uncommon to encounter loose soil pocket along the footing. For which the modulus of subgrade reaction value is low. Soil pressure is function of modulus of subgrade reaction value of soil, which is determines for plate load test subjected to corrections for shape and size of footing as discussed earlier. As the soil is not likely to be homogeneous throughout the length of footing, the subgrade reaction value will so vary and subsequently the base pressure of soil also vary. As the non-homogeneity of soil is taken into consideration, the result will be more accurate with respect to conventional analysis.

3.3 STEPS IN THE DESIGN OF FOOTING

3.3.1 Proportioning of Footing

The area of the footing can be determined from the actual unfactored external loads.

$$\text{Area of footing} = \frac{\text{External column load + self weight of footing}}{\text{Allowable bearing capacity of soil (SBC)}}$$

Self weight is generally taken 10% of column load.

Factored allowable soil pressure W_u is obtained as :

distance of c.g. of footing from left end (Fig. 3.2)

$$\bar{x} = \left[\frac{\text{sum of concentrated moment} + P_1 X_1 + P_2 X_2 + \ldots..P_n X_n}{\text{sum of external loads}} \right] \quad (3.1)$$

eccentricity (e) = $\bar{x} - 0.5\ L$ (3.2)

upward soil pressure W = (sum of loads / B L) x (1 + 6 e/L) (3.3)

factored upward soil pressure W_u = Partial safety factor x W, Critical section for punching shear is around the column at a distance of half the effective depth from the face of column (Fig. 3.3).

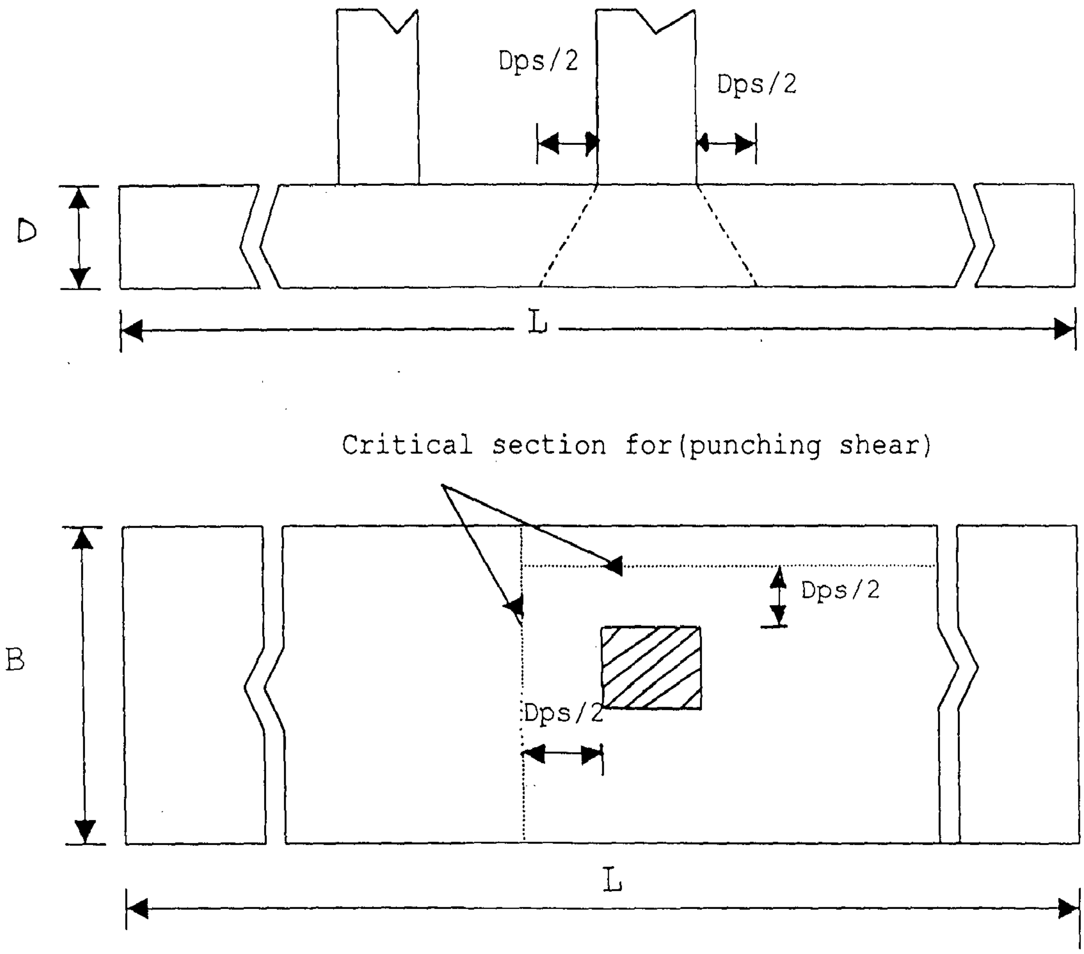


Fig. 3.3 Critical section for punching shear

Factored shear force at critical section

V_u = Maximum factored external column load P_{umax}

$$- \left[W_u \text{ x } (\text{size of column} + d_{ps}/2 \right]^2$$

$$V_u = P_{umax} - \left[W_u \text{ x } (a + d_{ps}/2)^2 \right] \qquad (3.4)$$

Shear strength of concrete of critical section is given by

$$V_c = 4\ (a+d_{ps})\ d_{ps}\ K_s\ \tau_c \qquad (3.5)$$

At the critical section,

$$V_u = V_c \qquad (3.6)$$

$$P_{umax} - \left[W_u\ (a + d_{ps}/2 \right]^2 = 4\ (a+d_{ps})\ d_{ps}\ K_s\ \tau_c \qquad (3.7)$$

where

a = column width

K_s = $0.5 + \beta_c \leq 1$

$\beta_c = \dfrac{\text{short dimension of column}}{\text{long dimension of column}}$

τ_c = $0.25\ \sqrt{f_{ck}}$ (limit state method)

= $0.16\ \sqrt{f_{ck}}$ (working stress method)

f_{ck} = characteristic strength of concrete

Effective depth from punching shear consideration (d_{ps}) is obtained by solving equation (3.7).

3.3.2.2 Depth from bending moment consideration

Bending moment distribution is obtained from the analysis of footing using finite difference approach. From the bending moment distribution, the maximum bending moment is obtained. In limit state design method, maximum factored moment is considered for the design consideration.

$$M_{umax} = PSF \times BM_{max}$$

where, M_{umax} = Maximum factored moment

Maximum moment in the longitudinal direction is given as

$$M_{umax} = 0.36\, f_{ck}\, (X_{umax}/d_{bm})\, B\, d_{bm}^{2}\, (1 - 0.42\, X_{umax}/d_{bm}) \qquad (3.8)$$

Transverse bending moment at the column face (critical section for bending moment) (Fig. 3.4) can be calculated by the following equation :

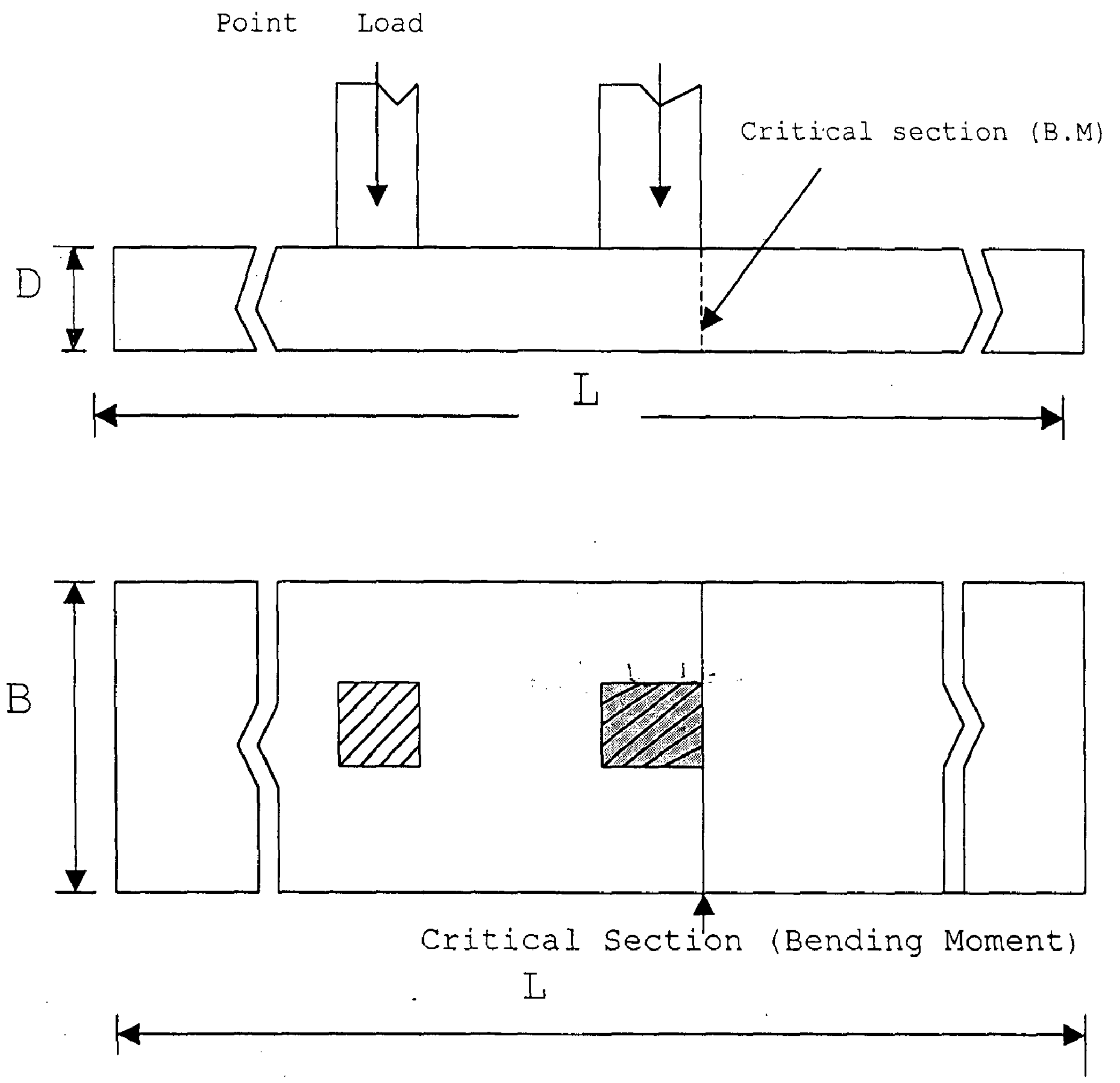


Fig. 3.4 Critical section for bending moment

$$M_{umax} = \frac{W_u L \, [(B-b)/2]^2}{2} \tag{3.8a}$$

where, X_{umax} = neutral axis depth for balanced section.

$$M_{umax} = 0.36 \, f_{ck} \, (X_{umax}/d_{bm}) \, L \, d_{bm}^{\,2} \, (1 - 0.42 \, X_{umax}/d_{bm}) \tag{3.8b}$$

Effective depth from bending moment consideration (d_{bm}) is obtained by solving the equation (3.8) & (3.8b), and the greater value of depth is considered as the effective depth from bending moment considerations.

Table 4 : Grade of steel vs limiting depth of neutral axis

f_y	$(X_{umax}/ d_{bm}$
250	0.53
415	0.48
500	0.46

Putting the limiting neutral axis depth ratio in the above equation (3.8), the equation will take the form as

$$M_{umax} = RBd_{bm}^{2} \tag{3.9}$$

Table 5 : Coefficient of R for different grades of steel

Grade of Steel	R
Fe 250	$0.149 \, f_{ck}$
Fe 415	$0.138 \, f_{ck}$
Fe 500	$0.133 \, f_{ck}$

The higher of two values d_{ps} and d_{bm}, obtained from above two considerations is selected as the effective depth d_{eff}.

3.3.3 Moment of Resistance of the Footing (Ramamrutham and Narayanan, 1995)

Case I

If the dimension provided is greater than it requires from the maximum bending moment consideration the moment of resistance of the footing will increase.

If moment of resistance (M_u) exceeds the limiting moment of resistance then the member should be designed as under reinforced section.

$$\text{percentage Steel} = 50 \left[\frac{1 - \sqrt{1 - \dfrac{4.6\ M_u}{f_{ck}\ bd^2}}}{(f_y/f_{ck})} \right] \tag{3.10}$$

Case II

If due to some restriction, the dimension provided is less than it requires from above said consideration, the moment of resistance of footing will decrease.

In this case, the member should be designed as over reinforced section or doubly reinforced section.

Case III

If the dimension of footing provided equals that requires from maximum bending moment consideration, the moment of resistance of footing equals the maximum bending moment in the footing.

Limiting percentage steel A_{stlim} is determined from following equation

$$M_{ulim} = 0.87\ f_y\ A_{stlim}\ d \left[\frac{1 - f_y A_{stlim}}{B_d f_{ck}} \right] \tag{3.11}$$

3.3.4 Reinforcement Calculation

3.3.4.1 Main longitudinal reinforcement

3.3.4.1.1 Area of longitudinal steel

Area of steel for main longitudinal reinforcement is determined from the following equation :

$$M_{umax} = 0.87\ f_y\ A_{st}\ d \left[1 - \frac{f_y A_{st}}{Bdf_{ck}} \right] \tag{3.12}$$

If A_{st} obtained using Equation (3.12) is less than the minimum steel specified by IS 456-1978 then minimum specified should be provided as following :

Mild strength deformed bars (MS) 0.15%

High strength deformed bars (HYSD) 0.12%

Maximum area of tension reinforcement shall not exceed 0.04 bD.

3.3.4.1.2 Selection of bar diameter and cover (IS:456)

(a) select diameter of bar (ϕ)

(b) total depth of footing D

$= d_{eff} + \phi/2 +$ cover

* Cover = 25 mm or ϕ which ever is greater

* Extra cover ranging from 15 to 50 mm depending upon the severity of the environment is provided.

* The total cover in any case should not exceed 75 mm.

(c) Carry out check to see that

$\phi \leq D/85$

The reinforcement bar is given some specified cover due to following reasons :

(i) To develop the desired strength of a bar by ensuring proper bond between concrete and steel throughout it's perimeter.

(ii) To provide protection against corrosion and fire

$\phi \leq D/85$

3.3.4.1.3 Spacing of longitudinal reinforcement

Spacing actually means the centre to centre distance between bars design spacing (centre to centre) = clear spacing + ϕ

Code has specified the clear spacing between the bars.

(a) Minimum clear spacing shall be maximum of (IS:456)

(i) ϕ, if all bars are of equal diameter

(ii) Highest ϕ, if bars are of unequal diameter

(iii) Nominal maximum size of coarse aggregate + 5 mm

(b) Maximum clear spacing :

The horizontal distance between parallel reinforcement bars near the tension face of a beam shall not be greater than the value given in table

(6) depending upon the amount of redistribution of moments and the characteristic strength of the reinforcement.

Table 6 : Clear Distance Between Bars vs Grade of Steel (IS:456)

Grade of Steel N/mm^2	Percentage redistribution to or from section considered				
	-30	-15	0	+15	+30
	Clear distance between bars				
250	215	260	300	300	300
415	125	155	180	210	235
500	105	130	150	175	195

If there is no redistribution of moments, the maximum clear spacing between bars for different grade of steel should be in accordance with zero redistribution.

3.3.4.2 Transverse reinforcement

Transverse reinforcement should be provided into groups proportionate in sectional area to the column loads. The transverse reinforcement under each column should be provided within a band (Fig. 3.5) having a width equal to the width of the column plus two times the effective depth of the foundations.

Transverse maximum bending moment can be obtained from the following equations :

$$Mu_{max} = \frac{Wu \times L\ [(B-b)/2]^2}{2} \qquad (3.13)$$

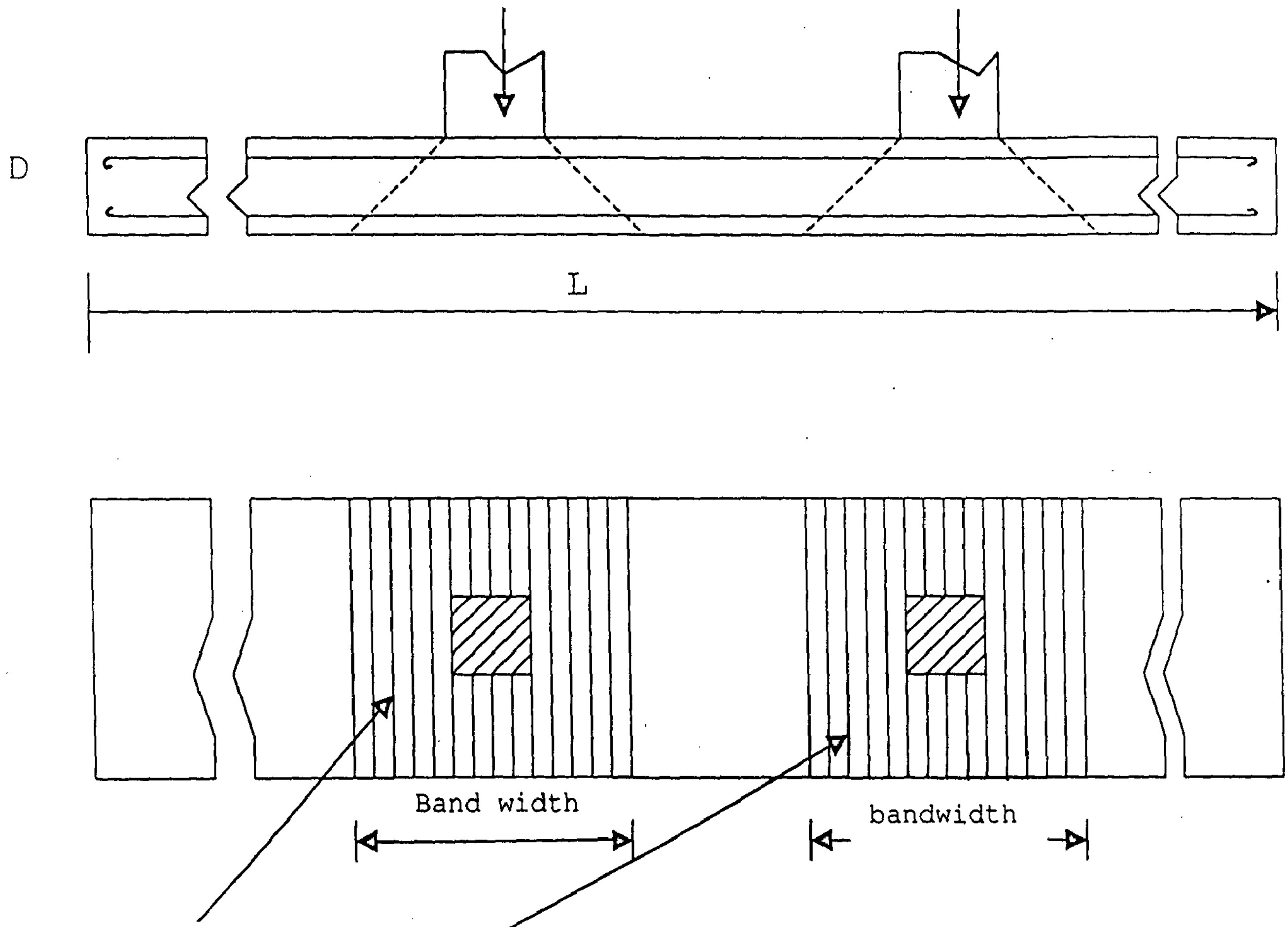


Fig. 3.5 Transverse reinforcement

Area of reinforcement in the transverse direction is given as

$$Mu = 0.87\ f_y\ Ast_2\ d \left[1 - \frac{f_y Ast}{Bdf_{ck}} \right] \qquad (3.14)$$

with the help of above equation Ast_2 can be calculated.

Selection of bar diameter and spacing calculation will be similar to that adopted in case of longitudinal reinforcement.

3.3.4.3 Compression reinforcement

The necessity of using steel in the compression region arises due to two main reasons :

(i) When depth of beam is restricted, the strength available from a singly reinforced beam is inadequate.

(ii) At a support of continuous beam where bending moment changes sign.

If considerable hogging moment come of the column points, the alternate bars of tensile reinforcement should be bent up to compression face for a specified distance from column point at either side of column.

If alternate bars are bent up to compression face the area of steel provided will be equal to half the area of main longitudinal steel.
However in general case, minimum compression reinforcement is provided throughout the length of footing.

3.3.4.4 Shear reinforcement

First of all, the shear strengths of footings is checked in one way bending action and two way bending action. When bending is primarily one way, the footing should be checked in vertical shear. When bending is primarily two way, the footing should be checked in punching shear.

When nominal shear stress at critical sections (d in case of one way shear and d/2 in case of two way shear) exceeds the design shear strength of concrete, shear reinforcement is must to provide.

Shear strength of concrete depends on percentage of main steel as well as grade of concrete.

For one way action,

$$\tau_v = \frac{V_u}{bd} \qquad (3.15)$$

For two way action,

$$\tau_v = \frac{V_u}{b_o d} \tag{3.16}$$

where b_o = perimeter of the critical section.

If τ_v exceeds τ_c (design shear strength), the shear reinforcement shall be provided to carry a shear equal to

$$V_{us} = V_u - \tau_c bd \tag{3.17}$$

3.3.4.4.1 Spacing of shear reinforcement will be as following :

(i) For vertical stirrups

$$V_{us} = \frac{0.87 f_y A_{sv} d}{S_v} \tag{3.18}$$

(ii) For inclined stirrups or a series of bars bent up at different cross section

$$V_{us} = \frac{0.87 f_y A_{sv} d (\text{Sin } \alpha + \text{Cos } \alpha)}{S_v} \tag{3.19}$$

(iii) For single bar or single group of parallel bars, all bent up at the same cross section

$$V_{us} = 0.87 f_y A_{SV} \text{Sin } \alpha \tag{3.20}$$

where α = angle between the inclined stirrup or bent up bar and the axis of the member, not less than 45^{0} and

S_v = spacing of the stirrups or bent up bars along the lengths of the member.

3.3.4.4.2 Maximum spacing of shear reinforcement (As per IS Code 456)

The maximum spacing of shear reinforcement measured along the axis of the member

is not greater than 0.75 d (for vertical stirrups)

is not greater than d (for inclined stirrups)

In no case spacing will exceed 450 mm

where d = effective depth of the section.

3.3.4.4.3 Minimum shear reinforcement

When nominal shear stress at critical section do not exceed the design shear strength of concrete, the minimum shear reinforcement shall be provided as

$$\frac{A_{sv}}{b_{sv}} \geq \frac{0.4}{f_y} \qquad (3.21)$$

Table 7 : **Design Shear Strength of Concretes (τ_c) (N/mm^2) (IS:456)**

$\frac{100\ A_s}{bd}$	Concrete Grade					
	M_{15}	M_{20}	M_{25}	M_{30}	M_{35}	M_{40}
0.25	0.35	0.36	0.36	0.37	0.37	0.38
0.50	0.41	0.48	0.49	0.50	0.50	0.51
0.75	0.54	0.56	0.57	0.59	0.59	0.60
1.00	0.60	0.62	0.64	0.66	0.67	0.68
1.25	0.64	0.67	0.70	0.71	0.73	0.74
1.50	0.68	0.72	0.74	0.76	0.78	0.79
1.75	0.71	0.75	0.78	0.80	0.82	0.84
2.00	0.71	0.79	0.82	0.84	0.86	0.88
2.25	0.71	0.81	0.85	0.88	0.90	0.92
2.50	0.71	0.82	0.89	0.91	0.93	0.95
2.75	0.71	0.82	0.90	0.94	0.96	0.98
3.00	0.71	0.82	0.92	0.96	0.99	1.01

where A_s = Area of longitudinal tensile reinforcement

3.3.5 Distribution of tensile reinforcement [Jain, 1990]

The tensile reinforcement should be provided in accordance with the following guide lines :

(i) In one way reinforced footing, the reinforcement must be distributed uniformly across the full width of the footing.

(ii) In two way reinforced rectangular footing, the reinforcement in the longer direction should be distributed uniformly across the full width of the footing. The reinforcement in the short direction should be provided by dividing the lengths (span) in three bands.

3.3.6 Curtailment of tension reinforcement

For curtailment reinforcement shall extend beyond the point at which it is no longer requires to resist flexure for a distance equal to the effective depth of the member or 12 times the bar diameter which ever is greater.

Flexural reinforcement shall not be terminated in a tension zone unless the following conditions are satisfied.

(a) The shear at the cut off point should not exceed two thirds of that permitted, including the shear strength of stirrups provided.

(b) Stirrup area in excess of that required for shear is provided along each terminated bar over a distance from the cut off point equal to three-fourths the effective depth of the member.

3.3.7 Requirements of reinforcement detailing [Jain, 1990]

The good detailing must fulfill the following requirements :

(i) Reinforcement detailing should be simple for fabrication and placing.

(ii) The crack widths must be within acceptable limits under service conditions. This is achieved by limiting the maximum spacing of reinforcement and minimum amount of reinforcement.

(iii) There should be sufficient space for concrete to be properly poured and compacted.

(iv) The detailing should be such that internal forces are safely transferred from one member to another and from reinforcement to concrete.

All the analysis and design steps are depicted in the flow chart (Fig. 3.6).

3.3.8 Check for bending shear (One way shear) [Jain, 1990]

When bending is primarily one way, the footing should be checked for vertical shear or bending shear. Bending shear stress of critical section at a distance 'd' from the column is checked against design strength of concrete. If bending shear stress does not exceed the design shear strength of concrete, the depth, area of steel and grade of concrete provided are satisfactory.

$$W_u L \left[\frac{L - (b+2d)}{2} \right] = \tau_c Bd \qquad (3.22)$$

If shear stress calculated from eqn. (3.22) exceeds design shear strength of concrete, the depth is increased and reinforcement calculation is revised accordingly.

3.3.9 Check for development length

Calculation for development length in case of continuous footing should be made for the bar at end column.

Tensile force T $= \pi/4\ \phi^2\ \sigma_s$

where,

$\sigma_s = 0.87\ f_y$ in LSM

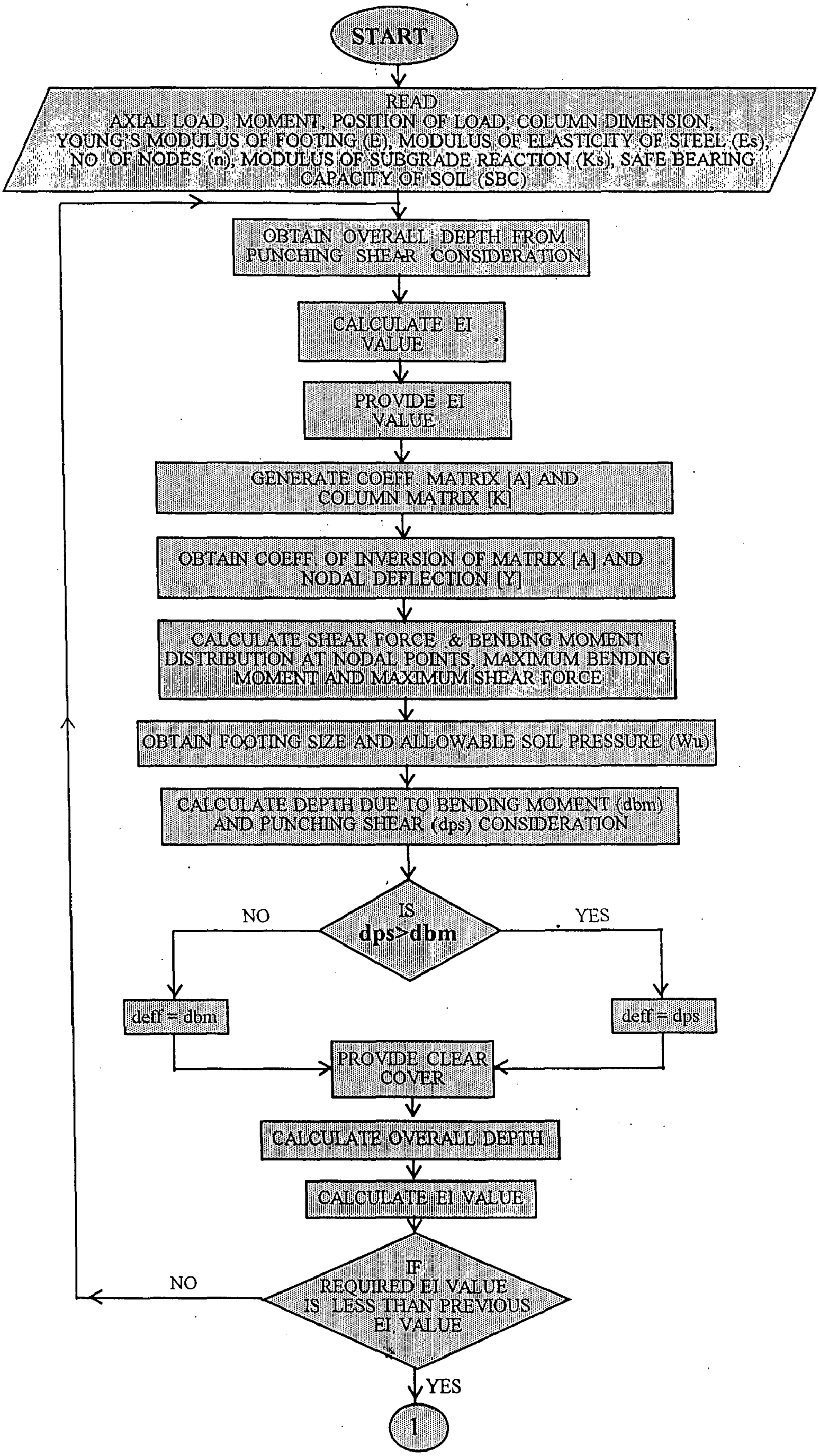
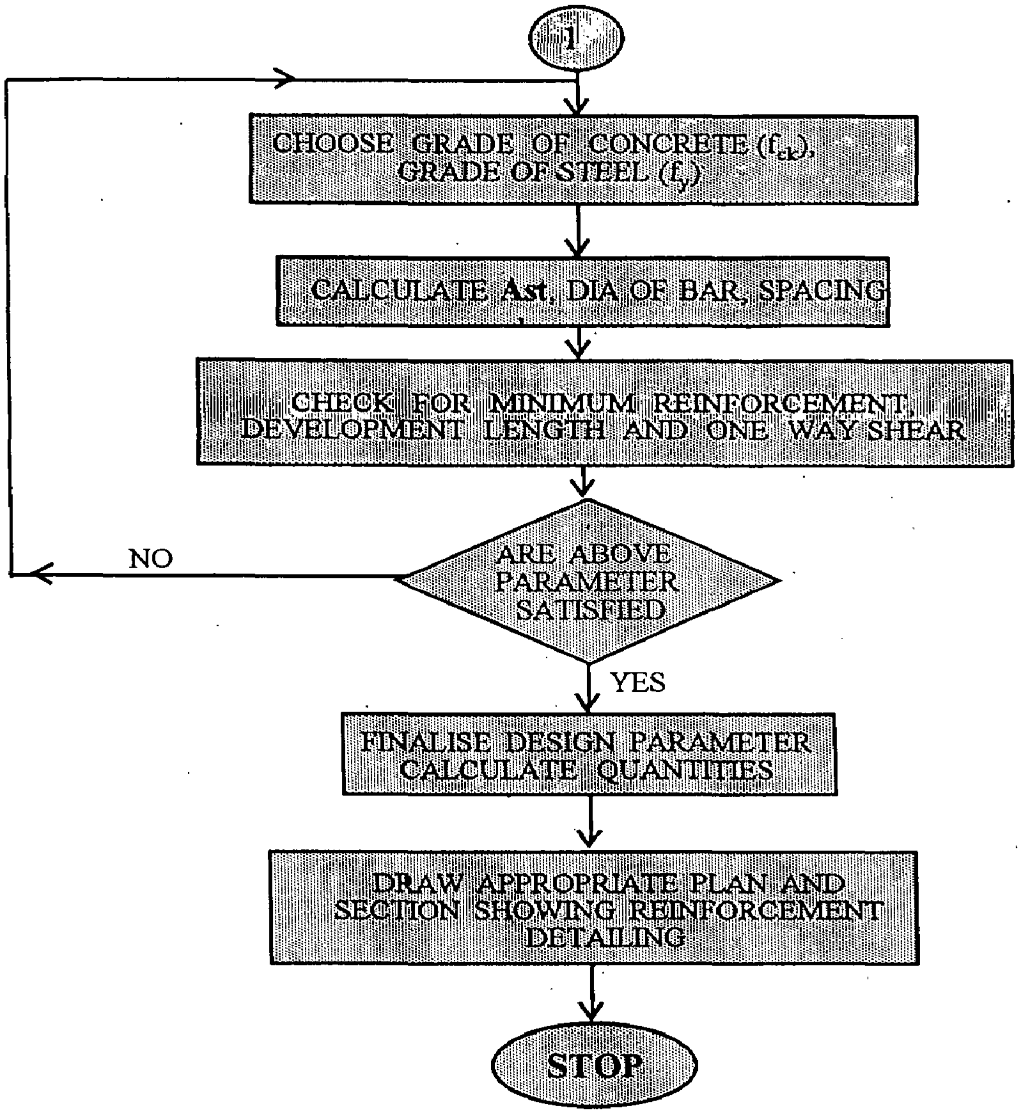


Fig. 3.6 : Flow Chart of Structural Analysis and Design of Continuous Footing


1
CHOOSE GRADE OF CONCRETE (f_{ck}), GRADE OF STEEL (f_y)
CALCULATE Ast, DIA OF BAR, SPACING
CHECK FOR MINIMUM REINFORCEMENT, DEVELOPMENT LENGTH AND ONE WAY SHEAR
ARE ABOVE PARAMETER SATISFIED
NO
YES
FINALISE DESIGN PARAMETER CALCULATE QUANTITIES
DRAW APPROPRIATE PLAN AND SECTION SHOWING REINFORCEMENT DETAILING
STOP

This force is transmitted to concrete by bond action in the embedded length (Fig 3.7)

if τ_{bd} is the average bond stress acting over the surface area, then

$$\pi \phi L_d \tau_{bd} = \pi/4 \phi^2 0.87 f_y$$

$$Ld = \frac{0.87 f_y \phi}{4 \tau_{bd}} \quad (3.23)$$

τ_{bd} = bond stress (N/mm^2)

Table 8 : Permissible Bond Stress τ_{bd} (N/mm^2) for MS bars (IS:456)

Grade of Concrete	M_{15}	M_{20}	M_{25}	M_{30}	M_{35}	M_{40}
τ_{bd} in WSM	0.6	0.8	0.9	1.0	1.1	1.2
τ_{bd} in LSM	1.0	1.2	1.4	1.5	1.7	1.9

Note 1 : The bond stress shall be increased by 25% for bars in compression.

Note 2 : In case of deformed bars, the bond stress given above may be increased by 40% while designing by WSM and by 60% while designing by LSM.

If L_d computed is more than the embedded length of the bar, the diameter of the bar may be changed or bends may be provided in steel to increase development length.

3.3.9.1 Guiding criteria for development lengths

Anchoring bars in tension :

(a) Deformed bars may be used without end anchorage provided development length requirement is satisfied. Hooks should normally be provided for plain bars in tension.

(b) Bends and hooks (IS 2502) (Fig. 3.8)

(i) Bends - The anchorage value of bend shall be taken as 4 times the diameter of bar for each 45° bend subject to a maximum of 16 times the diameter of bar.

(ii) Hooks - The anchorage value of a standard U-type hook shall be equal to 16 times the diameter of this bar.

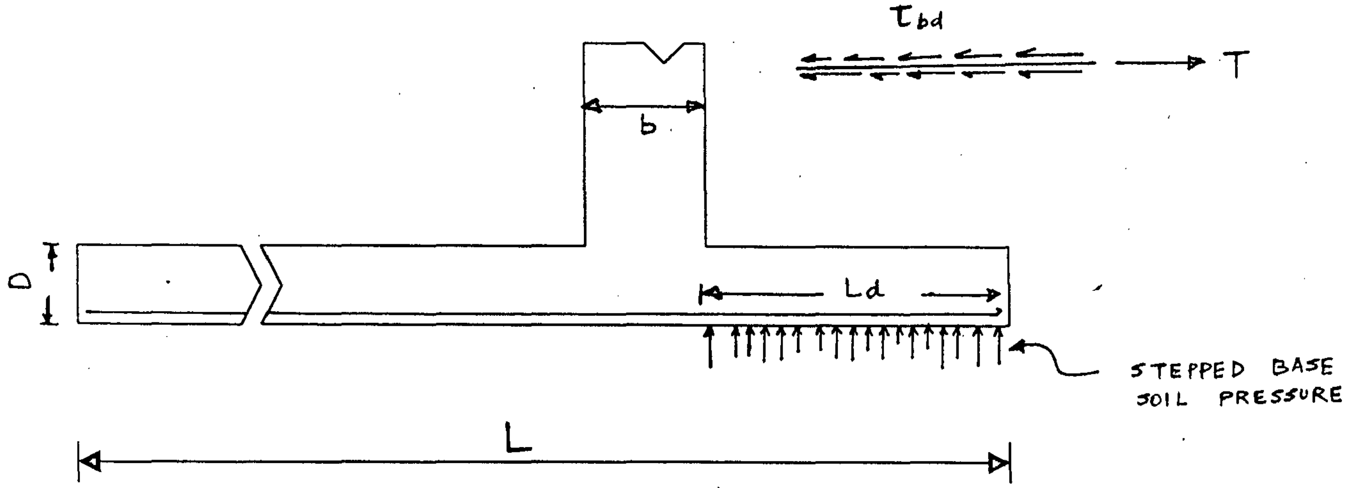


Fig. 3.7 Development length

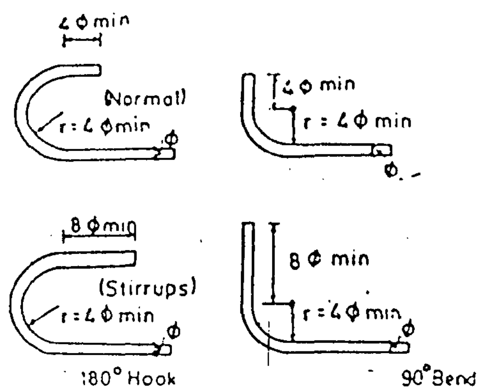


Fig. 3.8 Standard Bend and Hooks (IS:2502)

3.3.10 Check for bearing strength [Jain, 1990]

All forces acting at the base of column should be transferred into the footing. Compressive forces are transferred through direct bearing.

The permissible bearing stress (6_{br}) on full area of concrete is given by

$$6_{br} = 0.45 f_{ck}$$

Actually, this stress ($6b_r$) is the allowable stress in column concrete. The permissible bearing stress in the footing concrete may be increased because the footing area is much larger than the column area, thus permitting dispersion of concentrated load. (Fig. 3.9)

The permissible bearing stress for footing concrete is given by

$$6_{br} = 0.45\ f_{ck}\ \sqrt{A_1/A_2} \leq 0.90\ f_{ck} \tag{3.24}$$

where

A_1 = maximum area of the portion of the supporting surface that is geometrically similar to and concentric with the loaded area.

A_2 = Loaded area at the column base.

In slopped or stepped footings, area A_1 may be taken as the area of the lower base contained wholly within the footing.

The actual bearing pressure $\sigma_{cbr} = \dfrac{P}{bl}$ (3.25)

If the permissible bearing stress is exceeded either in column concrete or in footing concrete, reinforcement must be provided for developing the excess force. The reinforcement must be provided either by extending the longitudinal bars of column in the footing or by providing dowels in accordance with the code.

3.3.10.1 Codal provision for design of anchorage reinforcement (Fig. 3.10)

Following guidelines should be adopted for anchorage reinforcement :

(i) Minimum area of extended longitudinal bars or dowels must be 0.5% of cross sectional area of the supported column.

(ii) A minimum of four bars must be provided.

(iii) If dowels are used their diameter should not exceed the diameter of column bars by more than 3 mm.

(iv) Enough development length should be provided to bars for the compression or tension to the supporting member.

(v) The dowel must extend into the column a distance equal to the development length of column bar. At the same time, the dowel must extend vertically into the footing a distance equal to the development length of the dowel.

3.3.11 Important IS Code provisions

Various Indian Standard Codes give provision to be followed while designing a continuous foundation. The relative provisions are :

(a) IS 456-1978 code of practice for plain and reinforced concrete

(b) Design Aids for reinforcement concrete to IS 456-1978 (SP:16(S&T-1980)

(c) National Building Code

(d) Handbook on concrete reinforcement and detailing

Summary of important IS Code provisions on footing are tabulated in table (9).

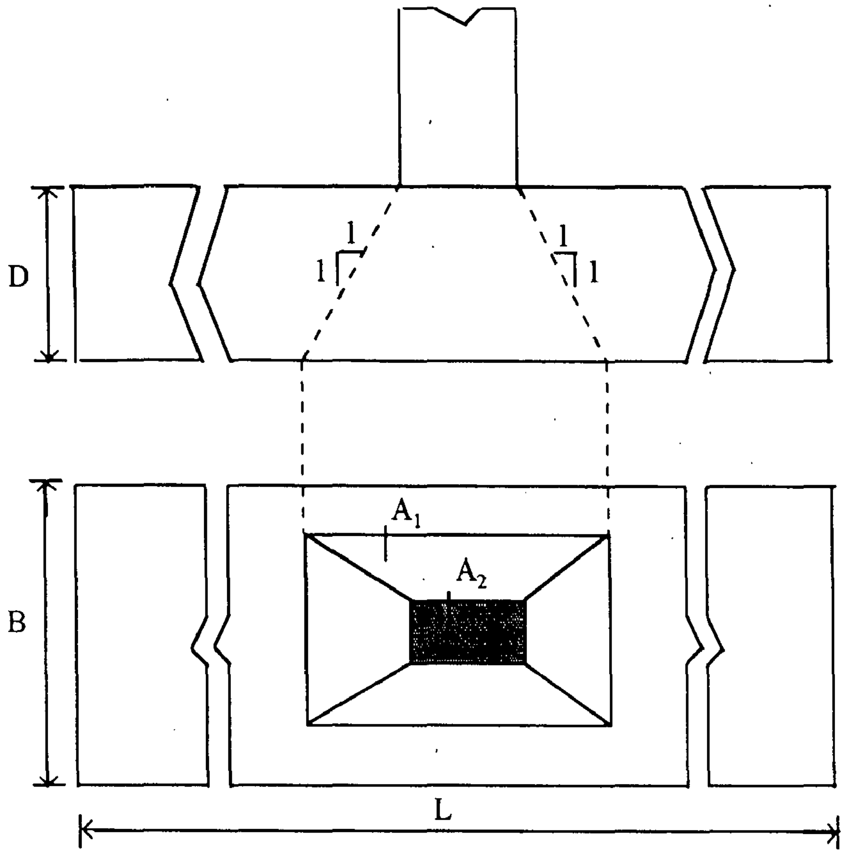


Fig. 3.9 Load Dispersion in the Footing for Bearing Stress Calculation

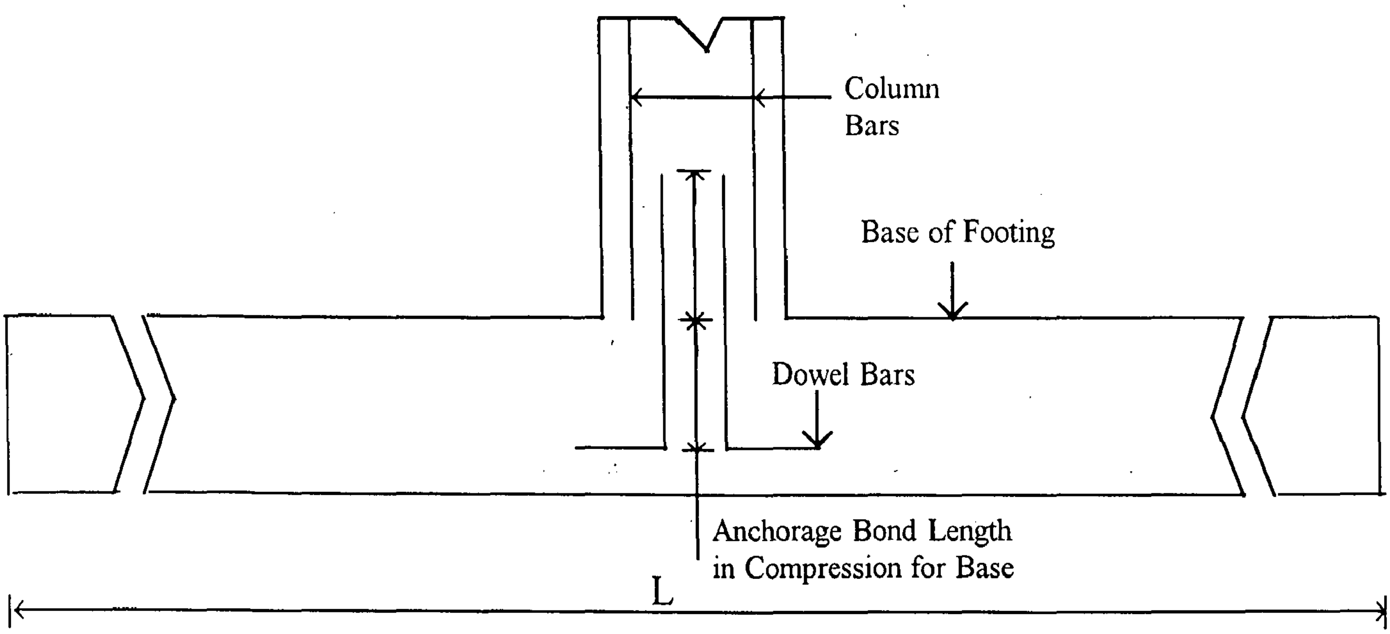


Fig. 3.10 Anchorage Length of Dowel Bar

Table 9 : Summary of codal provisions for footing requirements : IS 456-1978

Design Factor	IS Code Section	General Requirements
Bending moment	33.2.3	Critical section at the face of column
Shear force	33.2.4	For one-way shear, critical section at a distance 'd' from face of column $\tau_v = V/bd$
	30.6.3.1	For punching-shear, critical section at a distance 'd/2' from face of column. $\tau_v = V/b_o d < K_s \tau_c$, $K_s = 0.5 + \beta_c \leq 1$ $\tau_c = 0.25 \sqrt{f_{ck}}$ (LSM)
Transfer of load at the base of column	35.4	Permissible bearing stress in footing concrete $6_{br} = 0.45 f_{ck} \sqrt{A_1/A_2}$ (LSM) $\sqrt{A_1/A_2} < 2$ Dowel bars-minimum 4 No. > 0.5 % of area of column
Development length	25.2.1 25.2.3	$L_d = \frac{\phi \sigma_s}{4\tau_{bd}}$
Cover	25.4.1	25 mm, ϕ which ever is greater
Extra cover	25.4.2	15 to 50 mm Total cover $\leq$ 75 mm

Table 10 : Summary of codal provisions for footing requirements : IS 456-1978

Design Factor	IS Code Section	General Requirements
Diameter of bar	25.5.2.2	$\phi \leq D/8$, D = overall depth of section
Spacing of reinforcement in beam	25.3	Minimum : Highest of (i) dia of bar (ii) 5 mm + size of aggregate
	25.3.2	Maximum spacing : (i) Fe_{250} : 300 mm (ii) Fe_{415} : 210 mm (iii) Fe_{500} : 150 mm In case of no redistribution of moment
Tension reinforcement	25.5.1.1	Minimum (%) area of tension reinforcement is not less than $\frac{0.85}{f_y}$ Maximum reinforcement = 0.04 bD.
Compression reinforcement	25.5.1.2	Maximum area of compression reinforcement = 0.04bD
Shear reinforcement	39.4	Spacing of shear reinforcement
	25.5.1.6	Minimum shear reinforcement $\frac{A_{sv}}{b_{sv}} \geq \frac{0.4}{f_y}$
Partial safety factor	35.4	Table 12
Design shear strength of concrete	39.4	Table 13
Splicing of reinforcement bars	25.2.5	Depends on development length

CHAPTER - 4

SALIENT FEATURES OF THE PACKAGE

4.1 GENERAL

The package developed can also be used to analyse and design of isolated footings, combined footings in addition to continuous footings with many number of column loads.

Input parameters which are needed while using this package are as follows :

(i) Length of footing (L).

(ii) Modulus of elasticity of footing material (E).

(iii) Modulus of elasticity of steel (E_s).

(iv) Number of columns (LP).

(v) Axial load (P) and concentrated moment (M) carried by each column.

(vi) Distance of columns from the left end of the footing.

(vii) Dimension of subsequent column.

(viii) Number of nodes 'n' in which the footing is divided.

(ix) Modulus of subgrade reaction at each nodal point (K_s)

(x) Grade of concrete (f_{ck})

(xi) Grade of steel (f_y)

(xii) Partial safety factor for loading combination (PSF)

(xiii) Clear cover provided to the reinforcement (Cl_ cover)

(xiv) Diameter of longitudinal reinforcement as well as transverse reinforcement

(xv) Diameter of shear stirrups (d_V)

(xvi) Number of legs of stirrups (nleg)

The package has been developed in C language under WINDOWS NT-4 environment in a LAN system on Pentium and is compatible to any IBM machine. The package contains one program including a number of function as well as graphic function to draw the typical section and plan of continuous footing.

4.2 FEATURES OF THE PACKAGE

The package developed in C language uses various facilities of TURBO-C such as modular programming, graphics function, Window input output facility. An attempt has been made for making the package user friendly and interactive.

4.2.1 Data Input and Output

User can feed data through data file or through keyboard by interaction with screen. Data file can be prepared by running specified program on hard disk or through floppy drive. Important features of input data are :

Limit state method has been chosen to design the member in accordance with IS:456-1978 recommendations.

Subsequent input datas are fed for analysis and design part in sequence. Loads, column positions and dimension of column have been put together for better interaction. The results of the program are shown in the form of screen Window output and simultaneously stored in a file.

Output of the analysis part of the program in the form of deflection, bending moment and shear force values at all nodal points has been shown in tabular form of Window screen. It also calculates the maximum bending moment and maximum shear force in the footing member which provide help for design of footing. Subsequent codal provision related to selection of diameter of bar, cover to reinforcement, spacing of reinforcement has been incorporated to provide the information to user at the time of feeding data.

4.2.2 Corrections to Input Data

Corrections to input datas are provided at the subsequent stage of analysis and design. Once tentative proportioning is over program displays all the important input datas. At this stage the user can check any of these data before proceeding further to design part. After necessary corrections are done, again the corrected values are displayed and utilised further in the program.

4.2.3 Knowledge Base

The user of this package should have sufficient knowledge in foundation design and be well familiar to IS code provisions.

But to refresh the memory and to help the new user, the relevant knowledge base at appropriate place is flashed on screen.

4.2.4 Various Checks during Design

The package carries out design checks as necessitated by code during various stage of design. Important design parameters are subsequently checked at various stage for good results.

4.2.5 Graphical Output

Using graphic features of C language, drawing showing typical section, plan and reinforcement detailing have been incorporated. It is to be noted that, these drawings are not to appropriate scale. But it gives adequate details to enable the user prepare detailed design drawings to scale.

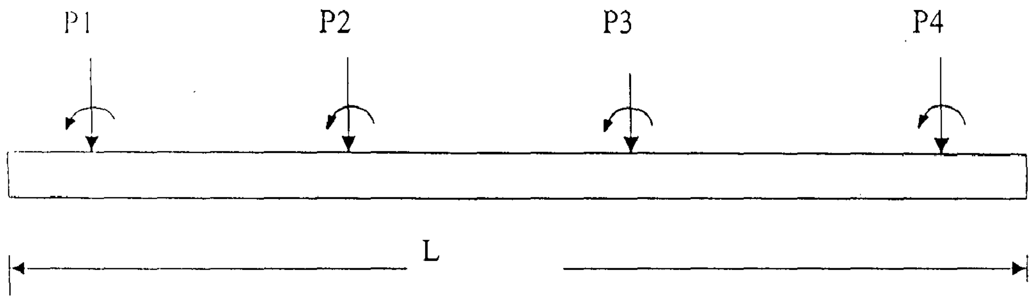
4.2.6 Estimates of Material and Economy

After design is completed, this package provides the user, the total quantity of concrete and steel required. However economy of materials solely depends upon the method of design adopted. Normally foundation costs 15-20% of this cost of superstructure.

4.3 SAMPLE RUN OF A TYPICAL PROBLEM WITH FULL DETAILS

A problem on continuous footing has been solved using the package and input datas as well as results are presented in the form of screen outputs to illustrate some of salient features of the package

Problem :



Length of footing (L) :16.00 m

No. of loaded column :4

Column point	Axial load(KN)	Moment(KNm)	Location from left end(m)	column length(mm)	column width(mm)
1	400.00	150.00	1.50	400.0	400.0
2	300.00	0.00	6.00	400.0	350.0
3	600.00	-200.00	10.00	500.0	500.0
4	500.00	50.00	15.00	500.0	400.0

Base Soil Data :

Safe bearing capacity of soil : 150 KN/m^2

Modulus of subgrade reaction of soil : 40000 KN/m^3

WELCOME

TO

COMPUTER PACKAGE ON CONTINUOUS FOOTING

```
Dear User,

You can feed data by screen(s),
by Input data file through floppy on drive A(A).
If you are using the package for the first time,
use option(s)
TO run program through data file,use option (d)

ENTER YOUR OPTION (s//d) :    s
```

Fig. 4.1 Provisions for data input.

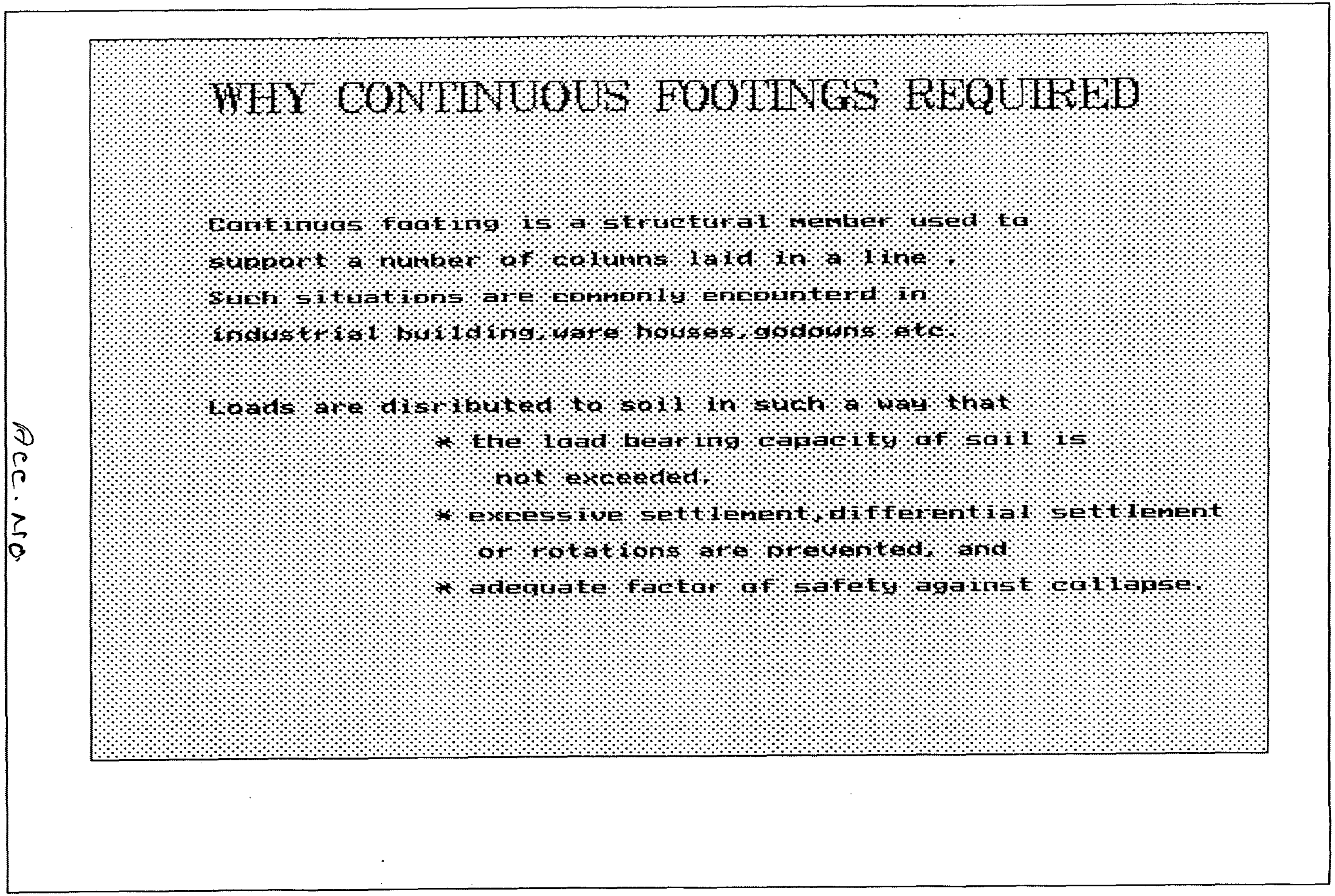


Fig. 4.2 General information on Footings (why continuous footing required.)

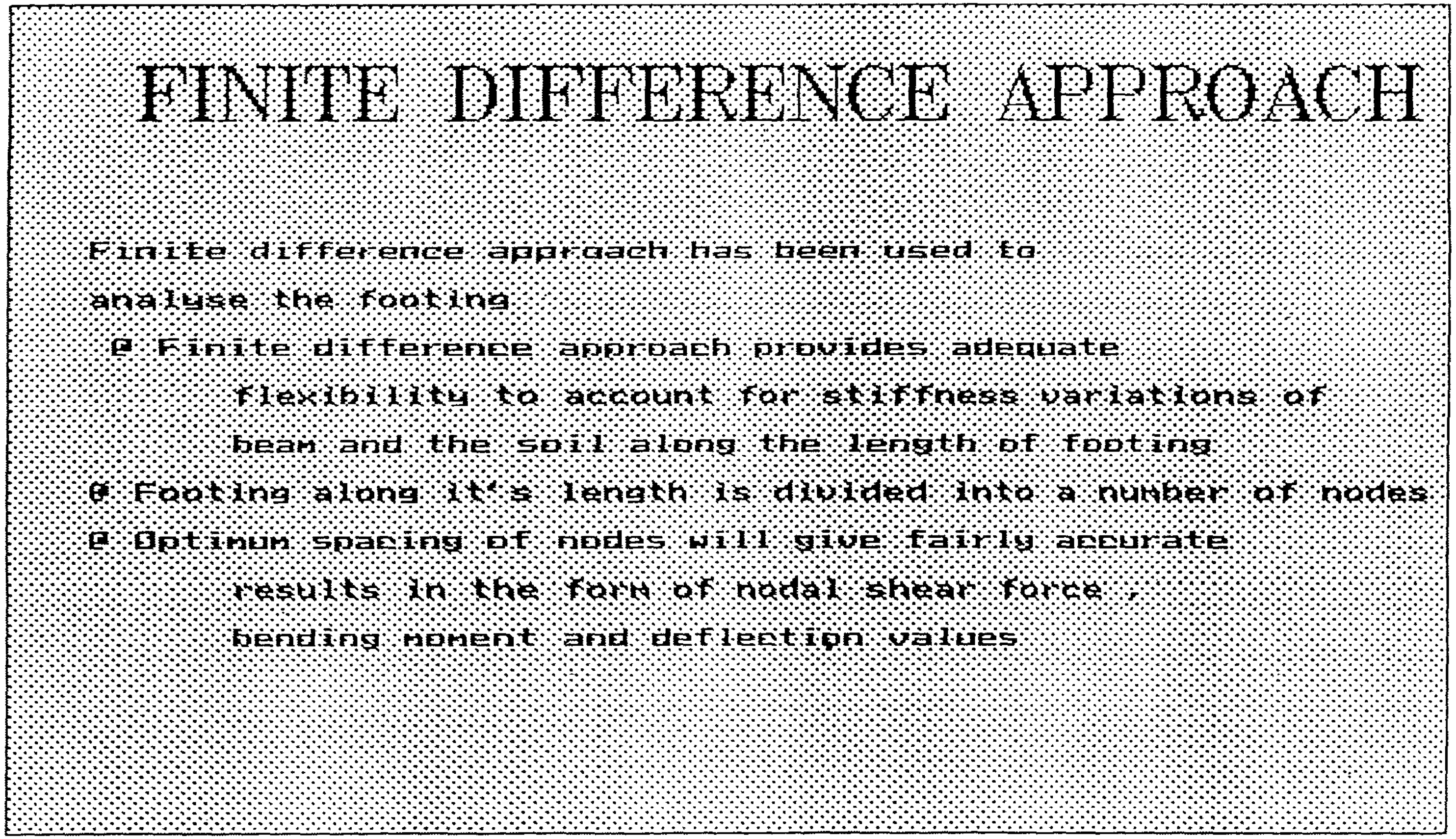


Fig. 4.3 General information about Finite difference approach.

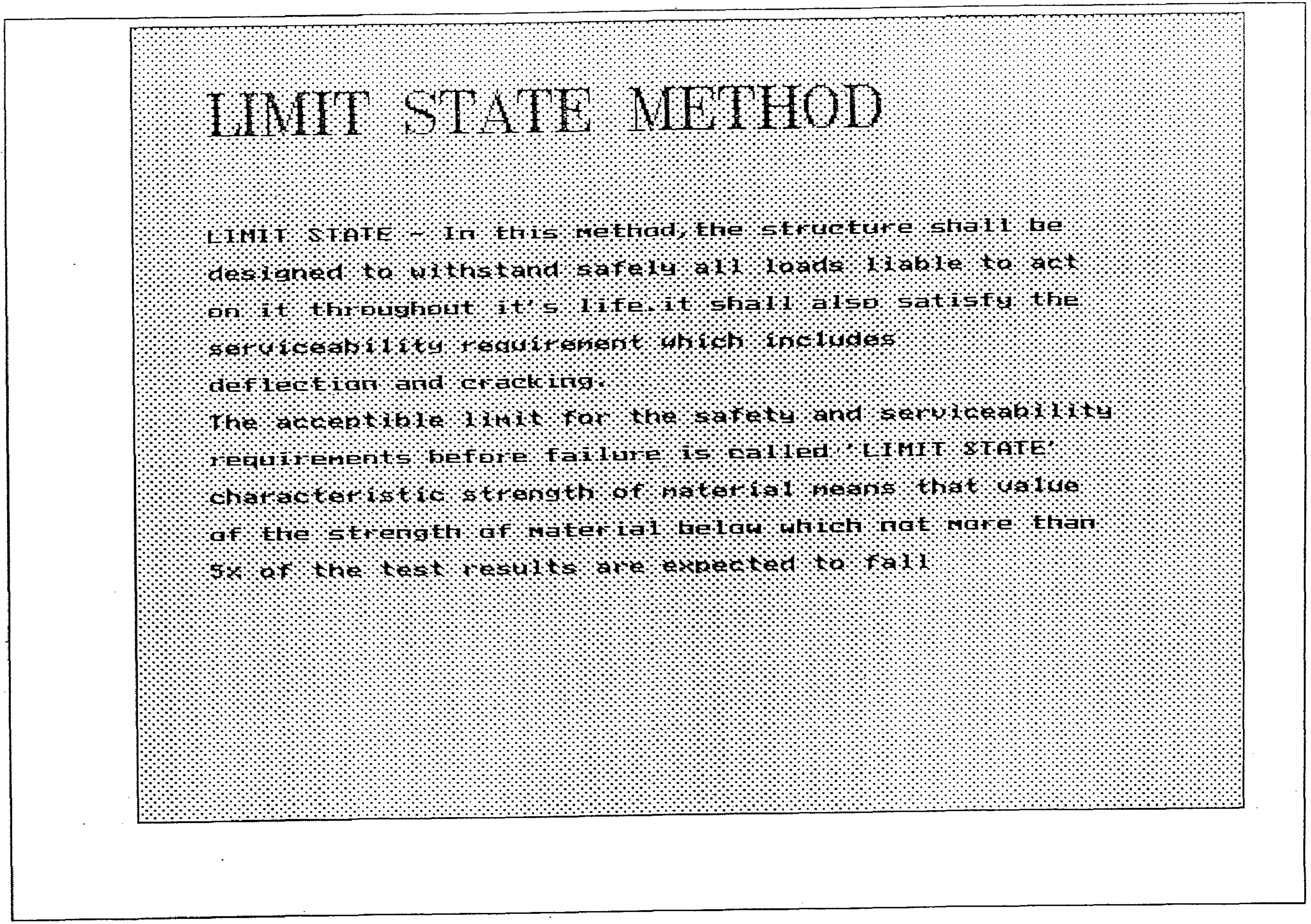


Fig. 4.4 **General information about Limit State method of design.**

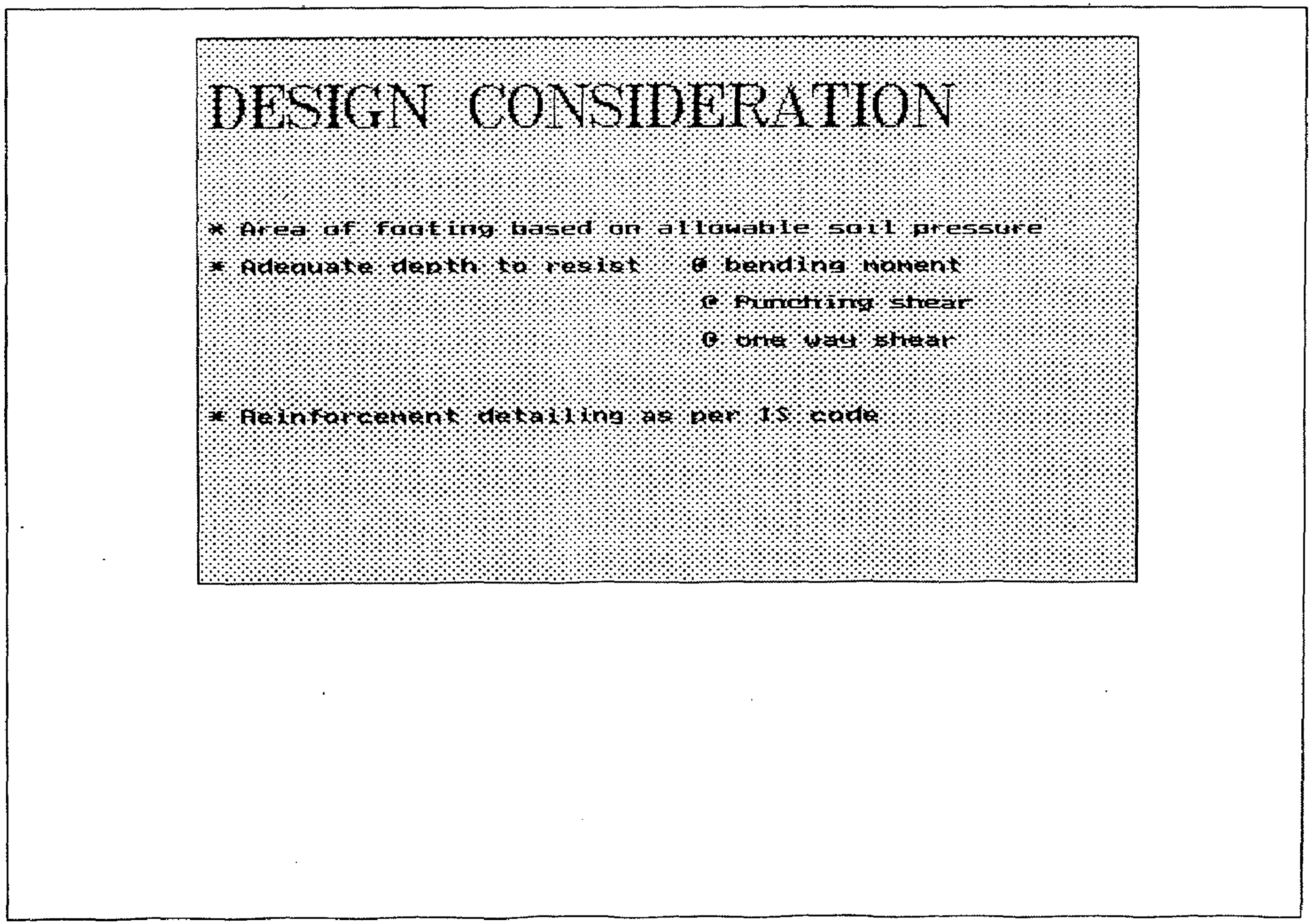


Fig. 4.5 General information on footings (Design consideration).

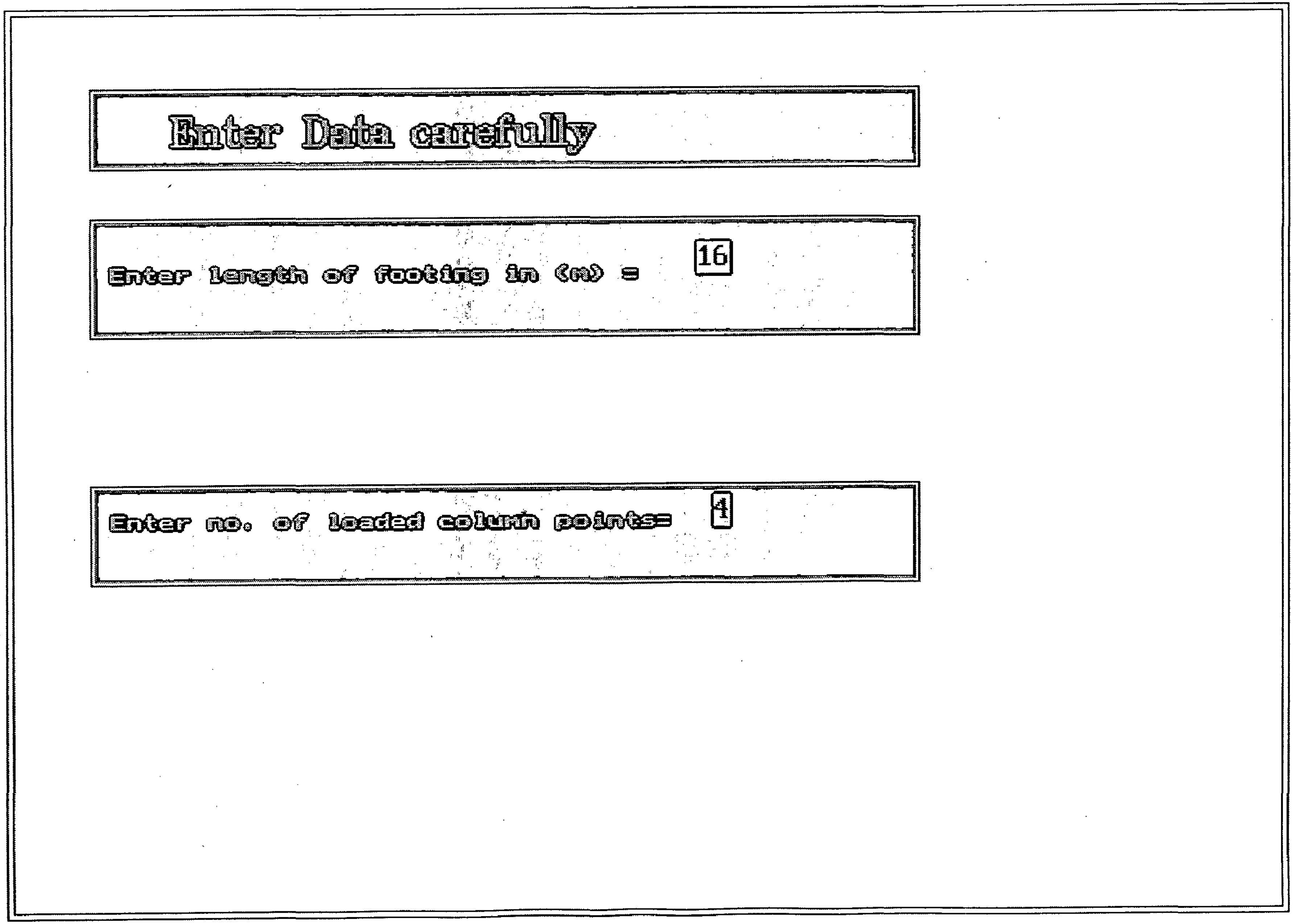


Fig. 4.6 Input data for typical problem on continuous footing.

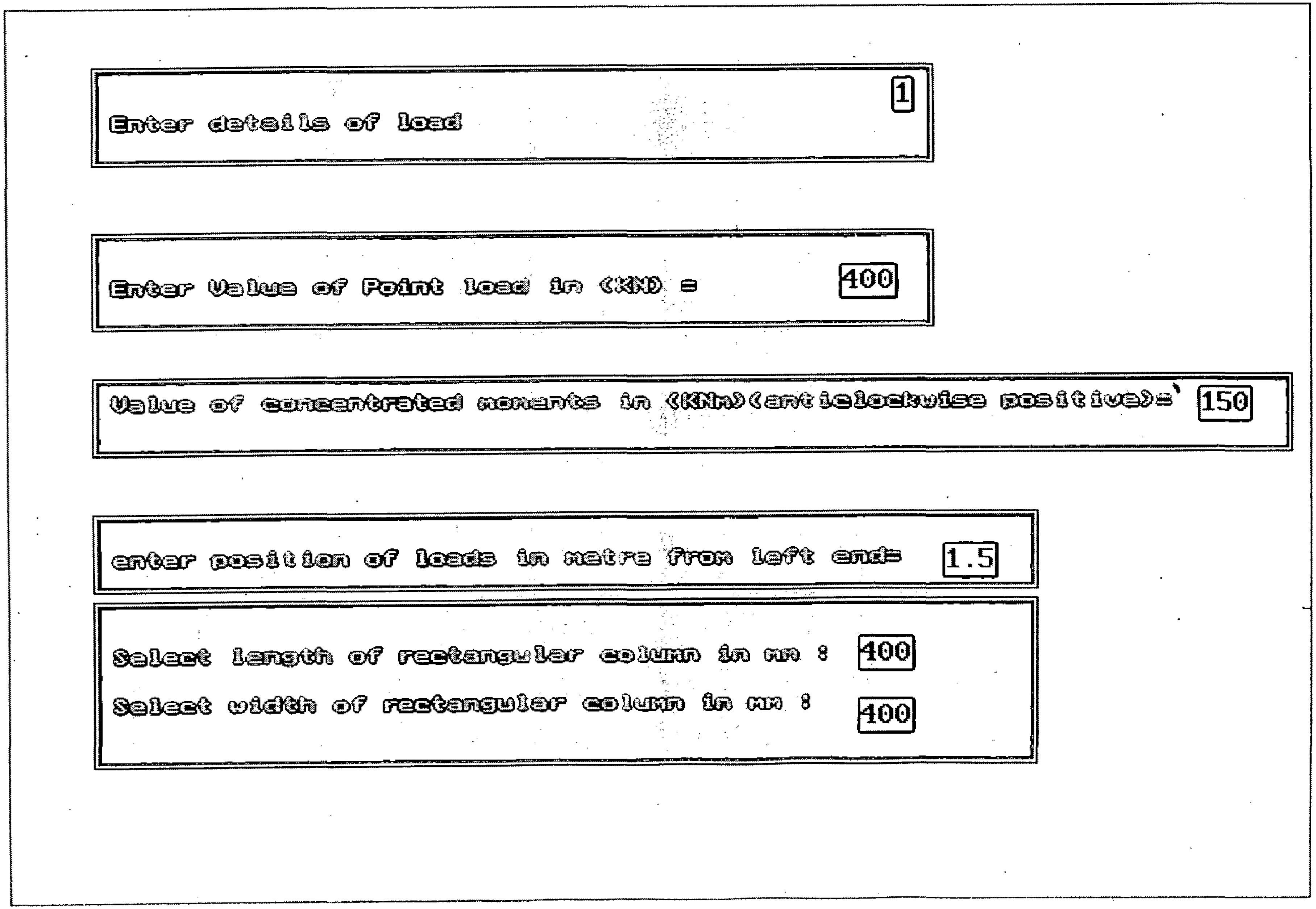


Fig. 4.7 Input data (Dimension of column and loadings)

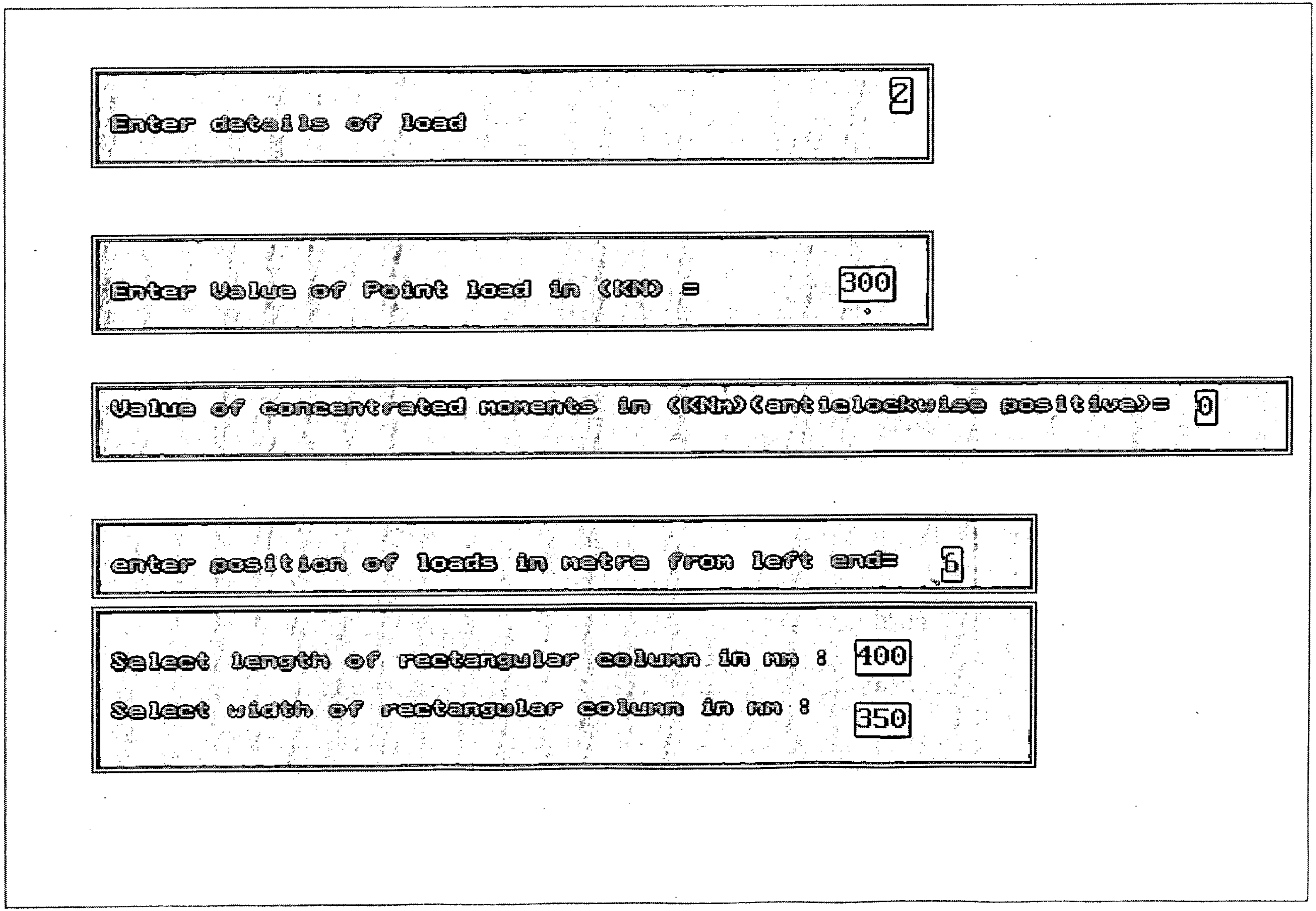


Fig. 4.8 **Input data (Dimension of column and loadings)**

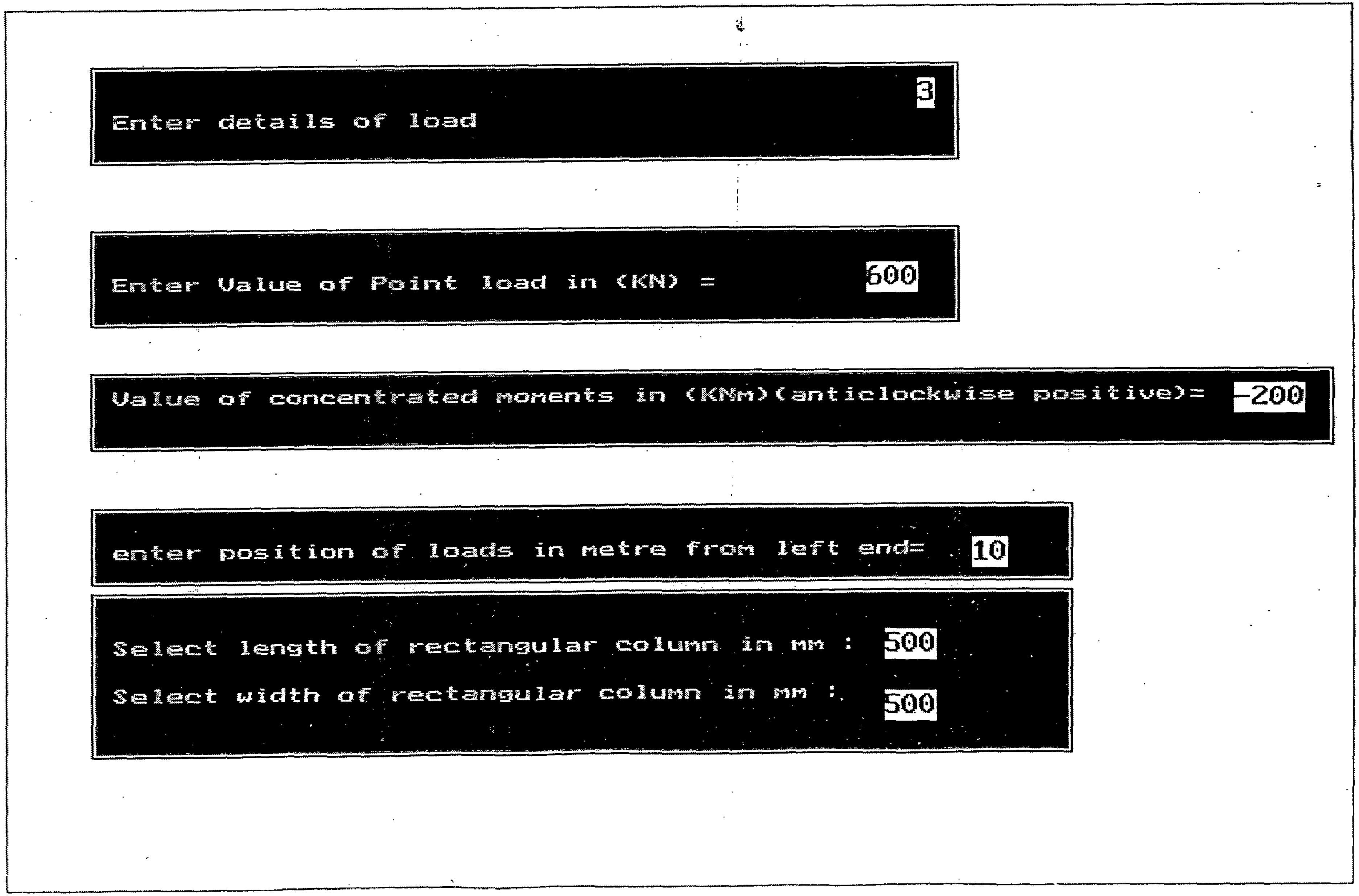


Fig. 4.9 Input data (Dimension of column and loadings)

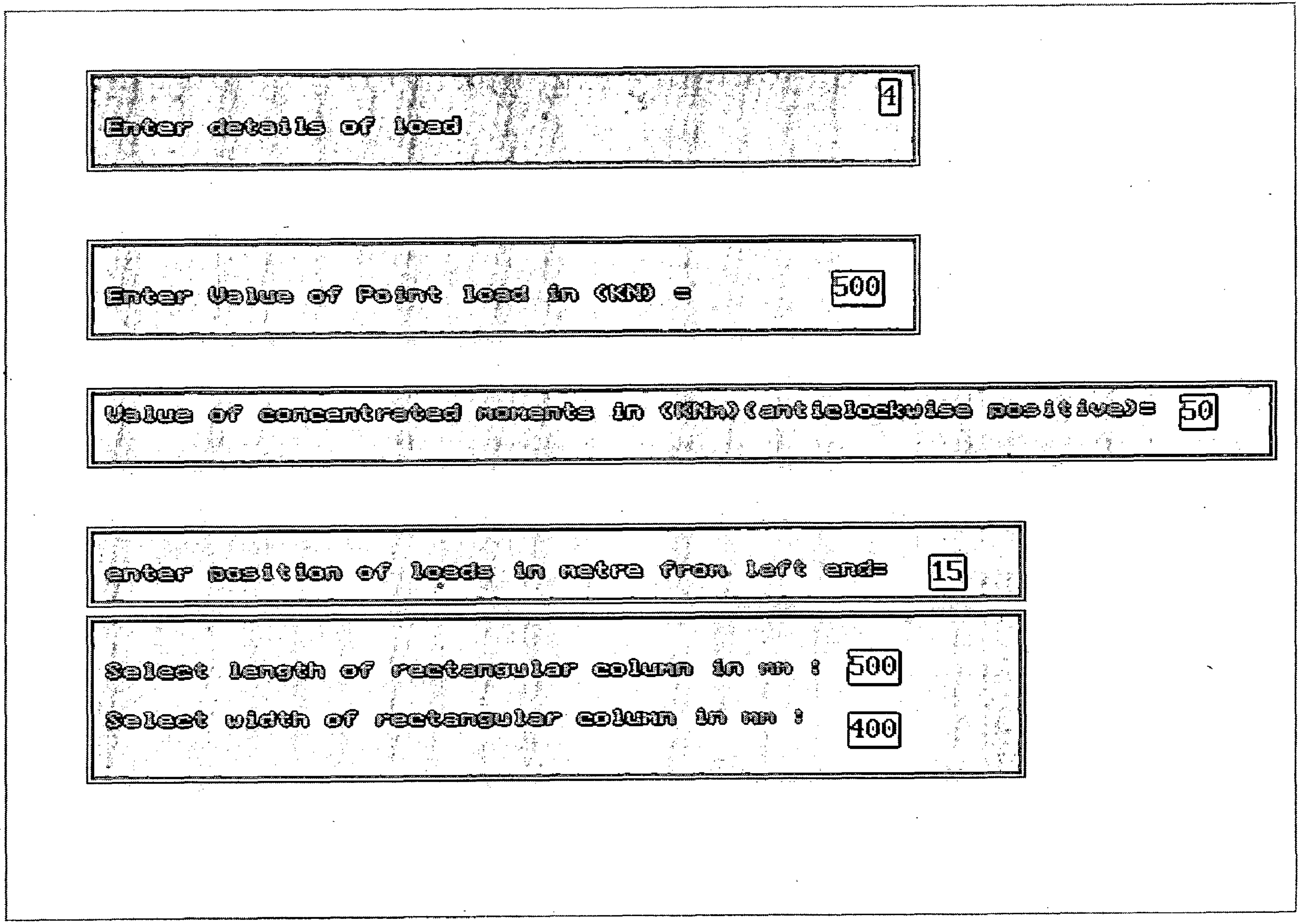


Fig. 4.10 **Input data (Dimension of column and loadings)**

* * Problem Data at a glance * *

Length of footing (L) :16.00 m

No. of loaded column :4

Column point	Axial load(KN)	Moment(KNm)	Location from left end(m)	column length(mm)	column width(mm)
1	400.00	150.00	1.50	400.0	400.0
2	300.00	0.00	6.00	400.0	350.0
3	600.00	-200.00	10.00	500.0	500.0
4	500.00	50.00	15.00	500.0	400.0

Fig. 4.11 Problem data at a glance

```
Enter Safe bearing capacity of soil(KN/sq.m):          150
```

```
NOTE:LL+DL------1.5
    :LL+DL+WL---1.2                          1.5
enter partial safety factor:
```

Fig. 4.12 Safe bearing capacity and partial safety factor.

```
                **** PROPORTIONING ****

Area of footing required                 :12.00  sq.m

Breadth of footing required              :0.75  m

 Choose breadth of footing in (m) :
                                          1.5

Area of footing provided                 :24.00  sq.m

Appx. depth of footing from punching shear consideration:280.83 mm
```

Fig. 4.13 Proportioning of footing.

FOOTING IS ANALYSED

USING

FINITE DIFFERENCE METHOD

```
Length of footing is divided into equally spaced
number of nodes (n)                     17
enter no of nodes=
```

Fig. 4.14 Method of analysis and number of equally spaced nodes.

NODE	DEFLECTION(mm)	SHEAR FORCE(KN)	BENDING MOMENT(KNm)
1	2.792393	-83.77	0.00
2	2.859122	-255.32	83.77
3	1.729112	40.93	-10.91
4	0.754946	-4.36	-51.84
5	0.521397	-35.65	-47.48
6	0.966142	-93.61	-11.83
7	1.579946	111.59	81.78
8	1.025151	50.06	-29.81
9	0.896775	-3.75	-79.87
10	1.909079	-118.29	-76.12
11	4.008858	241.18	242.17
12	2.649[illegible]	82.23	0.99
13	1.275247	5.72	-81.24
14	1.062003	-58.00	-86.96
15	2.091058	-183.47	-28.96
16	3.533790	104.51	104.51
17	3.483534	104.51	0.00

Fig. 4.15 **Result of analysis (Deflection, Shear Force and Bending Moment)**

Maximum value of bending moment :242.17 KNm

Maximum value of shear force :255.32 KN

Fig. 4.16 Maximum bending moment and shear force

```
Enter the grade of concrete (N/sq.mm)
fck:(15//20//25//30//35//40)          :   15
```

```
Enter the grade of steel(N/sq.mm)
fy:(250//415//500)                    :   415
```

Fig. 4.17 Selection of grade of concrete and steel

* * DEPTH OF FOOTING CALCULATION * *

Eff.depth from longitudinal bending moment consideration :340.81 mm

Eff.depth from transverse bending moment consideration :133.06 mm

Depth of footing from punching shear consideration :251.78 mm

Provide effective depth in mm : 345

Provide clear cover in mm
select (40//50//60//70) : 40

Overall depth required :385.00 mm

Provide overall depth of footing in mm : 385

Fig. 4.18 (a) Calculation of depth of footing

```
EI value of footing at each node              :66443.53      KN.m2

                                               70000
Provide new EI value of footing              :
Modulus of Subgrade reaction at each node    : 40000.00      KN/cu.m

Do you want to change the above data
            0.For no change
            1.For all nodes
            2.For particular node(s)

Enter your option(0/1/2): 0
```

Fig. 4.19 Stiffness of footing and subgrade reaction of soil

NODE	DEFLECTION(mm)	SHEAR FORCE(KN)	BENDING MOMENT(KNm)
1	2.899015	-86.97	0.00
2	2.559802	-240.56	86.97
3	1.714947	56.54	-22.47
4	1.000737	-3.50	-79.02
5	0.745921	-48.25	-75.52
6	0.930151	-104.06	-27.26
7	1.272876	119.56	76.80
8	1.169075	49.42	-42.76
9	1.313886	-29.41	-92.18
10	1.994628	-149.09	-62.77
11	3.040291	268.49	286.33
12	2.421269	123.21	17.84
13	1.698554	21.30	-105.38
14	1.588510	-74.01	-126.68
15	2.214982	-206.91	-52.67
16	3.147685	104.23	104.24
17	3.474363	104.23	0.00

Fig. 4.20 Results of analysis based on new EI value

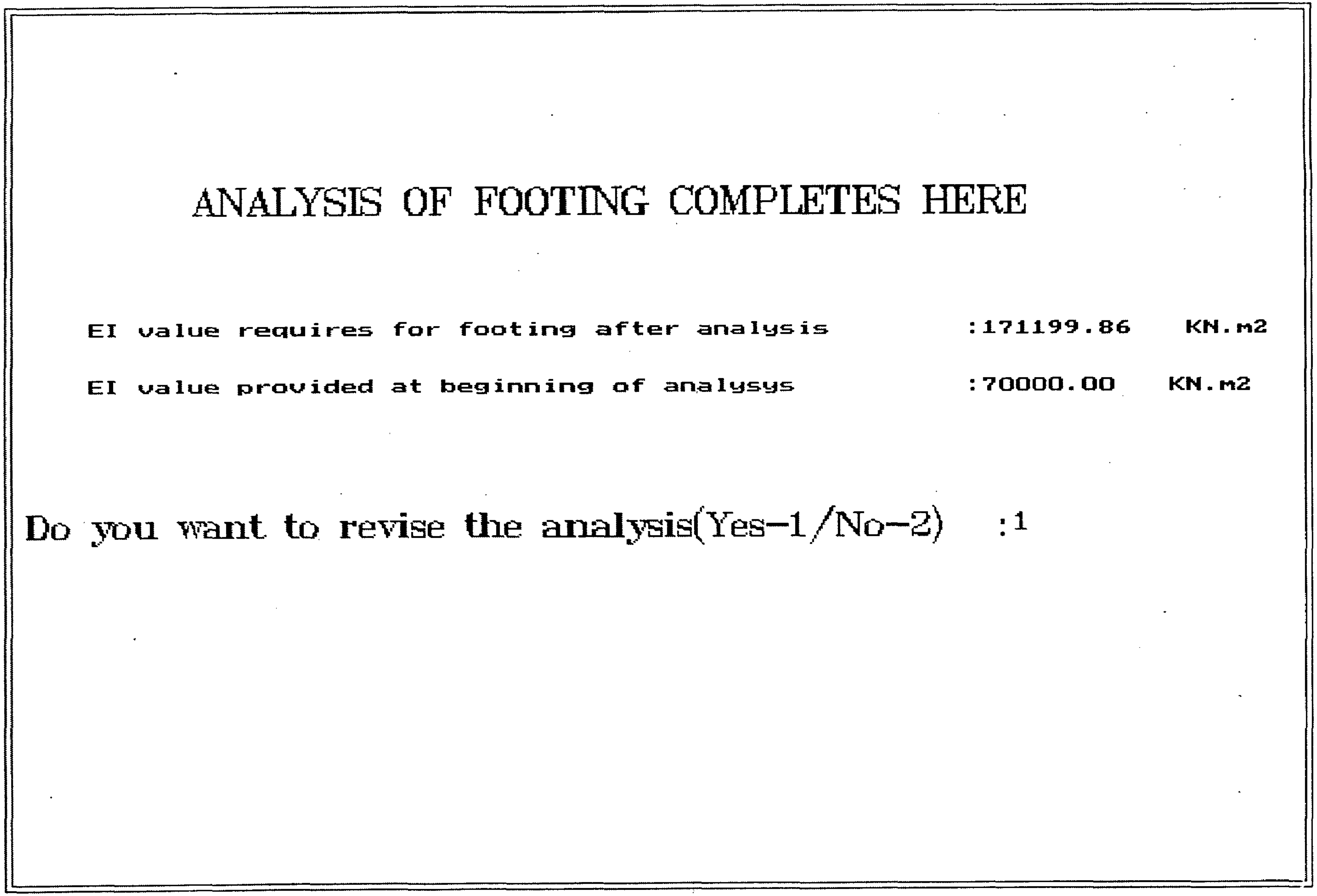


Fig. 4.21 Provision for revision of analysis

ANALYSIS OF FOOTING COMPLETES HERE

EI value requires for footing after analysis :214420.11 KN.m2

EI value provided at beginning of analysys :172000.00 KN.m2

Do you want to revise the analysis(Yes-1/No-2) :1

Fig. 4.22 Provision for revision of analysis

Maximum value of bending moment :295.57 KNm

Maximum value of shear force :274.20 KN

Fig. 4.23 Maximum value of longitudinal moment and shear force (after revision of analysis)

```
Provide new EI value of footing               :  223000
Modulus of Subgrade reaction at each node    : 40000.00        KN/cu.m

Do you want to change the above data
            0.For no change
            1.For all nodes
            2.For particular node(s)

Enter your option(0/1/2): 0
```

Fig. 4.24 Provision for revision of analysis

Maximum value of bending moment	:297.01	KNm
Maximum value of shear force	:275.09	KN

Fig. 4.25 Final longitudinal bending moment and shear force after iteration of analysis

ANALYSIS OF FOOTING COMPLETES HERE

EI value requires for footing after analysis	:222263.98	KN.m2
EI value provided at beginning of analysys	:223000.00	KN.m2

Do you want to revise the analysis(Yes–1/No–2) :2

Fig. 4.26 Completion of analysis

* * DEPTH OF FOOTING CALCULATION * *

Eff.depth from longitudinal bending moment consideration	:377.44 mm
Eff.depth from transverse bending moment consideration	:133.06 mm
Depth of footing from punching shear consideration	:251.78 mm
Provide effective depth in mm	: 380
Provide clear cover in mm select (40//50//60//70)	: 40
Overall depth required	:420.00 mm
Provide overall depth of footing in mm	: 420

Fig. 4.27 Depth of footing calculation

* * * Reinforcement Calculation * * *

```
Area of main longitudinal steel in percent              :0.72

                    Ast > 0.15 % (hence O.K.)

Area of main longitudinal steel                         :4548.26  sq.mm

Select dia of main bar                               :  20

spacing of main longitudinal bar                        :103.61  mm

If you want to change dia,Please select new dia.  :  20
New spacing of main longitudinal bar                    :103.61  mm
----------------------------------------------------------------
          As Per IS CODE 456:

     Minimum Spacing :
                 # Dia of bar,If all bars are of equal dia.
                 # Highest dia,if bars of unequal dia.
                  # Nominal maximum size of aggregate+ 5 mm

     Maximum Spacing   :215 mm to 300 mm for (Fe250)
                                 :125 mm to 235 mm for (Fe415)
                                 :105 mm to 195 mm for (Fe500)
----------------------------------------------------------------
Select spacing of main bar in mm                     :
```

Fig. 4.28 Calculation of longitudinal reinforcement and spacing

```
* * * Reinforcement Calculation (contd) * * *

 Percentage area of Transeverse steel(tensile)        :0.96

Ast > 0.15 % (Hence O.K.)
Area of Transeverse steel (tensile)                   :5405.57   sq.mm
select dia of  bar  (mm)                            :
                                                        22
spacing of transeverse steel                          :105.48    mm

If you want to change dia.,Please select new dia. :   22


Area of Transeverse steel (tensile)                   :3603.71   sq.mm
Minimum steel is required for long. compn. reinforcement
Area of compression steel  along length               :2274.13   sq.mm
Alternate longitudinal tensile steel should be bent

at column point spanning one fourth of span near

compression face of footing
```

Fig. 4.29 Calculation of transverse reinforcement and spacing

* * * Shear Reinforcement Calculation * * *

Nominal shear stress (Tv) :0.388 N/mm2

Design shear strength (Tc) of concrete :0.550 N/mm2

Tv < Tc

NOMINAL SHEAR STIRRUPS SHOULD BE PROVIDED

select dia of vertical shear stirrups(6/8/10/12) : 8

select no. of leg(s) of stirrups : 4

Total Area of Shear stirrups :23333.59 sq.mm

spacing of shear stirrups as calculated :139.07 mm

As Per Is code 456:

Maximum Spacing of Shear stirrups:

Not greater than 0.75d (For vertical stirrups)

Not greater than d (For inclined stirrups)

d is effective depth of section

---

provide spacing of shear stirrups : 135

Fig. 4. 30 Calculation of shear reinforcement and spacing

RESULTS

DESIGN MATERIALS

Grade of steel	:415
Grade of concrete	:15

PROPORTIONING OF FOOTING

Length of footing (L)	:16.00	m
Breadth of footing(B)	:1.50	m
Effective thickness of footing	:380	mm
Cover to reinforcement	:40	mm
Overall thickness of footing	:420	mm

REINFORCEMENT DETAILS

Main longitudinal tensile steel:::		
Longitudinal steel (Ast1)	:4548	sq.mm
Dia of bar provided	:20	mm
No. of bars	:15	
spacing of steel	:100.00	mm
Transeverse steel(breadthwise)		
Transeverse steel (Ast2)	:3604	sq.mm
Dia of bar provided	:22	mm
No.of bars provided near column band	:14	
spacing of steel	:105	mm
shear reinforcement	:24031	sq.mm
Dia of stirrup provided	:8	mm
spacing of stirrups	:135.00	mm

ESTIMATION OF QUANTITIES

Volume of concrete	:10.08	m3
Weight of steel	:10.71	KN

Fig. 4.31 Final design results

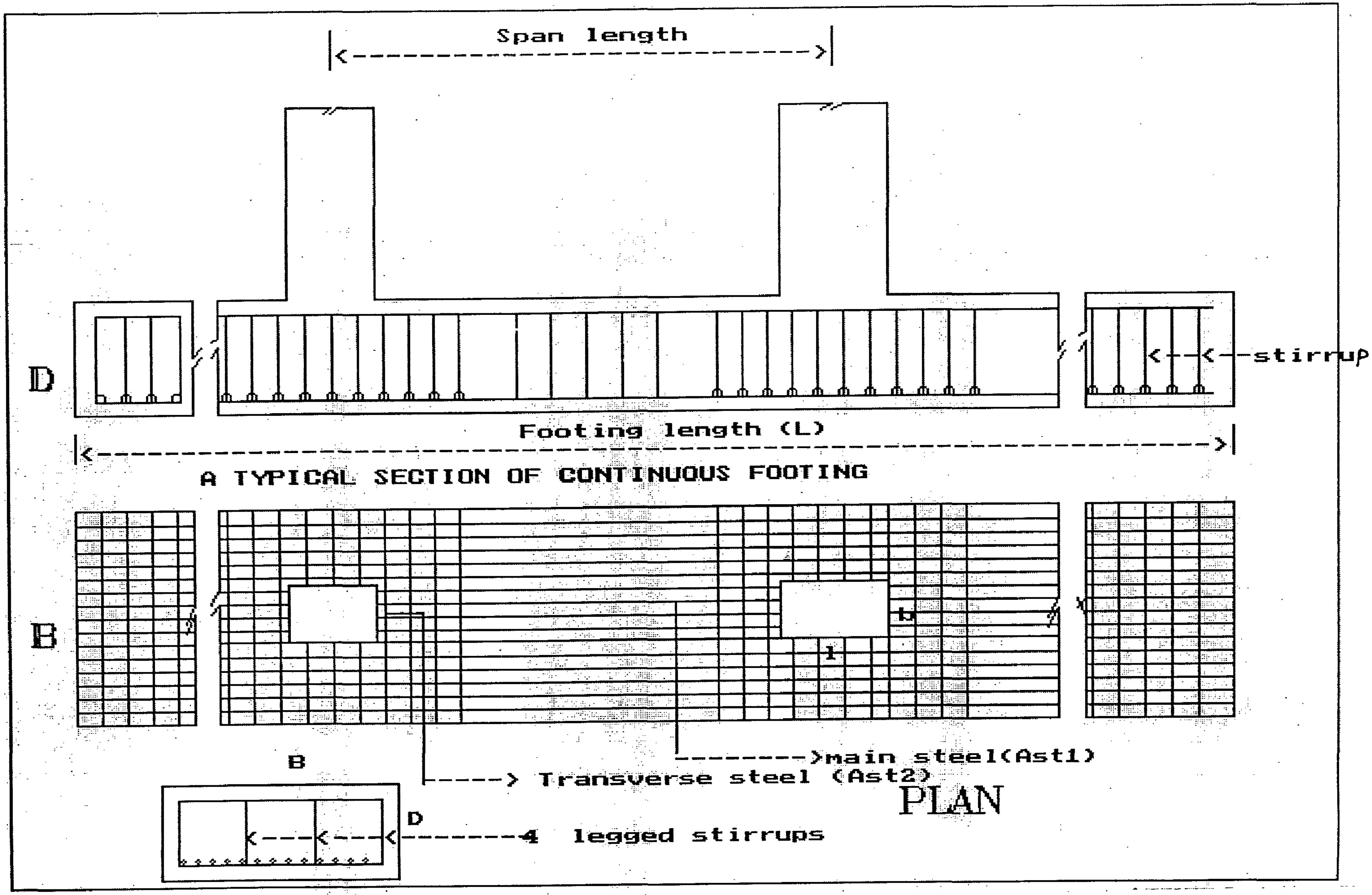


Fig. 4. 32 Graphical output of design drawing

CHAPTER - 5

RESULTS AND DISCUSSION

5.1 GENERAL

To demonstrate the utility of package a few examples have been solved using the package and the results are presented. The results are discussed to bring out the influence of various parameters on the behaviour of footings.

The package has been developed incorporating relevant provisions of Indian Standard Code, a help menu and relevant information in data feeding. An option for revision of analysis and design is given to user to obtain reasonably more accurate and efficient design.

The results of few problems have been discussed to bring out the following :

(i) Verification of the programs.

(ii) Role of stiffness of soil on design outcome.

(iii) Role of varying stiffness of footing on design outcome.

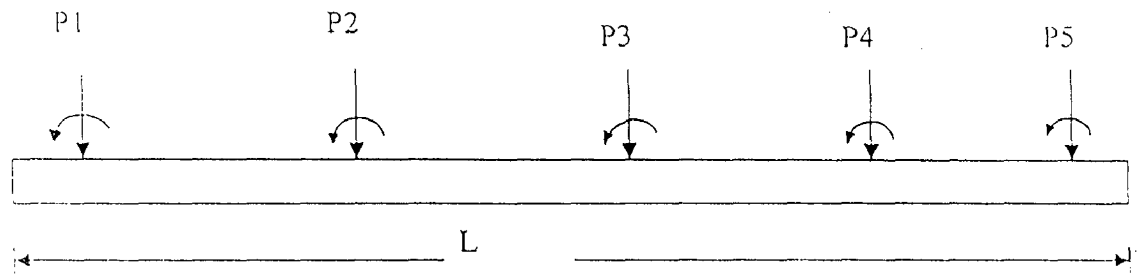
(iv) Effect of loose pockets of soil under the footing on the design outcome.

5.2 SOLUTION OF SOME TYPICAL PROBLEMS

Two problems on continuous footing, one for the footing on homogeneous soil with heavy column loads and another on non-homogeneous soil (soil with loose pockets) with moderate loads have been solved respectively and their screen results are presented.

5.2.1 Typical problem of footing on homogeneous soil

PROBLEM NO. 1



Length of footing (L) :20.00 m

No. of loaded column :5

Column point	Axial load(KN)	Moment(KNm)	Location from left end(m)	column length(mm)	column width(mm
1	800.00	150.00	1.50	600.0	600.0
2	900.00	0.00	6.50	650.0	600.0
3	700.00	-200.00	11.50	500.0	500.0
4	950.00	0.00	15.50	700.0	650.0
5	800.00	100.00	19.00	600.0	600.0

Subgrade reaction of soil (K_s) : 50000 kN/m^3

Bearing capacity of soil : 160 kN/m^2

RESULTS

DESIGN MATERIALS

Grade of steel	:415
Grade of concrete	:15

PROPORTIONING OF FOOTING

Length of footing (L)	:20.00 m
Breadth of footing(B)	:1.80 m
Effective thickness of footing	:310 mm
Cover to reinforcement	:40 mm
Overall thickness of footing	:350 mm

REINFORCEMENT DETAILS

Main longitudinal tensile steel:::	
Longitudinal steel (Ast1)	:4548 sq.mm
Dia of bar provided	:18 mm
No. of bars	:17
spacing of steel	:100.00 mm
Transeverse steel(breadthwise)	
Transeverse steel (Ast2)	:6224 sq.mm
Dia of bar provided	:30 mm
No.of bars provided near column band	:15
spacing of steel	:114 mm
shear reinforcement	:27009 sq.mm
Dia of stirrup provided	:8 mm
spacing of stirrups	:150.00 mm

ESTIMATION OF QUANTITIES

Volume of concrete	:12.60 m3
Weight of steel	:15.37 KN

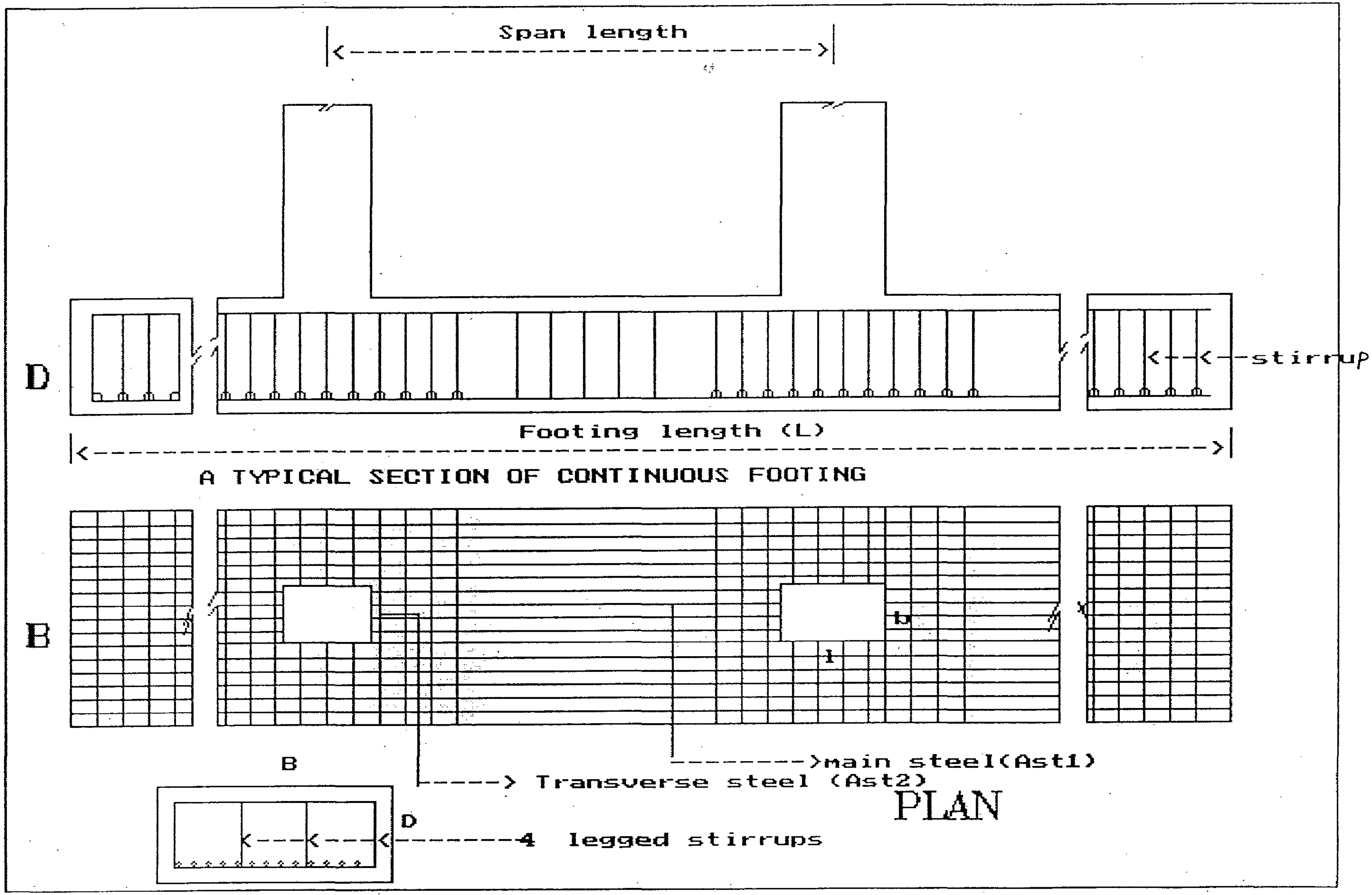
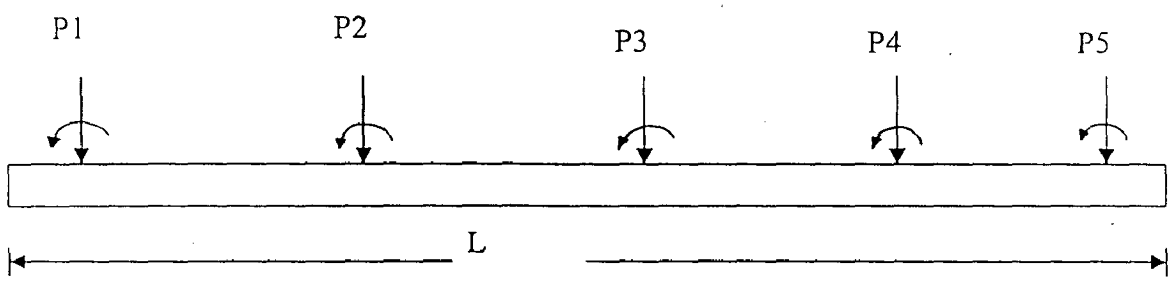


Fig. 5.1 Graphical output of design drawing

5.2.2 Typical problem of footing on non-homogeneous soil

PROBLEM NO. 2



Length of footing (L)	:20.00 m
No. of loaded column	:5

Column point	Axial load(KN)	Moment(KNm)	Location from left end(m)	column length(mm)	column width(mm)
1	350.00	0.00	1.50	350.0	350.0
2	450.00	0.00	6.50	400.0	400.0
3	300.00	0.00	11.50	450.0	350.0
4	400.00	0.00	15.50	400.0	400.0
5	300.00	0.00	19.00	350.0	400.0

Subgrade reaction of soil (K_s) : 35000 kN/m^3

Bearing capacity of soil : 130 kN/m^2

Number of Nodes : 21

K_s (node 1 to node 4) : 12000 kN/m^3

K_s (node 7 to node 10) : 12000 kN/m^3

K_s (node 15 to node 17) : 10000 kN/m^3

RESULTS

DESIGN MATERIALS

Grade of steel	:415
Grade of concrete	:15

PROPORTIONING OF FOOTING

Length of footing (L)	:20.00 m
Breadth of footing(B)	:1.30 m
Effective thickness of footing	:225 mm
Cover to reinforcement	:40 mm
Overall thickness of footing	:265 mm

REINFORCEMENT DETAILS

Main longitudinal tensile steel:::	
Longitudinal steel (Ast1)	:2487 sq.mm
Dia of bar provided	:18 mm
No. of bars	:9
spacing of steel	:130.00 mm
Transeverse steel(breadthwise)	
Transeverse steel (Ast2)	:6549 sq.mm
Dia of bar provided	:25 mm
No.of bars provided near column band	:17
spacing of steel	:75 mm
shear reinforcement	:27009 sq.mm
Dia of stirrup provided	:8 mm
spacing of stirrups	:150.00 mm

ESTIMATION OF QUANTITIES

Volume of concrete	:6.89 m3
Weight of steel	:9.43 KN

5.3 PARAMETRIC STUDIES

For better assimilation of study, a number of problems have been solved using the package to bring out the influence of various parameters. On the basis of results, the estimating of quantity of concrete and steel is tabulated to conclude the situations under which the design may be economical.

The problems and parameters varied are presented in Table 11 to Table 13.

PROBLEMS :

Loading Details

Column No.	Axial Load (KN)	Moment (KNm)	Position from Left End (m)	Column Dimension
1	500	100	1	500x400
2	400	0	5	400x400
3	600	-50	9	600x400
4	700	50	14	600x500

Length of Footing = 15 m

Number of Nodes = 16

Grade of Concrete selected : 15

Grade of Steel selected : 415

Loading on footing are taken same for all these problems for parametric studies but some parameters are varied to observe the effect on the final design of footing.

Problem No.	Safe bearing capacity (KN/m²)	K_s value (KN/m³)	Loose pockets from left end	K_s value of loose pockets
1	150	40000	Nil	-
2	250	40000	Nil	-
3	150	40000	Nil	-
4	150	80000	Nil	-
5	150	40000	1 m to 4 m	10000
6	150	40000	8 m to 12 m	10000

5.3.1 Role of relative stiffness of soil

When footing is designed for relative stiff soil, the plan dimension of footing is considerably reduced, resulting in considerable savings in concrete.

Table 11 : Role of Relative Stiffness of Soil

(problem 1 and 2)

Bearing Capacity of Soil (KN/m^2)	Dimension of Footing (m)	Depth of Footing (mm)	Volume of Concrete (m^3)	Weight of Steel (KN)
150	15x1.4	380	7.98	8.5
250	15x1.4	340	7.14	7.38

It is evident from table (11) that when footings are founded on relatively stiff soil, quantity of concrete and steel is reduced.

5.3.2 Effect of varying modulus of subgrade reaction of soil

Table 12 : Effect of Varying Modulus of Subgrade Reaction of Soil

(problem 1 and 4)

Modulus of Sub-grade reaction of soil (kN/m^3)	Dimension of Footing (m)	Depth of Footing (mm)	Volume of Concrete (m^3)	Weight of Steel (KN)
40000	15x1.4	380	7.98	8.5
80000	15x1.4	340	7.25	7.78

The results tabulated above show that the soil having less subgrade reaction value requires more quantity of concrete and steel and the soil having large modulus of subgrade reaction value give economical results in comparision to previous result.

5.3.3 Effect of loose pockets

To study the effect of loose pockets of soil, two cases have been considered.

Case I : Soft loose pockets of soil lies below the end column.

Case II : Soft loose pockets of soil lies below the middle column.

Table 13 : Effect of Loose Pockets of Soil

(problem 5 and 6)

Location of loose pockets from left end (m)	K_s value for loose pocket	K_s value for other nodes	Dimension (m)	Depth (mm)	Volume of Concrete (m^3)	Weight of Steel (KN)
1 to 4	10000	40000	15x1.45	400	8.8	9.1
8 to 12	10000	40000	15x1.5	420	9.1	9.8

The results in the following page so that the location of loose pocket significantly affects the deflection (3.7 mm) and bending moment (49.18 kNm) to deflection (7.97 mm) and bending moment (139.22 kNm) respectively for the Case I. For the Case II, when the loose pocket lies under the middle column the deflection varies from 2.83 mm to 9.03 mm and bending moment varies from 216.93 kNm to 309.53 kNm.

Thus it can be concluded that whenever the footing is constructed at such sites, the soil properties should thoroughly be studied and such conditions should be avoided as far as possible.

CHAPTER - 6

CONCLUSIONS

Based upon the work carried out in this study following conclusions have been drawn.

1. The developed computer package for the analysis and design can be efficiently used.

2. Introduction of such package relieves the design staff from the tedius routine and repetitive work.

3. Limit state design method has been adopted keeping the economy in mind.

4. Option to choose grade of concrete, grade of steel and to revise the design at various stage has been given to user.

5. The package is so designed as to provide options to the user to change certain input data after analysis and design stage respectively to avoid the repetition of all data feeding from initial stage.

6. Footing design has been carried out by following the recommendations of IS 456-1978. Graphical output on the screen enables the user to have a better understanding about the design dimension of member and reinforcement detailing.

7. Although the package has been developed for continuous footing but it can advantageously be used for anlaysis and design of isolated and combined footings.

8. This package can be an aid to a design office for improving it's overall productivity.

CHAPTER - 7

LIMITATIONS AND FURTHER SCOPE

7.1 GENERAL

The future scope of computer aided design and graphics is a subject of innovative ideas and their implementation. An initial demonstration of this idea is the present growing popularity of software package and it's application in almost all works of our life.

None of the computer software is complete and perfect in it's own, it always requires modification, upgradation and addition of new features to it. This is true even in the case of highly sophisticated professional software packages which are developed by a group of highly trained programmers and system designer.

7.2 LIMITATIONS OF PACKAGE

(i) The design is based only on limit state method as per IS code.

(ii) The analysis is carried by only finite difference approach.

7.3 SCOPE OF FUTURE WORK

The following aspects need to be incorporated for a more comprehensive package of this nature.

(i) The analysis should also be carried out by Finite Element method.

(ii) Using object oriented programming techniques.

(iii) Using latest languages like JAWA and VISUAL C++ to make it more compatible.

(iv) More detailed working drawings with latest graphic features.

(v) Incorporation of different International Standard Codes like ACI 318-85.

(vi) More detailed estimation of quantities and cost analysis.

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