∴ Total resistance provided by the pocket base

$= 4.3\,[180 \times 480 + n \times 20 \times 368]$ Newtons

Equating this to the external column load

$P = 750\text{ kN} = 750 \times 10^3$ Newtons, we have

$750000 = 4.3\,[180 \times 480 + n \times 20 \times 368]$, giving

n = 11.9 say 12 members.

Provide 6 shear connectors on each side of the web of the column. (see Figure 9.14)

Spacing of connectors = $5d = 5 \times 20 = 100$ mm

End cover = 200 mm of concrete below end plate.

Size of the pocket hole provided 200 × 500 mm × 1000 mm deep to be filled by mix M-15 cement concrete.

9.8 GRILLAGE FOUNDATION

When the foundation area required becomes too large, either due to heavy loads, or due to low bearing capacity of soil (or both), base slab type foundations become unsuitable.

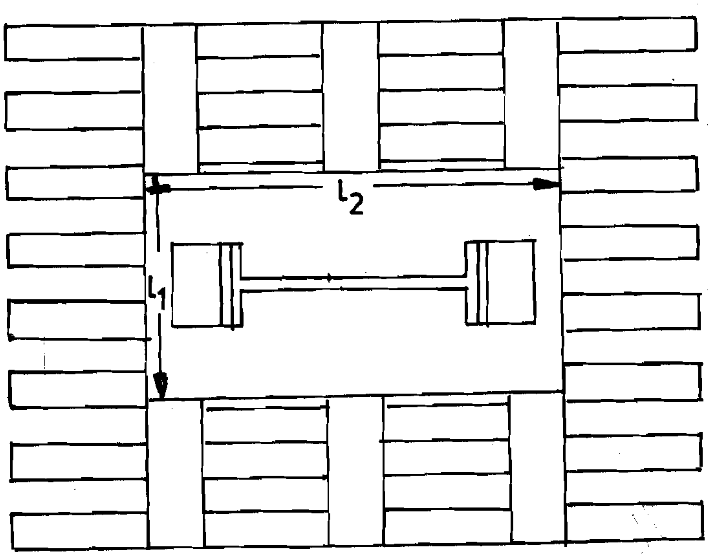
One of the methods is to spread the column load to the foundation through a series of steel beams arranged at right angles to each other in two or more tiers.

Finally the beams are encased in lean concrete. Such foundations are called grillage foundations.

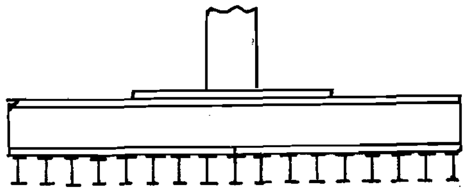
For a two tier grillage which is more common, the upper tier beams are connected to the column through a base plate. The lower tier beam which receives the load from the upper tier transfers it finally to the soil.

IS : 800 – has allowed an increase of $33\frac{1}{3}\%$ over the usual permissible bending stresses in the case of grillage beams. If the loads include wind/earthquake or erection stresses an increase of 50% is allowed. Normally the following conditions have to be fulfilled.

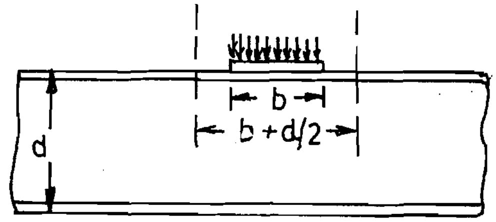
a) Beams are to be unpainted and solidly encased in at least M-15 concrete with 10 mm aggregate,



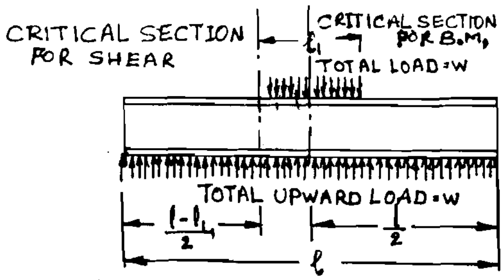
(a)



(b)



(c)



(d)

Figure 9.15

b) Adjacent beam flanges are to be separated clear at least 75 mm apart by means of suitable separators,

c) Side and top concrete cones should be at least 100 mm all round the edges of beams/flanges.

The process of design will be clear by the following example.

Example 9.9

Design a grillage foundation for a ISHB 400 column with a 300 × 20 mm plate on each flanges.

Total load on the column is 2000 kN. The base plate is 650 × 800 mm. The bearing capacity of the soil is 120 kN/m^2

(Permissible bending stress for beams is 165 MPa which may be increased by $33\frac{1}{3}\%$ for the grillage beams.)

Solution

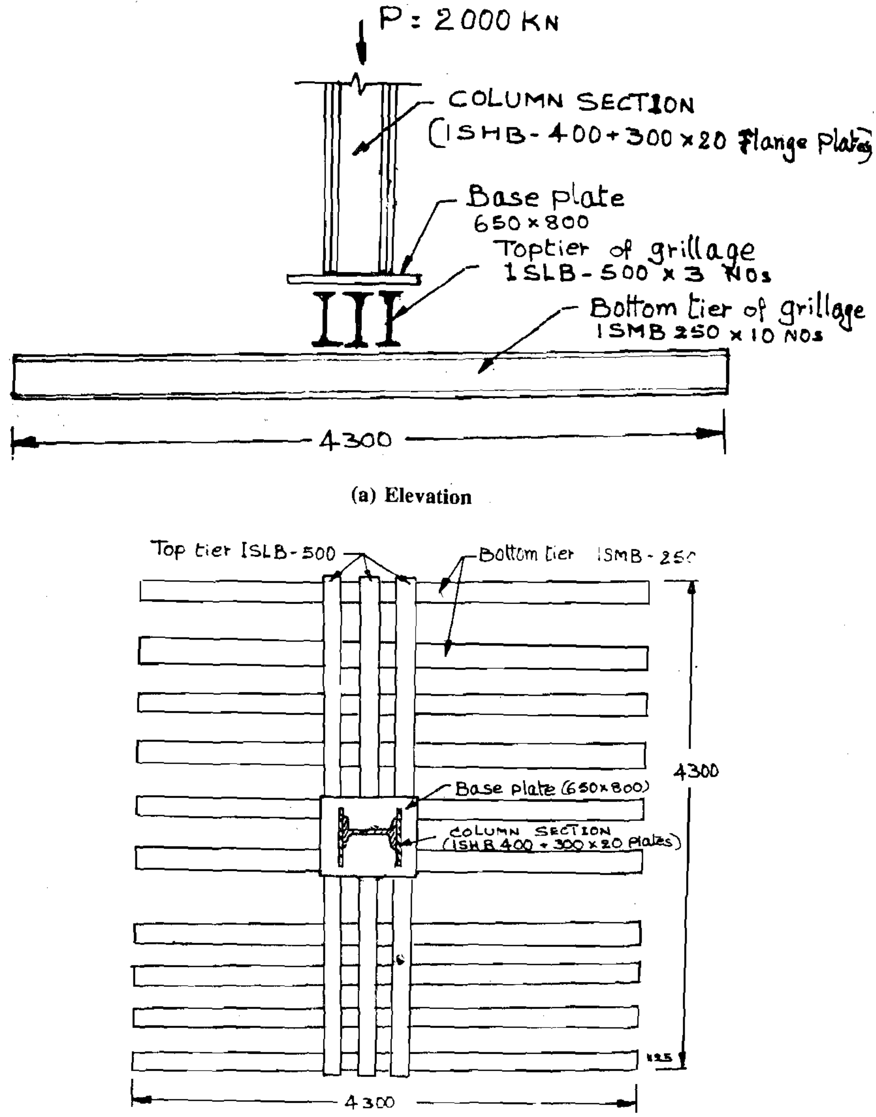
Total load on column = 2000 kN

Self weight of foundation (assumed 10%) = 200 kN

Total load transmitted to soil = 2200 kN

$$\text{Area of foundation required} = \frac{2200}{120} = 18.33\ \text{m}^2$$

Assuming a 4.3 × 4.3 m square foundation of area = 18.49 m^2



(a) Elevation

(b) Plan

Figure 9.16

Top Tier Beams

Assuming 3 beams in the top-tier, which will be placed at right angles to the longer dimension (800 mm) of the base plate.

$$\text{Max. total B.M.} = \frac{W}{8}(l - l_1) = \frac{2000000}{8}(4300 - 650) = 912{,}500{,}000$$

$$\text{Max. B.M. per beam} = \frac{912{,}500{,}000}{3} = 304{,}167{,}000 \text{ Nmm}$$

$$\text{Permissible bending stress} = 165 \times \frac{4}{3} = 220 \text{ MPa}$$

$$\text{Required section modules } Z = \frac{M}{f} = \frac{304{,}167{,}000}{220} = 1383000 \text{ mm}^3 = 1383 \text{ cm}^3$$

∴ Adopt ISLB 500 section (Z = 1543.2 cm^3)

Max. total shear force for top tier beams $= \frac{W}{l}\left(\frac{l - l_1}{2}\right)$

$$= \frac{2000{,}000}{4300}\left(\frac{4300 - 650}{2}\right) = 848800\ \text{N}$$

S.F. per beam $= \frac{848800}{3} = 282930\text{N}$

Actual shear stress in beam web $= \frac{282930}{500 \times 9.2}$

= 61.5 MPa < 94.5 MPa permissible ∴ OK.

Check for Vertical Web Buckling

Height of weg (h) = 500 – 2 × 14.1 = 471.8 mm

Web thickness (t) = 9.2 mm

Slenderness ratio $= \frac{h}{t}\sqrt{3} = \frac{471.8}{9.2}\sqrt{3} = 88.8$

Corresponding permissible compressive stress = 93.8 MPa

Length of spread for load (B) = length of bearing plate + $\frac{1}{2}$ depth of beam

$$= 650 + \frac{500}{2} = 900\ \text{mm}$$

∴ Corresponding bearing area for each beam = B.t = 900 × 9.2 = 8280 mm^2

Total bearing area provided by three upper tier beams = 3 × 8280 = 24840 mm^2

∴ Bearing stress $= \frac{2000000}{24840}$ = 80.5 MPa < 93.8 MPa (permissible)

Check for Diagonal Buckling

For diagonal compression slenderness ratio $= \frac{h}{t}\sqrt{6} = \frac{471.8}{9.2}\sqrt{6} = 125.6$

Corresponding allowable compressive stress = 63 MPa > 61.5 MPa (actual shear stress) ∴ OK.

Design of Bottom Tier Beams

Using 10 Beams in the bottom tier. Maximum bending moment for the bottom tier beams $= \frac{W}{8}(l - l_2)$

$$= \frac{2000000}{8}(4300 - 800) = 875{,}000{,}000\ \text{Nmm}$$

∴ Maximum B.M. per beam $= \frac{875{,}000{,}000}{10}$ = 87,500,000 Nmm

Permissible bending stress = 220 MPa

Section modulus required $= \frac{87{,}500{,}000}{220} = 397727\ \text{mm}^3 = 397.7\ \text{cm}^3$

Provide ISMB 250 (section modulus = 410.5 cm^3)

Check for Shear

Maximum total shear force for bottom tier beam = $\frac{W}{l}\left(\frac{l-l_2}{2}\right)$

$$= \frac{2{,}000{,}000}{4{,}300}\left(\frac{4300-800}{2}\right) = 813900\,\text{N}$$

Shear force per mean = $\frac{813900}{10} = 81390\text{N}$

Shear stress = $\frac{\text{S.F.}}{\text{Web area}} = \frac{81390}{250\times 6.9}$ = 47.2 MPa < 94.5 MPa (permissible)

Check for Vertical Buckling

Slenderness ratio of web = $\frac{h}{t}\sqrt{3} = \left(\frac{250-2\times 12.5}{6.9}\right)\sqrt{3} = 56.5$

Corresponding permissible compressive stress = 114.5 MPa

Effective length for load spread = length of bearing plate + $\frac{1}{2}$ depth of beam

$$= 800 + \frac{250}{2} = 925\,\text{mm}$$

Corresponding bearing area (each beam) = 925 × 6.9 = 6383 mm^2

Corresponding all ten webs = 63830 mm^2

∴ Bearing stress = $\frac{2{,}000{,}000}{63{,}830}$ = 31.3 MPa < Permissible stress ∴ OK.

Example 9.10 (Combined Grillage Foundation)

A combined grillage foundation is to be designed for two columns (A) & (B) given the following data:

Column	Section	Load
(A)	2 × ISLC-350 channels back to back (spacing 220 mm)	1000 kN
(B)	2 × ISMC-350 channels placed back to back (spacing 220 mm)	1500 kN

Spacing between the columns is 4.5 m centres.

Permissible stresses may be taken as follows:

bending (in steel beams) 220 MPa

direct compression (in steel beams) 252 MPa

shearing stress (in steel beams) 94.5 MPa

bearing (below base-plates) 4 MPa

safe bearing capacity of soil 150 kN/m^2

Solution

Load on column (A) ... 1000 kN

Load on column (B) ... 1500 kN

Self weight of foundation (10%) 250 kN

Total load 2750 kN

Safe bearing capacity (soil) = 150 kN/m^2

$\therefore$ Area of foundation required $= \dfrac{2750}{150} = 18.33\ \text{m}^2$

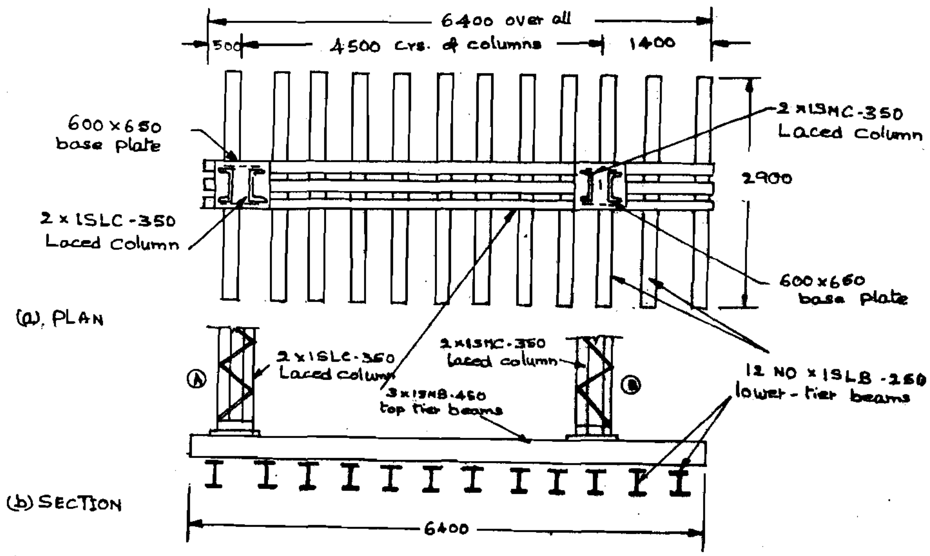


Figure 9.17

The plan of the foundation is so chosen that the C.G. of the foundation coincides with the C.G. of the loads. This is shown in Figure 9.17. If we assume a minimum distance of 0.5 m to the left of the lighter-loaded column (A), the total length of the foundation comes as 6.4 m

$$\therefore \quad \text{Width of foundation} = \frac{18.33}{6.4} = 2.86\ \text{m}\ (= 2.9\ \text{m say})$$

$$\text{Area of base plate below column (B)} = \frac{1{,}500{,}000}{4} = 375{,}000\ \text{mm}^2$$

Assuming a base plate of 600 × 650 mm size and similar plate for column (A) also.

Design of Top Tier Beams

The Top Tier Beams are parallel to the length of the foundation.

$$\text{The sub-soil reaction per metre run} = \frac{1000 + 1500}{6.5} = 390.6\ \text{kN/m.}$$

This can be assumed as an inverted overhanging beam supported at the column points (A) & (B). The B.M. and S.F. diagrams are drawn in Figure 9.18, which must be verified by you.

Maximum B.M. for top tier = 780 kNm

Assuming three beams in the top tier.

$$\text{B.M. per beam} = \frac{780}{3} = 260\ \text{kNm}$$

$$\text{Section modulus (z) of each beam} = \frac{260{,}000{,}000}{220} = 1{,}182{,}000\ \text{mm}^3 = 1182\ \text{cm}^3$$

Choose ISMB 450 section ($Z = 1350.7\ \text{cm}^3$).

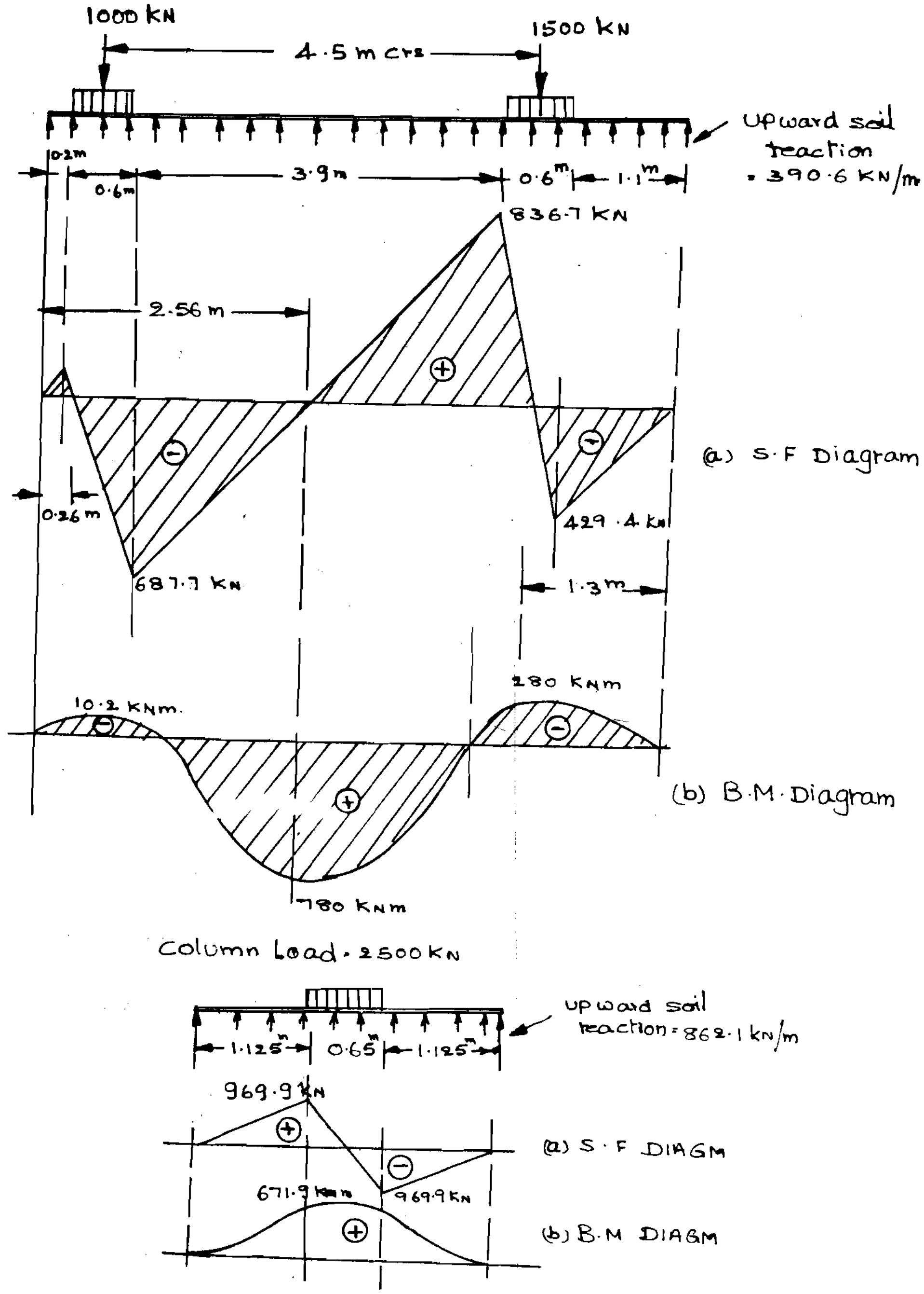


Figure 9.18

Check for Vertical Buckling under Column (B)

Column load on each beam = $\dfrac{1500}{3}$ = 500 kN.

Effective spread length (B) = Length of base plate + half the depth of beam

$$= 600 + \frac{450}{2} = 825 \text{ mm}$$

$$\text{Buckling stress} = \frac{500{,}000}{825 \times 9.4} = 64.5 \text{ MPa}$$

[Flange thickness (t_f) = 17.4 mm & web thickness (t_3) = 9.4 mm]

$$\therefore \quad \text{Slenderness ratio of web} = \frac{h}{t}\sqrt{3} = \left(\frac{450 - 2 \times 17.4}{9.4}\right)\sqrt{3} = 76.5$$

Corresponding safe compressive stress = 103 MPa > 64.5 MPa ($\therefore$ Safe)

Check for Shear

Maximum S.F. = 836.7 kN

$$\text{S.F. per beam} = \frac{836.7}{3} = 278.9\,\text{kN}$$

$$\text{Shear stress} = \frac{278{,}900}{450 \times 9.4} = 65.9\,\text{MPa} < 94.5\,\text{MPa (permissible)} \;(\therefore \text{safe})$$

Check for Diagonal Buckling

$$\text{Slenderness ratio} = \frac{h}{t}\sqrt{6}\,\frac{415.2}{9.4}\sqrt{6} = 108.1$$

Corresponding safe stress = 77 MPa > 65.9 MPa (actual) $\therefore$ safe.

Design of Bottom Tier Beams

$$\text{Maximum B.M. for bottom tier beam} = \frac{W}{8}(l - l_2)$$

$$= \frac{2{,}500{,}000}{8}[2900 - 650] = 703100000\,\text{Nmm}$$

Providing 12 beams in the lower tier

$$\text{B.M. per beam} = \frac{703{,}100{,}000}{12} = 58{,}592{,}000\ \text{Nmm}$$

$$\text{Section modulus required per beam } (Z) = \frac{58{,}592{,}000}{200} = 266400\ \text{mm}^3 = 266.4\,\text{cm}^3$$

Use ISLB 250 (Z = 297.4 cm^3)

Check for Vertical Buckling

$$\text{Load per beam } \frac{2500000}{12} = 208{,}300\ \text{N}$$

clear web height, h = 250 − 2 × 8.2 = 233.6; thickness t = 6.1

$$\text{slenderness ratio} = \frac{h}{t}\sqrt{3} = \frac{233.6}{6.1}\sqrt{3} = 66.3$$

corresponding safe compressive stress = 109.6 MPa

Effective length of beam for vertical buckling

= Length of base plate + half the depth of beam

$$= 650 + \frac{250}{2} = 775\ \text{mm}$$

$$\text{Buckling stress} = \frac{208300}{775 \times 601} = 44.1\ \text{MPa} < 109.6 \text{ (permissible stress)} \;\therefore \text{safe.}$$

Check for Shear

$$\text{Maximum S.F. for bottom tier} = \frac{W}{l}\left(\frac{l - l_2}{2}\right) = \frac{2{,}500{,}000}{2900}\left(\frac{2900 - 650}{2}\right) = 969400\,\text{N}$$

$$\text{S.F. per beam} = \frac{969400}{12} = 8079\ \text{N}$$

$$\text{Shear stress} = \frac{8079}{250 \times 6.1} = 53\ \text{MPa} < 94.5 \text{ (permissible shear stress)} \;\therefore \text{OK.}$$

Check for Diagonal Buckling

Slenderness ratio for diagonal buckling $= \frac{h}{t}\sqrt{6} = \frac{233.6}{6.1}\sqrt{6} = 94$

Corresponding safe compressive stress = 89.3 MPa > 53.0 MPa (actual shear stress) ∴ safe.

9.9 SUMMARY

All loads carried by columns are ultimately transferred to the Soil. As soil bearing pressures are much lower than steel strength, the relatively smaller column sections are to transfer the loads to a larger soil area. For this purpose suitable column bases and their connections are to be provided. The most common type is a slab base. For heavier loads gussetted bases are to be provided. Special arrangements are to be made for Moment resistant column bases. Grillage foundations are to be provided for very heavy column loads or poor bearing capacity soils, requiring a very large foundation area. The grillage beams which may be in several tiers are designed as (upward) loaded (cantilever) beams supported at the centre (column point).

9.10 ANSWERS TO SAQs

SAQ 1

Refer Example 9.1

SAQ 2

Refer Example 9.2

SAQ 3

Refer Example 9.3

FURTHER READING

Design of Steel Structures by M. Raghupathi

Design of Steel Structures by Edwin H. Gaylord, Jr.Charies N. Gaylord

Design of Steel and Timber Structures by S.Ramanmrutham

Design of Steel Structures–Vol. I by Dr. Ramchandra

Design of Steel Structures by S.M.A. Kazmi&R.S. Jindal

Design of Steel Structures by P. Dayarathnam

Design of Steel Structures by Prof. A.S. Arya & J.L. Ajmani

Steel Structures and Timber Structures Analysis, Design and Details of Structures by V.N. Vazirani & M.M. Ratwani