OPSC-AEE 2020

Odisha Public Service Commission

Assistant Executive Engineer

Civil Engineering

Design of Concrete Structures

Well Illustrated **Theory** *with*

Solved Examples and **Practice Questions**

MADE EASY Publications

Design of Concrete Structures

Contents

CHAPTER 6 Design of Beam

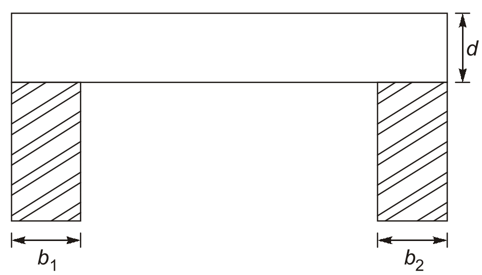
6.1 Introduction

Analysis and design of section are considered in previous chapters. In this chapter entire beam is going to be designed.

6.2 Effective Span

Span of beam that effectively perticipates in bending is called effective span.

6.2.1 Simply Supported Beam/Slab

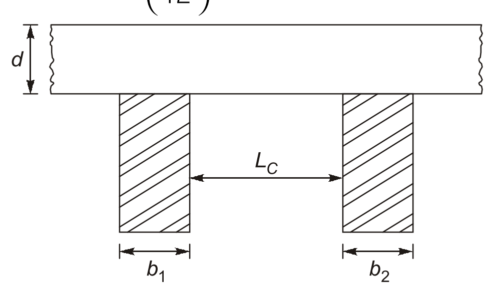


$$L_{eff} = \text{Minimum}\begin{cases} L_C + d \\ \dfrac{b_1}{2} + L_C + \dfrac{b_2}{2} \end{cases}$$

6.2.2 Continuous Beam/Slab

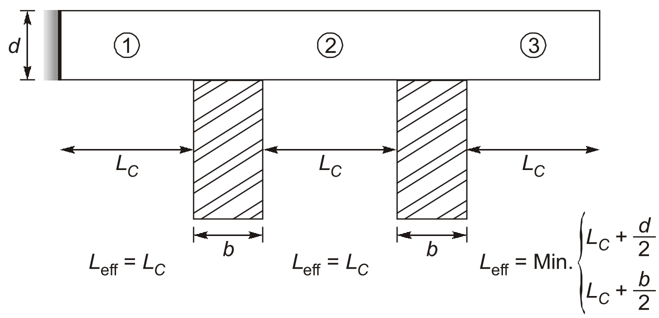
Case 1 : If support width is less than $\left(\frac{L_C}{12}\right)$ then L_{eff} is same as 6.2.1.

b_1 and $b_2 < \frac{L_C}{12}$



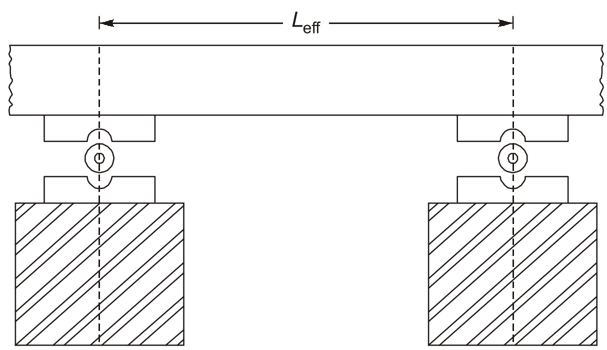
$$L_{eff} = \text{Minimum}\begin{cases} L_C + d \\ \dfrac{b_1}{2} + L_C + \dfrac{b_2}{2} \end{cases}$$

Case 2 : If support width is more than $\left(\frac{L_C}{12}\right)$ or 600 mm whichever is less than L_{eff} is given as below :

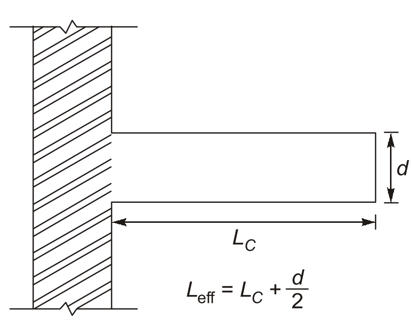


1 : For one end fixed and other continuous.
2 : Both end continuous (intermediate span)
3 : One end discontinuous and other continuous (simply supported)

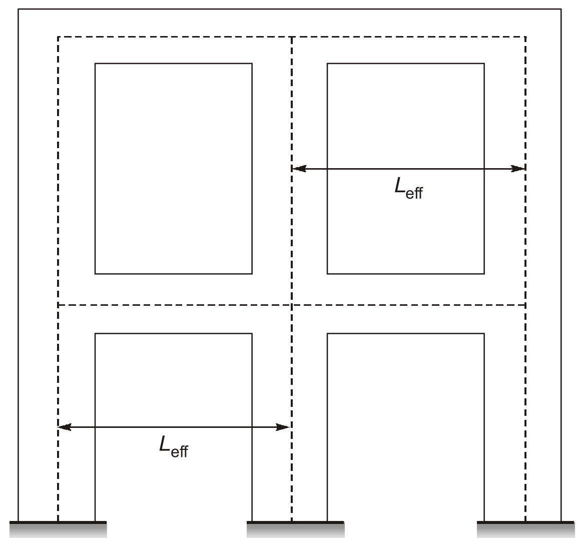
Case 3 : If beam is continuous over roller and rocker bearing, then L_{eff} is c/c distance between bearing.



6.2.3 Cantilever Beam



6.2.4 Rigid Frames



L_{eff} is c/c distance between columns.

6.3 Longitudinal Reinforcement

(a) Tension Reinforcement :

$$(A_{st})_{min} > \frac{0.85}{f_y} bd$$

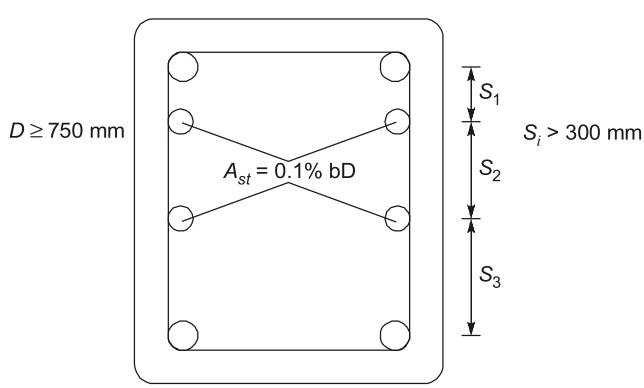
$$(A_{st})_{max} = 0.04\,bD$$

(b) Compression Reinforcement

Minimum = No value but at least two bars must be provided in compression zone.

Maximum = 0.04 bD

(c) Side Face Reinforcement

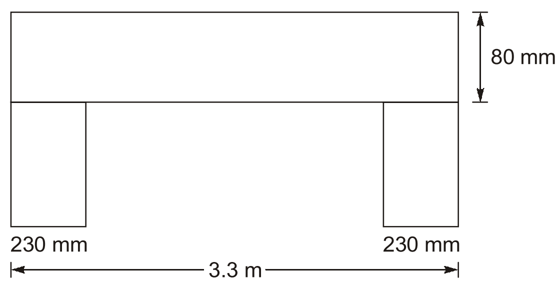


When overall depth $D \geq 750$ mm, then 0.1% of gross web area is provided as side face reinforcement equally distributed on both faces with spacing not more than 300 mm. It is provided to take care of longitudinal shrinkage of concrete (vertical crack) and torsional effect due to high depth of beam.

Example - 6.1 A reinforced concrete slab with effective depth of 80 mm is simply supported at two opposite ends on 230 mm thick masonary walls. The centre-to-centre distance between the walls is 3.3 m. As per IS 456-2000, the effective span of the slab (in m, upto two decimal places) is :

Solution:

$$L_{eff} = \text{Minimum}\begin{cases} L_c + d \\ \text{c/c distance between supports} \end{cases}$$



$$\text{Clear span} = 3.3 \text{ m} - 0.23 \text{ m} = 3.07 \text{ m}$$

$$\therefore \quad L_{eff} = \text{Minimum}\begin{cases} 3.07 + 0.08 = 3.15 \text{ m} \\ 3.3 \text{ m} \end{cases}$$

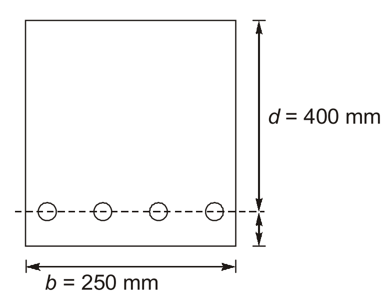
$$= 3.15 \text{ m}$$

Example - 6.2 A reinforced concrete (RC) beam with width of 250 mm and effective depth of 400 mm is reinforced with Fe415 steel. Consider 50 mm effective cover. As per the provision of IS 456:2000, the minimum and maximum amount of tensile reinforcement (expressed in mm²) for the

(a) 250 and 3500
(b) 205 and 4500
(c) 270 and 2000
(d) 300 and 2500

Solution: (b)

$$b = 250 \text{ mm}$$
$$D = 400 + 50 = 450 \text{ mm}$$
$$A_{st}^{min} = \frac{0.85}{f_y} bd = \frac{0.85}{415} \times 250 \times 400$$
$$= 204.819 \simeq 205 \text{ mm}^2$$
$$A_{st}^{max} = 0.04 \text{ bD} = 0.04 \times 250 \times 450 = 4500 \text{ mm}^2$$



6.4 Nominal Cover

Minimum nominal cover of member is governed by three criteria :

(i) Type of structural member (beam, column, etc.)

(ii) Exposure condition (mild, moderate etc.)

(iii) Fire resistance in terms of harsh.

1. **Concrete Cover to Reinforcement:** Concrete cover is provided to protect the reinforcing bars from corrosion, fire and also provides sufficient bond between steel and concrete to prevent slipping

out of reinforcing bars from concrete. **Clear cover** is defined as the distance of exposed surface of concrete to the nearest surface of reinforcing steel. **Cl. 26.4.1 of IS 456: 2000** defines **nominal cover** as **"The design depth of concrete cover to all steel reinforcement, including links."** **IS 456: 2000** specifies the deviation in concrete cover from 0 mm to +10 mm. The tolerance '0 mm' indicates that no reduction in the prescribed nominal cover is allowed.

Table *Nominal cover requirements based on exposure conditions*

Exposure condition	Minimum Grade of concrete	Nominal Cover (mm)	Permitted allowance
Mild	M 20	20	Can be reduced by 5 mm for bars less than 12 mm dia
Moderate	M 25	30	
Severe	M 30	45	Can by reduced by 5 mm if concrete grade is M 35 or higher
Very Severe	M 35	50	
Extreme	M 40	75	

NOTE

The earlier version of code i.e. **IS 456: 1978** specified clear cover requirements based on the type of structural elements (like 15 mm in slabs, 25 mm in beams, 40 mm in columns etc.), but in the latest version i.e. IS **456: 2000**, clear cover requirements are now made applicable for all types of structural elements. Cl. 26.4.2.1 of **IS 456: 2000** specifies certain minimum clear cover requirements for columns (generally 40 mm) and Cl. 26.4.2.2 of IS **456: 2000** specifies a certain minimum clear cover requirements for footings (generally 50 mm).

6.5 Spacing of Reinforcement

- The minimum limits are necessary to ensure that the concrete can be placed easily in between and around the bars during placement of fresh concrete.

  The following shall apply for spacing of bars:

  (i) The horizontal distance between two parallel main reinforcing bars shall usually be not less than the greatest of the following:

  (a) The diameter of the bar if the diameters are equal

  (b) The diameter of the larger bar if the diameters are unequal and

  (c) 5 mm more than the nominal maximum size of coarse aggregate.

  (ii) Where there are two or more rows of bars, the bars shall be vertically in line and the minimum vertical distance between the bars shall be 15 mm, two-thirds the nominal maximum size of aggregate or the maximum sizes of the bars, whicever is greater.

(iii) Maximum horizontal c/c spacing

Fe-250 → 300 mm

Fe-415 → 180 mm

Fe-500 → 150 mm

High grade steel yields at higher strain. So, it produces wide cracks to reduce crack width or to reduce cumulative effect of shrinkage and strain, maximum permitted spacing reduces with increase in grade of steel.

6.6 Deflection Criteria

6.6.1 Deflection Units

- The final deflection due to all loads including effect of temperature, creep, shrinkage should not be more than $\left(\frac{L_{eff}}{250}\right)$.
- The deflection including effect of temperature creep, shrinkage, partition loading should not be more than $\left(\frac{L_{eff}}{350}\right)$ or 20 mm whichever is less.

6.6.2 Deflection Control

Exact calculation of deflection and keeping it within permissible limits require a lot of calculation of simplify this IS456 provides a way to keep $\left(\frac{L_{eff}}{d}\right)$ ratio less than the values given in table below by satisfying this criteria, deflection of beam is kept within limits.

Supporting Condition	Value
Cantilever	7
Simply supported	20
Continuous	26

$$\frac{L_{eff}}{d} < K_1.K_2.K_3.K_4 \text{ (Value)}$$

K_1 depends upon span, $= 1$ (upto 10 m)

$$= \frac{10}{\text{span (m)}} \text{ (beyond 10 m except centilever)}$$

K_2 depends on percentage of tension reinforcement.

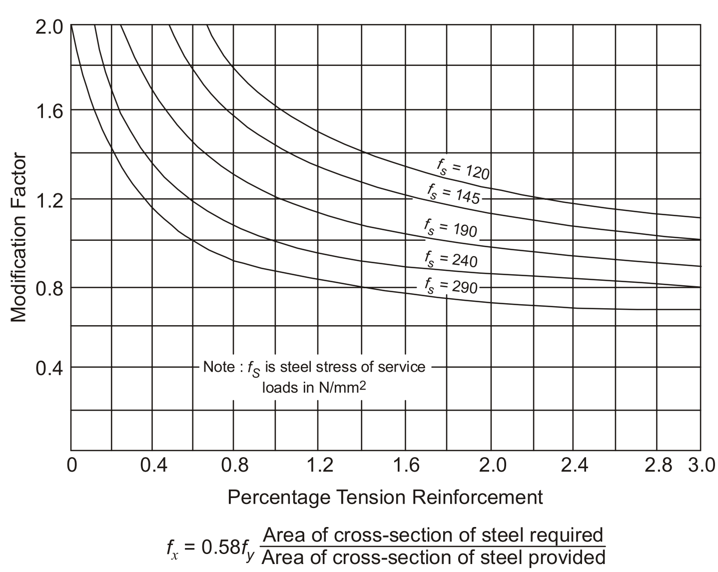


***Fig.** Modification Factor for Tension Reinforcement*

f_s = Stress level in steel

K_3 depends upon percentage of compression reinforcement

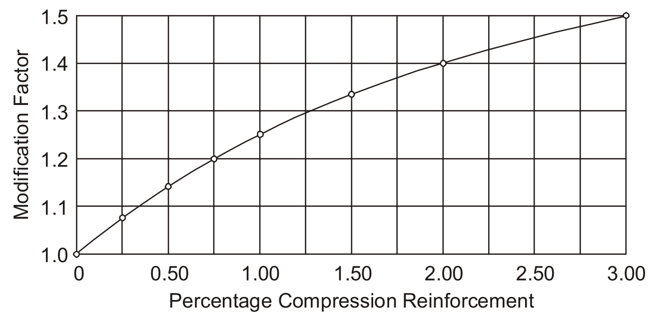


Fig. *Modification Factor for Compression Reinforcement*

K_4 depends on ratio of web width to flange width.

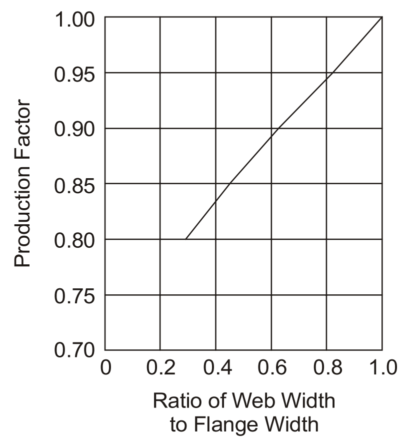


Fig. *Reduction Factors for Ratios of Span to Effective Depth for Flanged Beams*

$$\frac{L_{eff}}{d} < K_1.K_2.K_3.K_4 \text{ (Value)}$$

$$d > \frac{L_{eff}}{K_1 \cdot K_2 \cdot K_3 \cdot K_4 \text{ (Value)}}$$

- Value of K_1 reduces with increase in span. So, higher depth is required to satisfy deflection criteria.
- As we move from flanged section to rectangular section K_4 increases so depth requirement to satisfy deflection criteria reduces. In other words, rectangular section produces less deflection compared to flanged section.
- As percentage of compression reinforcement increases K_3 also increases. So, depth requirement to satisfy deflection criteria reduces. In other words, higher percentage of compression reinforcement produces lesser deflection.
- For given service load, percentage of tension reinforcement reduces when depth is increased. Beam with lesser percentage of steel and higher depth will always produce less deflection.
- K_2 is lower for HYSD steel. So depth requirement to satisfy deflection criteria increases with increases in grade of steel. In other words, high HYSD steel produces more deflection.