

5. DEVELOPMENT OF PROGRAM FOR COMPOSITE BEAMS

5.1 AN OVERVIEW

Composite beam is the most common form of composite element in steel frame building construction and has been the major form for mid range steel bridges. A steel concrete composite beam consists of a steel beam, over which a reinforced concrete slab is cast with shear connectors, as shown in **Fig. 5.1(a)**. The composite beam can also be constructed with profiled sheeting with concrete topping, instead of cast-in place or pre-cast reinforced concrete slab (**Fig 5.1 (b)**).

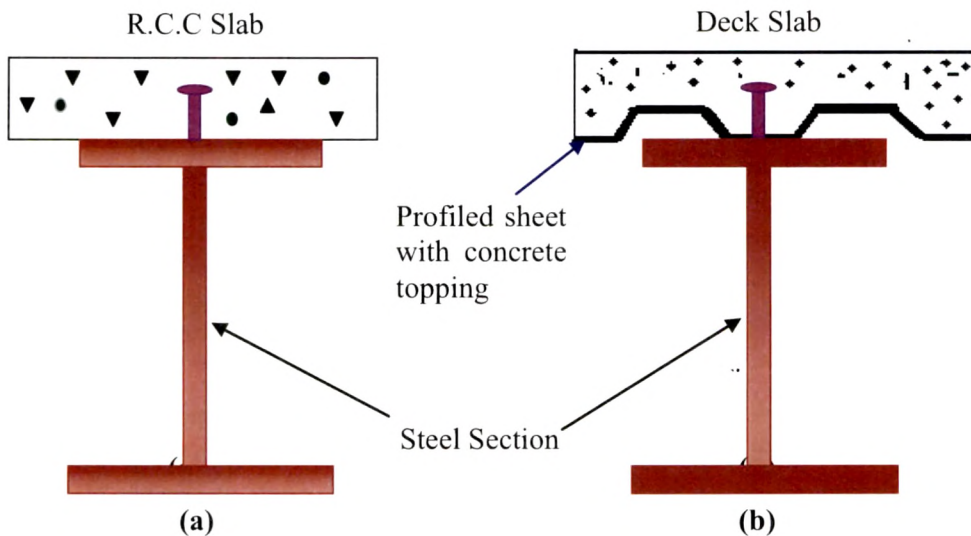


Fig. 5.1 Typical Section of Composite Beam [6]

The high bearing capacity and stiffness of composite beams allow the construction of very wide column free rooms with comparatively little construction height. Until now composite beams have only been built single span or continuous; rigid composite connections to the columns have been avoided because of missing knowledge. For higher column spacing castellated beams and trusses are brought into action. In special cases the steel beam sections may be partially encased. The normal method of designing simply-supported beams for strength is by plastic analysis of the cross-section. Full shear connection means that sufficient

shear connectors are provided to develop the full plastic capacity of the section. Beams designed for full shear connection result in the lightest beam size. Where fewer shear-connectors are provided (known as partial shear connection) the beam size is heavier but the overall design may be more economical.

Partial shear connection is most attractive where the number of shear-connectors is placed in a standard pattern, such as one per deck trough or one per alternate trough where profiled decking is used. In such cases, the resistance of the shear connectors is a fixed quantity irrespective of the size of the beam or slab. Conventional elastic design of the section results in heavier beams than with plastic design because it is not possible to develop the full tensile resistance of the steel section.

5.2 BEHAVIOUR OF SIMPLY SUPPORTED COMPOSITE BEAM

The behaviour of simply supported composite beams under uniformly distributed load of w /unit length as shown in Fig. 5.2 is best illustrated by using two identical beams, each having a cross section of $b \times h$ and spanning a distance of ℓ , one placed at the top of the other. For theoretical explanation, two extreme cases of no interaction and 100% (full) interaction are considered and their effect on bending and shear stress distribution is depicted in Figs. 5.2 (b) and (c) respectively.

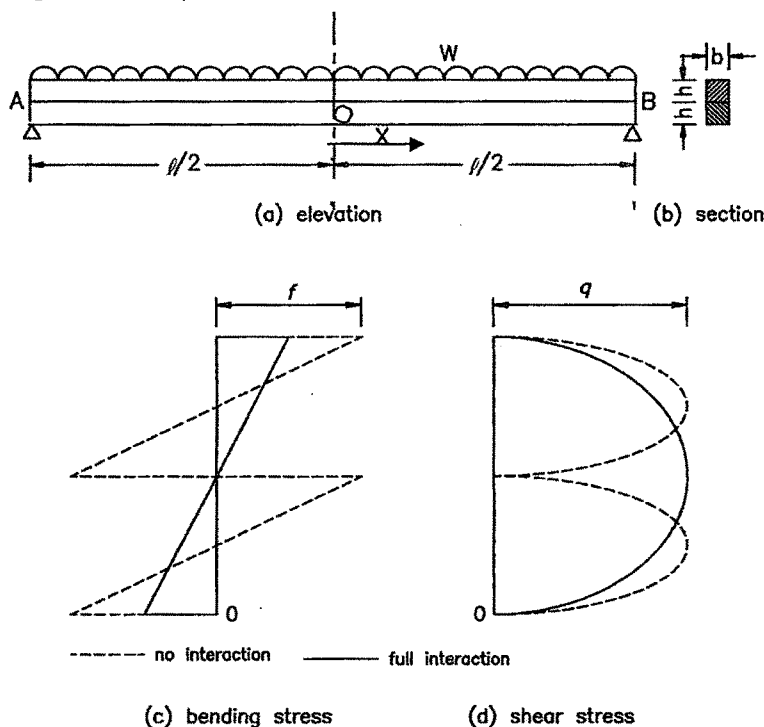


Fig. 5.2 Effect of Shear Connection on Bending and Shear Stresses

5.3 BEHAVIOUR OF CONTINUOUS COMPOSITE BEAM

Continuous beams offer greater load resistance and greater stiffness which result in a smaller steel section being required to withstand specified loading. However, continuity of structural steel can be achieved economically by running a single length of section across two or more spans. The concrete is cast continuously over the supports and, to control shrinkage and other cracking, the concrete is reinforced. The mid span regions of continuous composite beams behave in the same way as the simple span composite beam. However, the support regions display a considerably different behaviour as shown diagrammatically in Fig. 5.3 [95]. The concrete in the mid span region is generally in compression and the steel in tension. Over the support this distribution reverses as the moment is now hogging. The concrete cannot carry significant tensile strains and therefore cracks. To avoid cracking longitudinal reinforcements are provided as shown in Fig. 5.3.

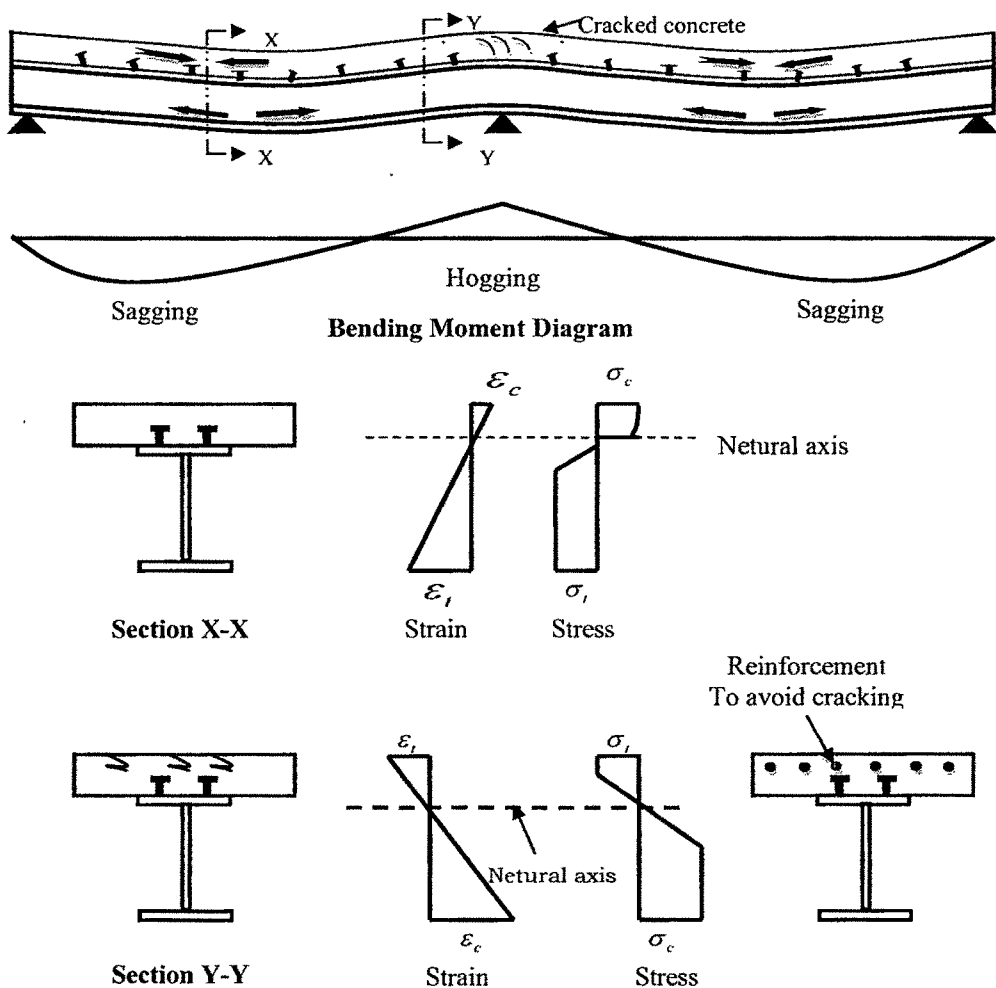


Fig. 5.3 Behavior of Continuous Composite Beam under Gravity Load[6]

5.4 BASIS OF THE DESIGN

For design purpose, the analysis of composite section is made using Limit State of Collapse method. IS: 11384-1985 Code deals with the design and construction of only simply supported composite beams. Some of the design criteria are also considered as per EC4.

5.4.1 SPAN TO DEPTH RATIO

EC4 specifies the span to depth (total beam and slab depth) ratios as given in Table 5.1 for which the serviceability criteria will be deemed to be satisfied.

Table 5.1 Span to Depth Ratio as According to EC4

Types of Beam	Eurocode 4
Simply supported	15-18 (Primary Beams) 18-20(Secondary Beams)
Continuous	18-22 (Primary Beams) 22-25 (end bays)

5.4.2 EFFECTIVE BREADTH OF FLANGE

A composite beam acts as a T-beam with the concrete slab as its flange. The bending stress in the concrete flange is found to vary along the breadth of the flange as in Fig. 5.4, due to the shear lag effect. This phenomenon is taken into account by replacing the actual breadth of flange (B) with an effective breadth (b_{eff}), such that the area $FGHIJ$ nearly equals the area $ACDE$. Research based on elastic theory has shown that the ratio of the effective breadth of slab to actual breadth (b_{eff}/B) is a function of the type of loading, support condition, and the section under consideration. For design purpose a portion of the beam span (20% - 33%) is taken as the effective breadth of the slab.

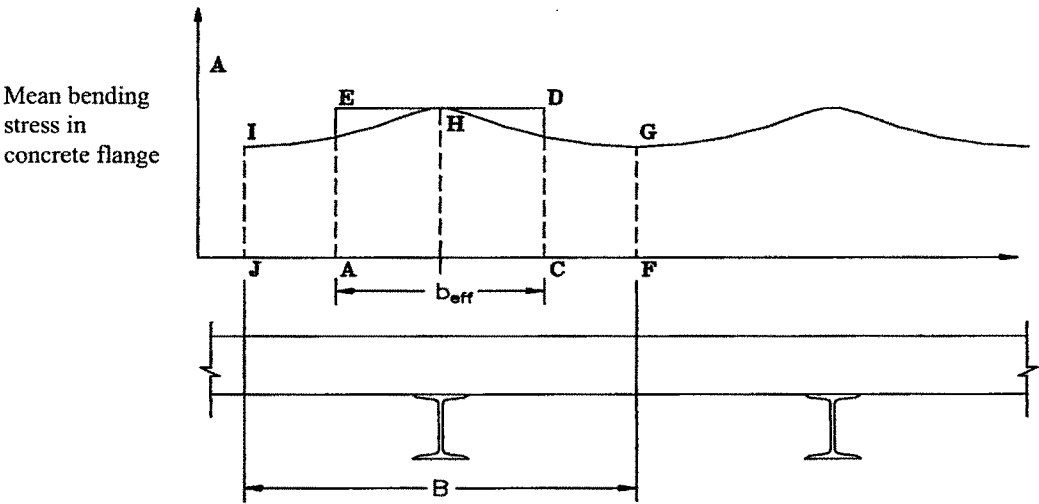


Fig. 5.4 Use of Effective Width to Allow for Shear Lag

In EC4, the effective breadth of simply supported beam is taken as $l_o/8$ on each side of the steel web, but not greater than half the distance to the next adjacent web. For simply supported beam $l_o = l$. Therefore,

$$b_{eff} = \frac{l}{4} \text{ but } \leq B \quad \dots (5.1)$$

where, l_o = The effective span taken as the distance between points of zero moments, l = Actual span and B = Centre to centre distance of transverse spans for slab.

For continuous beams l_o is obtained from Fig. 5.5 [6].

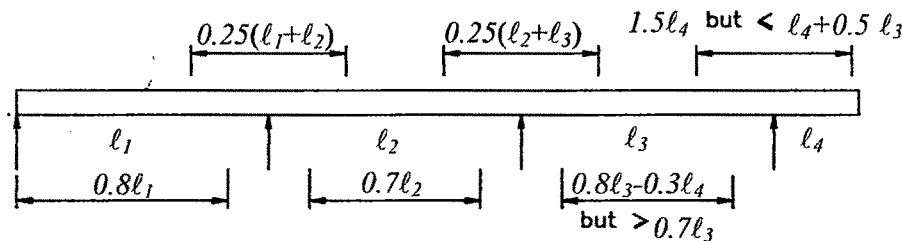


Fig. 5.5 Value of l_o for Continuous Beam as Per EC4

5.4.3 PARTIAL SAFETY FACTOR FOR LOADS AND MATERIALS

The partial safety factors for load γ_f and for materials γ_m are shown in Table 5.2.

Table 5.2 Partial Safety Factors as per the New IS: 800: 2007

Load	Partial safety factor, γ_f
Dead load	1.5
Live load	1.5
Materials	Partial safety factor, γ_m
Concrete	1.5
Structural Steel	1.15
Reinforcement	1.15

5.4.4 SECTION CLASSIFICATIONS

Four classes of sections are defined as follows:

- a) Plastic – Cross sections, which can develop plastic hinges and have the rotation capacity required for failure of the structure by formation of a plastic mechanism.
- b) Compact – Cross sections, which can develop plastic moment of resistance, but have inadequate plastic hinge rotation capacity for formation of a plastic mechanism.
- c) Semi-Compact – Cross sections, in which the extreme fibre in compression can reach, yield stress, but cannot develop the plastic moment of resistance, due to local buckling.

- d) Slender – Cross sections in which the elements buckle locally even before reaching yield stress.

Local buckling of the elements of a steel section reduces its capacity. Because of local buckling, the ability of a steel flange or web to resist compression depends on its slenderness, represented by its breadth/thickness ratio. The effect of local buckling is therefore taken care of in design, by limiting the slenderness ratio of the elements i.e. web and compression flange. The classification of web and compression flange is presented in the **Table 5.3**.

Table 5.3 Classification of Section

Type of Element	Type of Section		Class of Section		
			Plastic(β_1)	Compact(β_2)	Semi-compact(β_3)
Outstand element of compression flange	Rolled		$b/t \leq 9.4\epsilon$	$b/t \leq 10.5\epsilon$	$b/t \leq 15.7\epsilon$
	Welded		$b/t \leq 8.4\epsilon$	$b/t \leq 9.4\epsilon$	$b/t \leq 13.6\epsilon$
Internal element of compression flange	Bending		$b/t \leq 29.3\epsilon$	$b/t \leq 33.5\epsilon$	$b/t \leq 42\epsilon$
	Axial Comp.		Not Applicable		$b/t \leq 42\epsilon$
web	N.A. at mid depth		$d/t \leq 84\epsilon$	$d/t \leq 105\epsilon$	$d/t \leq 126\epsilon$
	Generally d/t	If r1 is negative	$\frac{84\epsilon}{1+r_1}$	$\frac{105\epsilon}{1+r_1} \leq 42\epsilon$	$\frac{126\epsilon}{1+2r_1} \leq 42\epsilon$
		If r1 is positive	$\leq 42\epsilon$	$\frac{105\epsilon}{1+1.5r_1} \leq 42\epsilon$	

where, b = half width of flange of rolled section, t = Thickness, d = clear depth of web, $\epsilon = \sqrt{250/f_y}$, and f_y = compressive stress taken as positive and tensile stress negative.

If the compression flange falls in the plastic or compact category as per the above classification, plastic moment capacity of the composite section is used provided the web is not slender. For compression flange, falling in semi-compact or slender category elastic moment capacity of the section is used.

5.5 DESIGN OF COMPOSITE BEAMS

The composite beam is designed to have sufficient bending strength and stiffness and secure connection to the slab. The principle aspect of behaviors of the composite beam which need

to be considered in this respect are bending strength, adequacy of the connection between slab and beam and its deflection performance.

5.5.1 REINFORCED CONCRETE SLAB SUPPORTED ON STEEL BEAMS

Reinforced concrete slab connected to rolled steel section through shear connectors (Fig. 5.6) is perhaps the simplest form of composite beam.

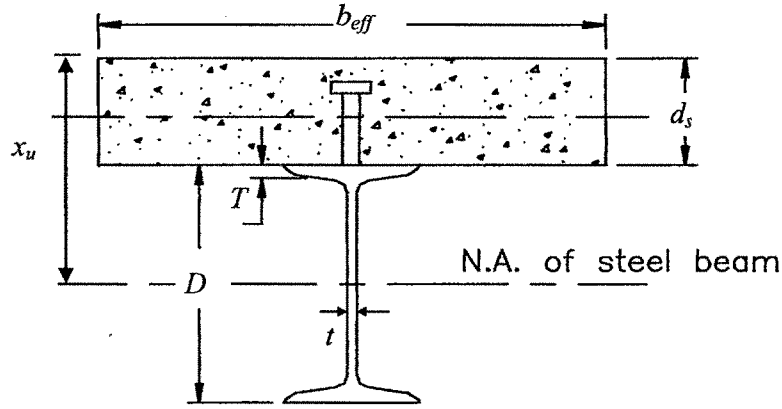


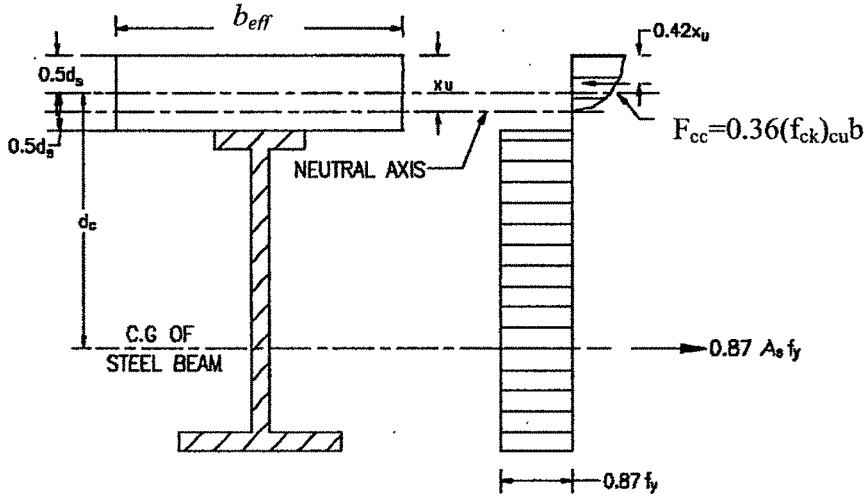
Fig. 5.6 Notations as per IS: 11384-1985

The ultimate strength of the composite beam is determined from its collapse load capacity. The moment capacity of such beams can be found by the method given in IS:11384-1985 [1]. In this code a parabolic stress distribution is assumed in the concrete slab. Here a stress factor $a = 0.87f_y/0.36(f_{ck})_{cu}$ is applied to convert the concrete section into steel. The additional assumptions made by the IS: 11384-1985 are given below:

- The maximum strain in concrete at outermost compression member is taken as 0.0035 in bending.
- The total compressive force in concrete is given by $f_{cc} = 0.36 (f_{ck})_{cu} b x_u$ and this acts at a depth of $0.42 x_u$, not exceeding d_s .
- The stress strain curve for steel section and concrete are as per IS: 456-2000.

The notations used here are : A_f = area of top flange of steel beam, A_s = cross sectional area of steel beam, b_{eff} = effective width of concrete slab, b_f = width of top flange of steel section, d_c = distance between centroids of concrete slabs and steel beam in a composite section, t_f = thickness of the top flange of the steel section, x_u = depth of neutral axis at ultimate limit state of flexure, M_u = ultimate bending moment.

The three cases that may arise are given below with corresponding M_u .

Case I: Plastic neutral axis within the slab (Fig. 5.7)**Fig. 5.7 Stress Distribution with Neutral Axis within Concrete Slab**

This occurs when $b_{eff} d_s \geq a A_s$

Taking moment about centre of concrete compression

$$M_u = 0.87 A_s f_y (d_c + 0.5 d_s - 0.42 x_u) \quad \dots (5.2)$$

Where, $x_u = a A_s / b_{eff}$ and $a = 0.87 f_y / 0.36 (f_{ck})_{cu}$

Case II: Plastic neutral axis within the top flange of steel section (Fig. 5.8)

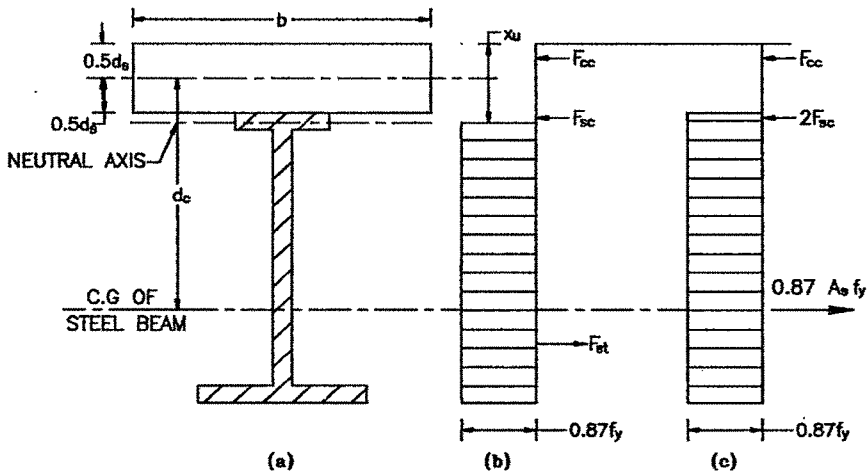
This happens when $b_{eff} d_s < a A_s < (b_{eff} d_s + 2 a A_f)$

Equating forces, one gets

$$x_u = d_s + \frac{a A_s - b_{eff} d_s}{2 b_f a} \quad \dots (5.3)$$

Taking moment about centre of concrete compression

$$M_u = 0.87 f_y [A_s (d_c + 0.08 d_s) - b_f (x_u - d_s) (x_u + 0.16 d_s)] \quad \dots (5.4)$$

**Fig. 5.8 Stress Distribution with Neutral Axis within Flange of Steel Beam**

Case III: Plastic neutral axis lies within web (Fig. 5.9)

This happens when, $a (A_s - 2A_f) > b_{eff}d_s$

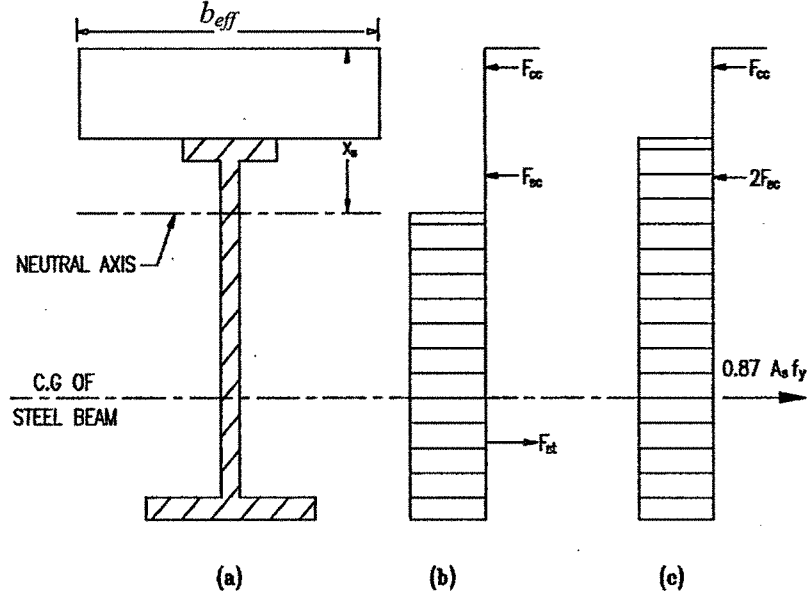


Fig. 5.9 Stress Distribution with Neutral Axis within the Web of the Steel Beam

Equating area under tension and compression

$$x_u = d_s + t_f + \frac{a(A_s - 2A_f) - b_{eff}d_s}{2at_w} \quad \dots (5.5)$$

Taking moment about the centre of concrete compression

$$M_u = 0.87f_y A_s (d_c + 0.08d_s) - 2A_f (0.5t_f + 0.58d_s) - 2t_w (x_u - d_s - t_f) (0.5x_u + 0.08d_s + 0.5t_f) \quad \dots (5.6)$$

5.5.2 REINFORCED CONCRETE SLABS WITH PROFILED DECK AND STEEL BEAMS

The design procedure of composite beams depends upon the class of the compression flange and web. **Table 5.4** shows the classification of the sections suggested in EC4 based upon the buckling tendency of steel flange or web. The resistance to buckling is a function of width to thickness ratio of compression members. **Table 5.4** shows that for sections falling in Class 1 and 2 [7], plastic analysis is recommended. For simply supported composite beams the steel compression flange is restrained from local as well as lateral buckling due to its connection to concrete slab. Moreover, the plastic neutral axis is usually within the slab or the steel flange for full interaction. So, the web is not in compression. This allows the composite section to be analysed using plastic method.

Table 5.4 Classification of Sections and Methods of Analysis (EC4)

Slenderness class and name	1 plastic	2 compact	3 semi-compact	4 slender
Method of global analysis	plastic	elastic	elastic	elastic
Analysis of cross-sections	plastic	plastic	elastic	elastic
Maximum ratio of c/t for flanges of rolled I-section				
Uncased web	8.14	8.95	12.2	no limit
Encased web	8.14	12.2	17.1	no limit

Where, c is half the width of a flange of thickness t .

The notations used here are as follows:

A_a = area of steel section, γ_a = partial safety factor for structural steel, γ_c = partial safety factor for concrete, b_{eff} = effective width of flange of slab, f_y = yield strength of steel, $(f_{ck})_{cy}$ = characteristic (cylinder) compressive strength of concrete, (f_{sk}) = yield strength of reinforcement, h_c = distance of rib from top of concrete, h_t = total depth of concrete slab and h_g = depth of centre of steel section from top of steel flange.

Note: Cylinder strength of concrete $(f_{ck})_{cy}$ is usually taken as 0.8 times the cube strength.

Case I: Neutral axis within the concrete slab (Full shear connection, Fig. 5.10)

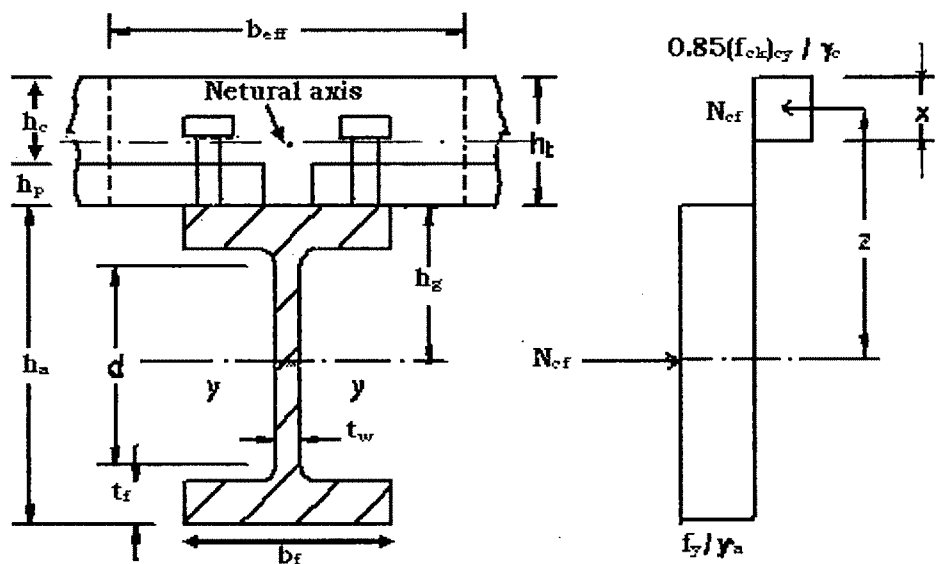


Fig. 5.10 Distribution with Neutral Axis in Concrete Slab

This occurs when

$$0.85 \frac{(f_{ck})_{cy}}{\gamma_c} b_{eff} h_c \geq \frac{A_a f_y}{\gamma_a} \quad \dots (5.7)$$

The depth of plastic neutral axis can be found by using force equilibrium.

$$N_{cf} = \frac{A_a f_y}{\gamma_a} = b_{eff} x 0.85 \frac{(f_{ck})_{cy}}{\gamma_c} \quad \dots (5.8)$$

$$\therefore x = \frac{A_a f_y / \gamma_a}{b_{eff} 0.85 \frac{(f_{ck})_{cy}}{\gamma_c}} \quad \dots (5.9)$$

This expression is valid for $x \leq h_c$.

The plastic moment of resistance of the section,

$$M_p = \frac{A_a f_y}{\gamma_a} (h_g + h_t - x/2) \quad \dots (5.10)$$

Case II: Neutral axis within the steel top flange (Full shear connection, Fig. 5.11)

This case arises when

$$N_{cf} < N_{a,pl}$$

$$i.e. b_{eff} h_c 0.85 \frac{(f_{ck})_{cy}}{\gamma_c} < \frac{A_a f_y}{\gamma_a} \quad \dots (5.11)$$

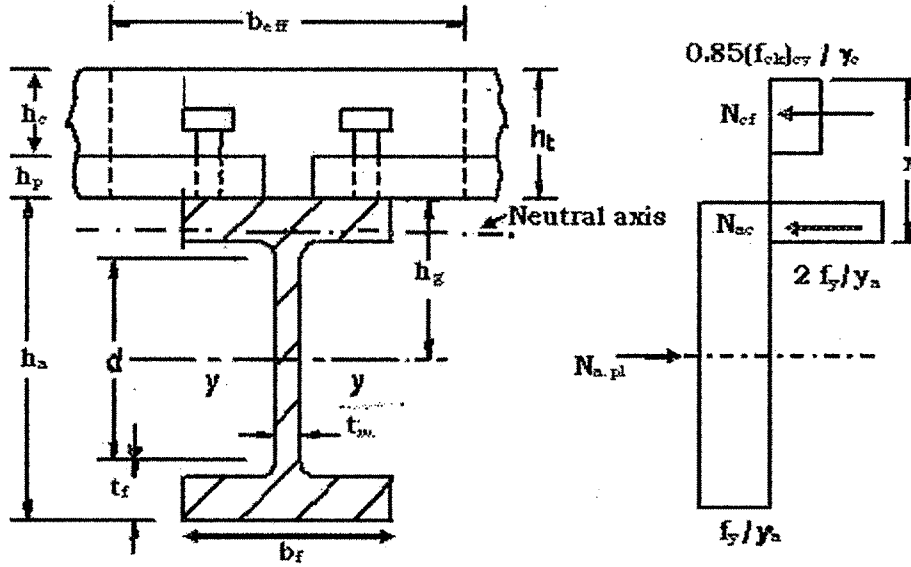


Fig. 5.11 Stress Distribution with Neutral Axis in Flange of Beam

To simplify the calculation it is assumed that strength of steel in compression is $2f_y/\gamma_a$, so that, the force $N_{a,pl}$ and its line of action remain unchanged. Note that the compression flange is assumed to have a tensile stress of f_y/γ_a and a compressive stress of $2f_y/\gamma_a$, giving a net compressive stress of f_y/γ_a . So, the plastic neutral axis will be within steel flange if,

$$N_{a-pl} - N_{cf} \leq 2 b_f t_f f_y / \gamma_a$$

Equating tensile force with compressive,

$$N_{a-pl} = N_{cf} + N_{ac}$$

$$i.e. \frac{A_a f_y}{\gamma_a} = 0.85 \frac{(f_{ck})_{cy}}{\gamma_c} b_{eff} h_c + 2 b_f (x - h_l) \frac{f_y}{\gamma_a} \quad \dots (5.12)$$

The value of x is found from the above equation.

The plastic moment of resistance is found from

$$M_p = N_{a-pl} (h_g + h_l - h_c/2) - \frac{N_{ac}(x - h_c + h_l)}{2} \quad \dots (5.13)$$

Case III: Neutral axis lies within web (Full shear connection, Fig. 5.12)

If the value of x exceeds $(h_c + t_f)$, then the neutral axis lies in the web. In design this case should be avoided, otherwise the web has to be checked for slenderness.

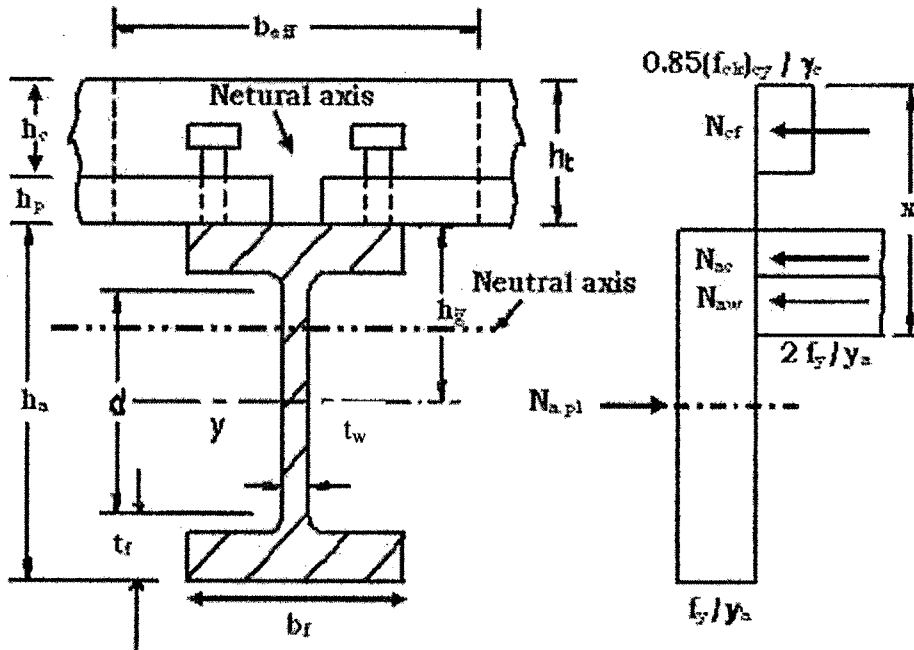


Fig. 5.12 Stress Distribution with Neutral Axis in the Web of the Beam

In similar procedure as the previous one, here x can be found from

$$\begin{aligned} N_{a-pl} &= N_{cf} + N_{acf} + N_{aw} \\ &= N_{cf} + 2 b_f t_f f_y / \gamma_a + 2 t_w (x - h_l - t_f) f_y / \gamma_a \end{aligned} \quad \dots (5.14)$$

Plastic moment of resistance

$$\begin{aligned} M_p &= N_{a-pl} (h_g + h_l - h_c/2) - N_{acf} (h_l + t_f/2 - h_c/2) \\ &\quad - N_{aw} (x + h_l + t_f - h_c)/2 \end{aligned} \quad \dots (5.15)$$

Case IV: Resistance to hogging Bending Moment

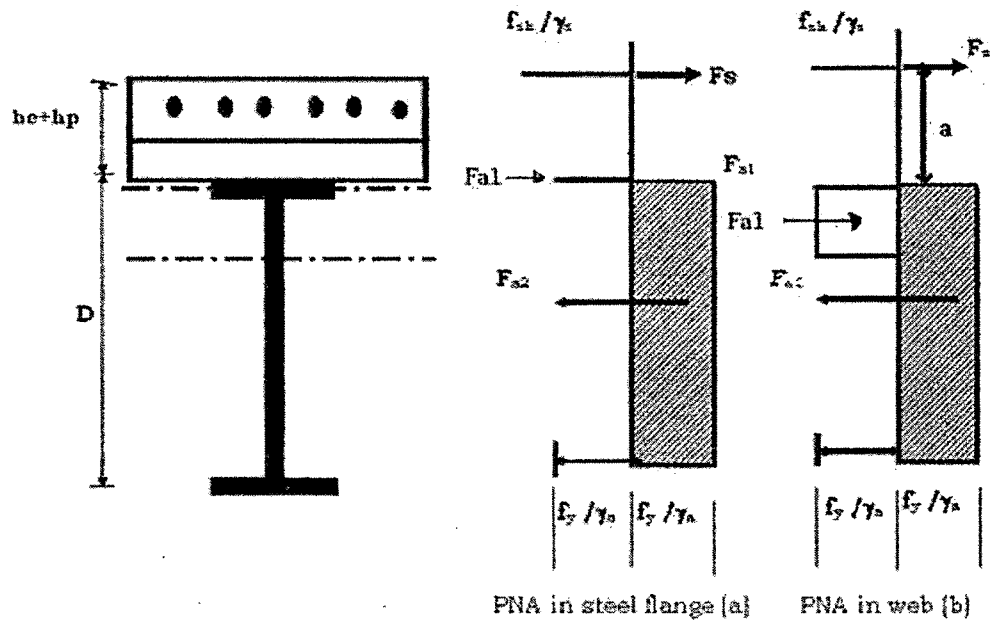


Fig. 5.13 Resistance to Hogging Bending Moment

The stress distribution for hogging moment region for neutral axis within flange and for neutral axis within web is shown in Fig. 5.13. In case of continuous composite beam resistance to hogging moment is calculated by using formula given in Table 5.5.

Table 5.5 Negative Moment Capacity of Section with Full Shear Connection

Position of Plastic Neutral Axis	Condition	Moment Capacity M_p
Plastic neutral axis in steel flange, Fig. 5.13 (a)	$\frac{A_{aw}f_y}{\gamma_a} < \frac{A_s f_{sk}}{\gamma_s} < \frac{A_a f_y}{\gamma_a}$	$M_p \approx \frac{A_a f_y D}{\gamma_a} + \frac{A_s f_{sk} a}{\gamma_s}$
Plastic neutral axis in web, Fig. 5.13 (b)	$\frac{A_s f_{sk}}{\gamma_s} < \frac{A_{aw} f_y}{\gamma_a}$	$M_p = M_{ap} + \frac{A_s f_{sk}}{\gamma_s} \left(\frac{D}{2} + a \right) + \left(\frac{A_{sk} f_{sk}}{\gamma_s} \right)^2 / 4 * t * \frac{f_y}{\gamma_a}$

5.6 OTHER DESIGN ASPECTS

5.6.1 VERTICAL SHEAR RESISTANCE

In a composite beam, the concrete slab resists some of the vertical shear. But there is no simple design model for this, as the contribution from the slab is influenced by whether it is continuous across the end support, by how much it is cracked, and by the local details of the

shear connection. It is therefore assumed that the vertical shear is resisted by steel beam alone, exactly as if it was not composite.

The shear force resisted by the structural steel section should satisfy:

$$V \leq V_p$$

where, V_p is the plastic shear resistance given by,

$$= 0.6Dt \frac{f_y}{\gamma_a} \text{ (for rolled I, H, C sections)} \quad \dots (5.16)$$

$$= dt \frac{f_y}{\gamma_a \sqrt{3}} \text{ (for builtup I sections)} \quad \dots (5.17)$$

In addition to this the shear buckling of steel web should be checked.

The shear buckling of steel web can be neglected if following condition is satisfied

$$\frac{d}{t} \leq 67\varepsilon \quad \text{for web not encased in concrete} \quad \dots (5.18)$$

$$\frac{d}{t} \leq 120\varepsilon \quad \text{for web encased in concrete} \quad \dots (5.19)$$

where, $\varepsilon = \sqrt{(250/f_y)}$ and d is the depth of the web considered in the shear area.

5.6.2 RESISTANCE OF SHEAR CONNECTORS

5.6.2.1 Effect of Shape of Deck Slab on Shear Connection

The profile of the deck slab has a marked influence on strength of shear connector. There should be a 45° projection from the base of the connector to the core of the solid slab for smooth transfer of shear. But the profiled deck slab limits the concrete around the connector. This in turn makes the centre of resistance on connector to move up, initiating a local concrete failure as cracking. This is shown in **Fig 5.14**. EC 4 suggests the following reduction factor k (relative to solid slab).

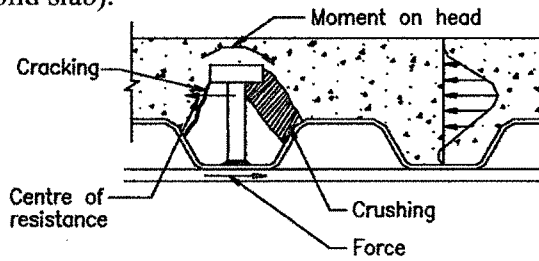


Fig. 5.14 Behaviour of a Shear Connection Fixed Through Profile

- (i) Profiled steel decking with the ribs parallel to the supporting beam.

$$K_p = 0.6 \frac{b_0}{h_p} \left(\frac{h - h_p}{h_p} \right) \leq 1.0 \text{ where } h \leq h_p + 75 \quad \dots (5.20)$$

- (ii) Profiled steel decking with the ribs transverse to the supporting beam.

For studs of diameter not exceeding 20 mm,

$$k_t = \frac{0.7}{\sqrt{N_r}} \frac{b_0}{h_p} \left(\frac{h - h_p}{h_p} \right) \leq 1.0 \text{ where } h_p \leq 85 \text{ and } b_0 \geq h_p \quad \dots (5.21)$$

where, b_0 = is the average width of trough, h = is the stud height, h_p = is the height of the profiled decking slab, and N_r = is the number of stud connectors in one rib at a beam intersection (Should not be greater than 2).

For studs welded through the steel decking, k_t should not be greater than 1.0 when $N_r=1$, and not greater than 0.8 when $N_r \geq 2$.

5.6.3 LONGITUDINAL SHEAR FORCE

5.6.3.1 Full Shear Connection

Single span beams

For single span beams the total design longitudinal shear, V_l to be resisted by shear connectors between the point of maximum bending moment and the end support is given by:

$$V_l = F_{cf} = \frac{A_a f_y}{\gamma_a} \quad \dots (5.22)$$

Or

$$V_l = 0.85 f_{ck} \frac{(f_{ck})_{cy} b_{eff} h_c}{\gamma_c} \quad \dots (5.23)$$

Whichever is smaller.

Continuous span beams

For continuous span beams the total design longitudinal shear, V_l to be resisted by shear connectors between the point of maximum positive bending moment and an intermediate support is given by

$$V_l = F_{cf} + \frac{A_s f_{sk}}{\gamma_s} + \frac{A_{ap} f_{yp}}{\gamma_{ap}} \quad \dots (5.24)$$

where, A_s is the effective area of longitudinal slab reinforcement and A_{ap} is the effective area of profiled steel sheeting.

Numbers of shear connectors

The number of shear connector should be calculated to resist the horizontal shear force to be transmitted at collapse between point of maximum and zero moment. This force is taken as the force in the concrete F_{cc} at ultimate moment (IS: 11384-1985). Number of connectors is calculated by dividing the total load carried by connectors to the design strength of connectors.

The number of required shear connectors in the zone under consideration for full composite action is given by:

$$n_f = \frac{V_l}{P} \quad \dots (5.25)$$

where, V_l is the design longitudinal shear force, and P is the design resistance of the connector. The shear connectors are usually equally spaced.

5.6.3.2 Minimum degree of shear connectors

The minimum degree of shear connection for headed studs with an overall length after welding not less than 4 times diameter and shank diameter not less than 16 mm and not exceeding 22 mm is defined by the following equations:

For steel sections with equal flanges :

$$\begin{aligned} L \leq 5 & \quad n/n_f \geq 0.4 \\ 5 \leq L \leq 25 & \quad \frac{n}{n_f} \geq 0.25 + 0.03L \\ L \geq 5 & \quad n/n_f \geq 1.0 \end{aligned}$$

where, L is the span of the beam in meter, N_f is the number of stud connectors determined for relevant length of beam in accordance of with 5.8.1, and N is the number of stud connectors.

- (i) Between the point of maximum bending moment and the end support V_l to be resisted by shear connectors is given by;

$$V_l = F_c \quad \dots (5.26)$$

- (ii) Between the point of maximum positive bending moment and an intermediate support V_l to be resisted by shear connectors is given by:

$$V_l = F_c + \frac{A_s f_{sk}}{\gamma_s} + \frac{A_{ap} f_{yp}}{\gamma_{ap}} \quad \dots (5.27)$$

where,

$$F_c = \frac{M - M_{ap}}{M_p - M_{ap}} F_{cf} \quad \dots (5.28)$$

5.6.4 INTERACTION BETWEEN MOMENT AND SHEAR

Interaction between bending and shear can influence the design of continuous beam. **Fig. 5.15** shows the resistance of the composite section in combined bending (hogging or sagging) and shear. When the design shear force, V exceeds $0.5V_p$ (point A in the **Fig. 5.15**), moment capacity of the section reduces non-linearly as shown by the parabolic curve AB, in the presence of high shear force. At point B the remaining bending resistance M_f is that contributed by the flanges of the composite section, including reinforcement in the slab.

Along curve AB, the reduced bending resistance is given by

$$M \leq M_f + (M_p - M_f) \left[1 - \left(2 \frac{V}{V_p} - 1 \right)^2 \right] \quad \dots (5.29)$$

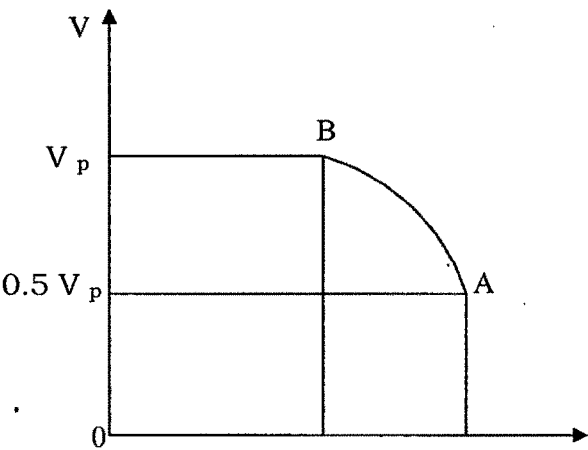


Fig. 5.15 Resistance to Combined Bending and Vertical Shear

Where, M = design bending moment, M_f = plastic resistance of the flange alone, M_p = plastic resistance of the entire section, V = design shear force and V_p = plastic shear resistance.

5.6.5 TRANSVERSE REINFORCEMENT

Shear connectors transfer the interfacial shear to concrete slab by thrust. This may cause splitting in concrete in potential failure planes as shown in Fig. 5.16. Therefore reinforcement is provided in the direction transverse to the axis of the beam. Like stirrups in the web of a reinforced T beam, the reinforcement supplements the shear strength of the concrete.

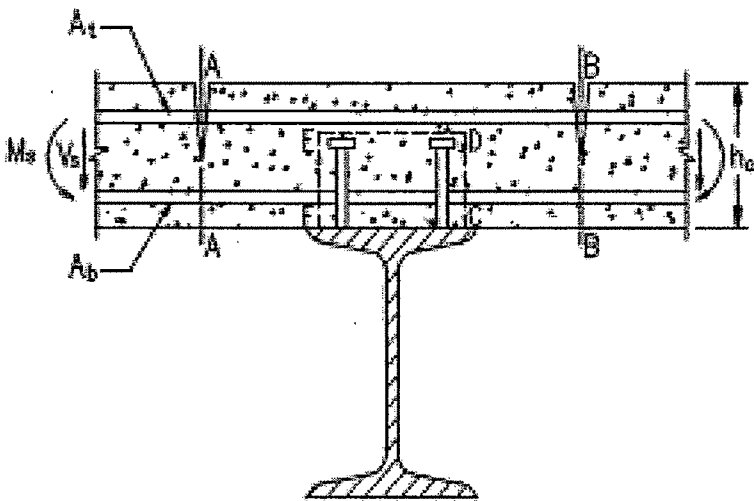


Fig. 5.16 Surfaces of Potential Shear Failure [90]

The formulae suggested by EC4 and IS: 11384 – 1985 are given in Table 5.6 [6].

Table 5.6 Comparison of Provisions for Transverse Reinforcement

EC4	IS 11384 – 1985
$V_r = 2.5A_{cv}\eta\tau + A_e f_{sk}/\gamma_s + v_{pd}$ or $v_r = \frac{0.2A_{cv}\eta(f_{ck})_{cy}}{\gamma_c} + \frac{V_{pd}}{\sqrt{3}}$ where, A_e is the sum of the cross sectional areas of transverse reinforcement (assumed to be perpendicular to the beam) per unit length of beam crossing the shear surface under consideration including any reinforcement provided for bending of the slab, A_{cv} is the mean cross sectional area per unit length of the beam of the concrete shear surface under consideration. $\eta = 1$ for normal weight concrete, $\eta = 0.3 + 0.7(\rho/24)$ for light weight concrete, τ basic shear strength to be taken as $0.25 f_{ctk}/\gamma_c$, where f_{ctk} is the characteristic tensile strength of concrete, V_{pd} contribution of profiled steel sheeting, if any $= A_p f_{yp}/\gamma_{ap}$ (for ribs running perpendicular to the beam) $= \frac{P_{pb}}{s}$ but $\leq A_p f_{yp}/\gamma_{ap}$ (for ribs running parallel to the beam), P_{pd} = design resistance of the headed stud A_p = cross-sectional area of the profile steel sheeting per unit length of the beam, f_{yp} = yield strength of steel sheeting, s = is the spacing centre to centre of the studs along the beam	$v_r = \frac{N_c F_s}{s} < 0.232 L_s \sqrt{(f_{ck})_{cu}} + 0.1 A_{sv} f_y n < 0.623 L_s \sqrt{(f_{ck})_{cu}}$ where, N_c = Number of a shear connector at a section, F_c = Load in kN on one connector at ultimate load, s = Spacing of connectors in m, L_s = Length of shear surface (mm as shown in Fig.(5d) of previous chapter but $2d_s$ for T - beam d_s for L – beam, A_{sv} = Area of transverse reinforcement in cm per meter of beam, $n = 2$ for T beam, $n = 1$ for L – beams. [n is the number of times each lower transverse reinforcement intersects shear surface].

5.6.6 EFFECT OF CONTINUITY

The above design formulae are applicable to simply supported beams as well as to continuous beams. Besides these, a continuous beam necessitates the check for the stability of the bottom flange, which is in compression due to hogging moments at supports.

In order to determine the distribution of bending moments under the design loads, structural analysis has to be performed. For convenience, the IS: 456-2000 [96] lists moment coefficients as well as shear coefficients that are close to exact values of the maximum load effects obtainable from rigorous analysis on an infinite number of equal spans on point supports.

The concrete slab is usually assumed to prevent the upper flange of the steel section from moving laterally. In negative moment regions of continuous composite beams the lower flange is subjected to compression. Hence, the stability of bottom flange should be checked at that region. The tendency of the lower flange to buckle laterally is restrained by the distortional stiffness of the cross section. The tendency for the bottom flange to displace laterally causes bending of the steel web, and twisting at top flange level, which is resisted by bending of the slab as shown in Fig. 5.17.



Fig. 5.17 Inverted – U Frame Action

Local-torsional buckling of continuous beams can be neglected if following conditions are satisfied:

- Adjacent spans do not differ in length by more than 20% of the shorter span or where there is a cantilever; its length does not exceed 15% of the adjacent span.
- The loading on each span is uniformly distributed and the design permanent load exceeds 40% of the total load.
- The shear connection in the steel-concrete interface satisfies the requirements of section 5.8.
- $h_a \leq 550 \text{ mm}$.

5.6.7 SERVICEABILITY LIMIT STATES

For simply supported composite beams the most critical serviceability limit state is usually deflection. This would be a governing factor in design for un-propped construction. Besides, the effect of vibration, cracking of concrete, etc. should also be checked under serviceability criteria. Often in exposed condition, it is preferable to design to obtain full slab in compression to avoid cracking in the shear connector region. IS: 11384 – 1985 limits the maximum deflection of the composite beam to $L/325$. The total elastic stress in concrete is

limited to $f_{ck}/3$ while for steel, considering different stages of construction, the elastic stress is limited to $0.87 f_y$.

5.6.7.1 Stresses and deflection in service

As structural steel is supposed to not to yield at service load, elastic analysis is employed in establishing the serviceability performance of composite beam. In this method the concrete area is converted into equivalent steel area by applying modular ratio $m = E_s/E_c$. The analysis is done in terms of equivalent steel section. It is assumed that full interaction exists between steel beam and concrete slab. The effect of reinforcement in compression, the concrete in tension and the concrete between rib of profiled sheeting are ignored.

Refer to Fig. 5.18, where a transformed section is shown.

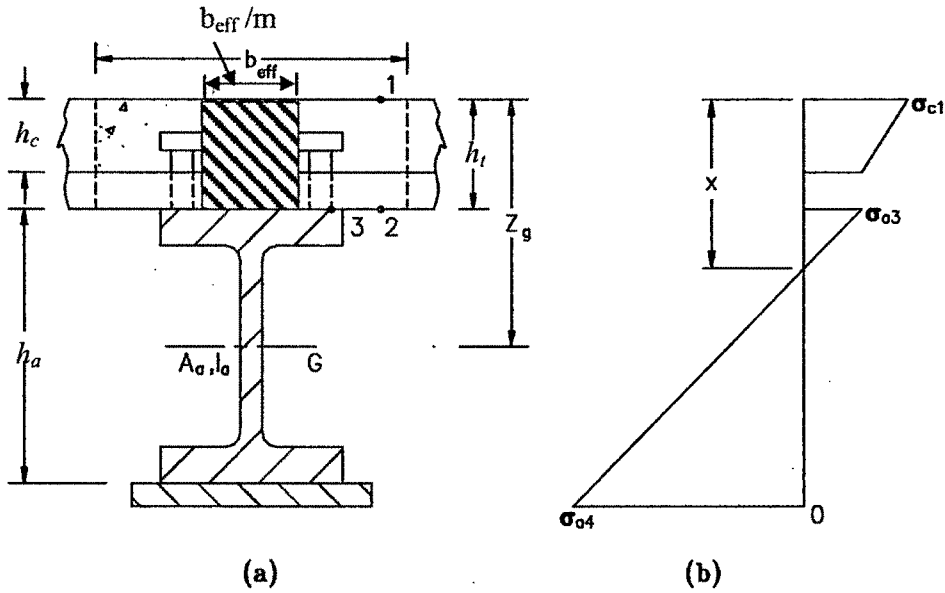


Fig. 5.18 Elastic Analysis of Composite Beam Section in Sagging Bending

When neutral axis lies within the slab,

$$A_a(Z_g - h_c) < \frac{1}{2} b_{eff} \frac{h_c^2}{m} \quad \dots (5.30)$$

The actual neutral axis depth can be found from

$$A_a(Z_g - x) = \frac{1}{2} b_{eff} \frac{x^2}{m} \quad \dots (5.31)$$

and the moment of inertia of the transformed section is given by

$$I = I_a + A_a(Z_g - x)^2 + \left(\frac{b_{eff}}{m} \right) \frac{x^3}{3} \quad \dots (5.32)$$

When neutral axis depth exceeds h_c , its depth x is found from the following equation.

$$A_a(Z_g - x) = \frac{b_{eff}}{m} h_c \left(x - \frac{h_c}{2} \right) \quad \dots (5.33)$$

and moment of inertia of the transformed section is obtained by

$$I = I_a + A_a(Z_g - x)^2 + \frac{b_{eff}}{m} h_c \left(\frac{h_c^2}{12} + \left(x - \frac{h_c}{2} \right)^2 \right) \quad \dots (5.34)$$

For distributed load w over a simply supported composite beam, the deflection at mid-span is

$$\delta_c = \frac{5wL^4}{384E_a I} \quad \dots (5.35)$$

where, E_a = Young's Modulus for structural steel, and I = moment of inertia.

The beam can be checked for stresses under service load using the value of ' I ' as determined above.

When the shear connection is only partial the increase in deflection occurs due to longitudinal slip. This depends on method of construction. Total deflection is given by the formula,

$$\delta = \delta_c \left(1 + k \left(1 - \frac{N}{N_f} \right) \left(\frac{\delta_a}{\delta_c} - 1 \right) \right) \quad \dots (5.36)$$

Where $k = 0.5$ for propped construction, $k = 0.3$ for un-propped construction, and δ_a = deflection of steel beam acting alone.

The expression gives acceptable results when $n_p/n_f \geq 0.4$

The increase in deflection can be disregarded where:

- either $n_p/n_f \geq 0.5$ or
- when the transverse rib depth is less than 80 mm.

5.6.7.2 Continuous Beam

In the case of continuous beam, the deflection is modified by the influence of cracking in the hogging moment regions (at or near the supports). This may be taken into account by calculating the second moment of area of the cracked section under negative moment (ignoring concrete). In addition to this there is a possibility of yielding in the negative moment region. To take account of this the negative moments may be further reduced. As an approximation, a deflection coefficient of $3/384$ is usually appropriate for determining the deflection of a continuous composite beam subject to uniform loading on equal adjacent spans. This may be increased to $4/384$ for end spans. The second moment of area of the section is based on the uncracked value.

5.6.7.3 Crack Control

Cracking of concrete should be controlled in cases where the functioning of the structure or its appearance would be affected. In order to avoid the presence of large cracks in the hogging moment regions, the amount of reinforcement should not exceed a minimum value given by,

$$p = \frac{A_s}{A_c} = k_c * k * \frac{f_{ct}}{\sigma_s} \qquad \dots (5.37)$$

where p = is the percentage of steel, k_c = is a coefficient due to the bending stress distribution in the section($k_c \approx 0.9$), k = is a coefficient accounting for the decrease in the tensile strength of concrete ($k \approx 8$), f_{ct} = is the effective tensile strength of concrete with the minimum value as 3 N/mm^2 and σ_s = maximum permissible stress in concrete.

5.7 ILLUSTRATIVE EXAMPLE

Design a simply supported composite beam with 10 m span shown in the **Fig. 5.19**. The thickness of slab is 125 mm. The floor is to carry an imposed load of 3.0 kN/m^2 , partition load of 1.5 kN/m^2 and a floor finish load of 0.5 kN/m^2 .

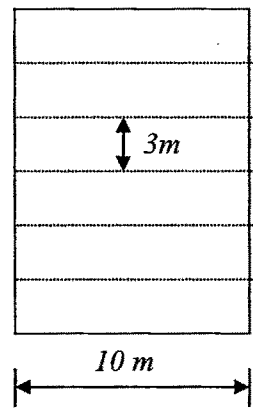


Fig. 5.19 Layout of Composite Beam

Given data

Imposed load	-	3.0 kN/m^2	Floor finish load	-	0.5 kN/m^2
Partition load	-	1.5 kN/m^2	Construction load	-	0.75 kN/m^2

Data assumed

$(f_{ck})_{cu}$	-	30 N/mm^2
f_y	-	250 N/mm^2
Density of concrete	-	24 kN/m^3

Partial safety factors

Load Factor (γ_f)		
for LL	-	1.5
for DL	-	1.35

Step 1: Load Calculation

Construction stage

Self weight of slab $= 3 \times 0.125 \times 24 = 9 \text{ kN/m}$

Self weight of beam $= 0.71 \text{ kN/m (ISMB 450)}$

Construction load $= 0.75 \times 3 = 2.25 \text{ kN/m}$

Total design load at construction stage

$$= \{1.5 \times 2.25 + 1.35 \times (9 + 0.71)\} = 16.5 \text{ kN/m}$$

Composite stage

Dead Load

Self weight of slab $= 9 \text{ kN/m}$

Self weight of beam $= 0.71 \text{ kN/m}$

Load from floor finish $= 0.5 \times 3$
 $= 1.5 \text{ kN/m}$

Total dead load $= 11.2 \text{ kN/m}$

Live Load

Imposed load $= 3 \times 3 = 9.0 \text{ kN/m}$

Load from partition wall $= 1.5 \times 3 = 4.5 \text{ kN/m}$

Total live load $= 13.5 \text{ kN/m}$

Design load carried by composite beam $= (1.35 \times 11.2 + 1.5 \times 13.5) = 35.4 \text{ kN/m}$

Step 2: Calculation of Bending Moment

Construction Stage

$$M = 16.5 \times 10^2 / 8 = 206 \text{ kNm}$$

Composite Stage

$$M = 35.4 \times 10^2 / 8 = 442 \text{ kNm}$$

Step 3: Classification of Composite Section

Sectional Properties

$T = 17.4 \text{ mm};$

$I_y = 8.34 \times 10^6 \text{ mm}^4$

$D = 450 \text{ mm};$

$Z_x = 1350 \times 10^3 \text{ mm};$

$t = 9.4 \text{ mm}$

$r_y = 30.1 \text{ mm}$

$I_x = 303.9 \times 10^6 \text{ mm}^4$

Classification of composite section

$0.5 B/T = 0.5 \times 150 / 17.4 = 4.3 < 8.9\epsilon$

$d/t = (450 - 2 \times 17.4) / 9.4 = 44.2 < 83\epsilon$

Therefore the section is a plastic section.

Step 4: Check for Adequacy of the Section at Construction Stage

Design moment in construction stage $= 206 \text{ kNm}$

Moment of resistance of steel section $= f_{yd} \times Z$

$$= [(250 / 1.15) \times 1.14 \times 1350.7 \times 10^3] / 10^6 \text{ kNm}$$

$$= 334.7 \text{ kNm} > 206 \text{ kNm}$$

As the top flange of the steel beam is unrestrained and under compression, stability of the top flange should be checked.

Step 5: Check for Lateral Buckling of the Top Flange

Elastic critical stress, f_{cb} is given by

$$f_{cb} = k_1 \frac{c_2}{c_1} \frac{26.5 \times 10^5}{\left(\frac{l}{r_y}\right)^2} \left[\sqrt{1 + \frac{1}{20} \left(\frac{l T}{r_y D}\right)^2} + k_2 \right]$$

$$k_1 = 1 \quad (\text{as } \Psi = 1.0)$$

$$D = 450 \text{ mm};$$

$$k_2 = 0 \quad (\text{as } \phi = 0.5)$$

$$\ell = 10,000 \text{ mm};$$

$$c_2 = c_1 = 225 \text{ mm};$$

$$r_y = 30.1 \text{ mm}$$

$$T = 17.4 \text{ mm};$$

$$f_{cb} = \frac{26.5 \times 10^5}{\left(\frac{10000}{30.1}\right)^2} \left[\sqrt{1 + \frac{1}{20} \left(\frac{10000}{30.1} \times \frac{17.4}{450}\right)^2} \right] = 73 \text{ N/mm}^2$$

Therefore the bending compressive stress in beams

$$F_{cb} = \frac{f_{cb} \times f_y}{\left[(f_{cb})^{1.4} + (f_y)^{1.4} \right]^{\frac{1}{1.4}}} = 64.9 \text{ N/mm}^2$$

Moment at construction stage = 206 kNm

Maximum stress at top flange of steel section

$$f_{cb} = \frac{206 \times 10^6 \times 225}{303.9 \times 10^6} = 152.5 \text{ N/mm}^2 > 64.9 \text{ N/mm}^2$$

So, we have to reduce the effective length of the beam.

Provide 2 lateral restraints with a distance of approximately 3330 mm between them.

$$f_{cb} = \frac{26.5 \times 10^5}{\left(\frac{3330}{30.1}\right)^2} \left[\sqrt{1 + \frac{1}{20} \left(\frac{3330}{30.1} \times \frac{17.4}{450}\right)^2} \right] = 299.6 \text{ N/mm}^2$$

Therefore, the bending compressive stress in beams

$$f_{cb} = \frac{299.6 \times 250}{\left[(299.6)^{1.4} + (250)^{1.4} \right]^{\frac{1}{1.4}}} = 165.9 \text{ N/mm}^2$$

$$f_{cb} = 165.9 > 152.5 \text{ N/mm}^2$$

Note: These restraints are to be kept till concrete hardens.

Step 6: Check for Adequacy of the Section at Composite Stage

Bending Moment at the composite stage, $M = 442 \text{ kNm}$

Effective breadth of slab is smaller of

(i) $\text{span}/4 = 10000/4 = 2500 \text{ mm}$

(ii) C/C distance between beams = 3000 mm

Hence, $b_{\text{eff}} = 2500 \text{ mm}$

Position of neutral axis

$$a = \frac{0.87 f_y}{0.36(f_{ck})_{cu}} = \frac{0.87 \times 250}{0.36 \times 30} = 20.1$$

$$A_a = 9227 \text{ mm}^2$$

$$a \times A_a = 20.1 \times 9227 = 1.85 \times 10^5 \text{ mm}^2$$

$$b_{\text{eff}} \times d_s = 2500 \times 125 = 3.13 \times 10^5 \text{ mm}^2 > aA_a$$

Hence PNA lies in concrete.

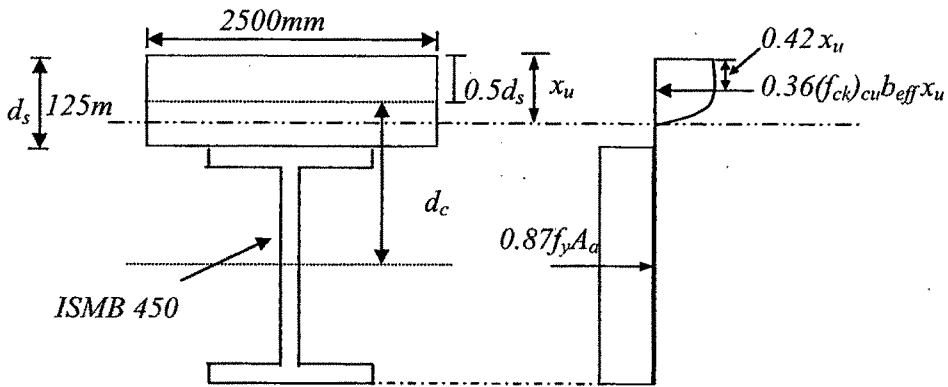


Fig. 5.20 Cross Section of Composite Beam with Stress Diagram

Step 7: Design of Shear Connectors

The position of neutral axis is within slab.

\therefore Total load carried by connectors,

$$F_{cc} = 0.36(f_{ck})_{cu} b_{\text{eff}} x_u = (0.36 \times 30 \times 2500 \times 74.3)/1000 \text{ kN} = 2006 \text{ kN}$$

The design strength of 20 mm (dia) headed stud for M30 concrete is 58 kN.

\therefore Number of shear connectors required for $10/2 \text{ m} = 5 \text{ m}$ length = $2006/58 \approx 34$

These are spaced uniformly; Spacing = $5000/34 = 147 \text{ mm} \approx 145 \text{ mm}$

If two connectors are provided in a row the spacing will be = $145 \times 2 = 290 \text{ mm}$

Step 8: Serviceability Check

Modular ratio for live load = 15

Modular ratio for dead load = 30

Deflection

For dead load deflection is calculated using moment of inertia of steel beam only

$$\delta_d = \frac{5 \times 9.71 \times (10000)^4}{384 \times 2 \times 10^5 \times 303.91 \times 10^6} = 20.8 \text{ mm}$$

For live load deflection is calculated using moment of inertia of composite section.

To find the moment of inertia of the composite section, one has to first locate the position of neutral axis x_u as

$$x_u = \frac{0.87 \times 9227 \times 250}{0.36 \times 30 \times 2500} = 74.3 \text{ mm from the top of slab}$$

Moment of resistance of the section, M_p

$$\begin{aligned} M_p &= 0.87 A_a f_y (d_c + 0.5 d_s - 0.42 x_u) \\ &= 0.87 \times 9227 \times 250 (287.5 + 0.5 \times 125 - 0.42 \times 74.3) = 640 \text{ kNm} > 442 \text{ kNm} \end{aligned}$$

Position of neutral axis

$$A(d_g - d_s) < \frac{1}{2} (b_{eff}/\alpha_e) d_s^2$$

$$9227 (350 - 125) < \frac{1}{2} \times 2500/15 \times 125^2$$

$$2.08 \times 10^6 < 1.3 \times 10^6 \text{ which is not true}$$

\therefore N.A. depth exceeds d_s

$$A_a(d_g - x_u) = \frac{b_{eff}}{m} d_s \left(x_u - \frac{d_s}{2} \right)$$

$$9227 \left(\frac{450}{2} + 125 - x_u \right) = \frac{2500}{1500} 125 \left(x_u - \frac{125}{2} \right)$$

$$x_u = 150.75 \text{ mm}$$

Moment of inertia of the gross section (I_g),

$$I_g = I_x + A_a(d_g - x_u)^2 + \frac{b_{eff}}{\alpha_e} d_s \left[\frac{d_s^2}{12} + (x_u - d_s)^2 \right]$$

$$= 303.91 \times 10^6 + 9227(350 - 150.75)^2 + \frac{2500 \times 125}{15} \left[\frac{125^2}{12} + \left(150.75 - \frac{125}{2} \right)^2 \right]$$

$$= 859.6 \times 10^6$$

$$\delta_1 = \frac{5 \times 15(1000)^2}{384 \times 2 \times 10^5 \times 859.6 \times 10^6}$$

$$\text{Total Deflection} = \delta_d + \delta_l = 20.8 + 11.4 \text{ mm} = 32.2 \text{ mm} > l/325$$

The section fails to satisfy the deflection check.

Composite Stage:

Dead load

At composite stage, dead load W_d

$$W_d = 11.2 \text{ kN/m}$$

$$M = 11.2 \times 10^2/8 = 140 \text{ kNm}$$

Position of neutral axis

Assuming neutral axis lies within the slab

$$A(d_g - d_s) < \frac{1}{2} b_{eff} d_s^2 / \alpha_e$$

$$9227(350 - 125) < \frac{1}{2} \times 2500/30 \times 125^2$$

$$2.07 \times 10^6 > 6.5 \times 10^5$$

\therefore N.A. depth exceeds d_s .

Location of neutral axis

$$A_a(d_g - x_u) = \frac{b_{eff}}{m} d_s \left(x_u - \frac{d_s}{2} \right)$$

$$9227 \left(\frac{450}{2} + 125 - x_u \right) = \frac{2500}{30} 125 \left(x_u - \frac{125}{2} \right)$$

$$x_u = 197.5 \text{ mm}$$

Moment of area of the section

$$I_g = I_x + A_a(d_g - x_u)^2 + \frac{b_{eff}}{\alpha_e} d_s \left[\frac{d_s^2}{12} + (x_u - d_s)^2 \right]$$

$$= 303.91 \times 10^6 + 9227(350 - 197.5)^2 + \frac{2500 \times 125}{15} \left[\frac{125^2}{12} + \left(197.5 - \frac{125}{2} \right)^2 \right]$$

$$= 721.9 \times 10^6 \text{ mm}^4$$

Stress in steel flange

$$= \frac{140 \times 10^6 (450 + 125 - 197.5)}{721.9 \times 10^6} = 73.2 \text{ N/mm}^2.$$

Live load

At composite stage, stress in steel for live load

$$W_l = 13.5 \text{ kN/m}$$

$$M = 13.5 \times 10^2/8 = 168.75 \text{ kNm}$$

Stress in steel flange

$$= \frac{168.75 \times 10^6 (450 + 125 - 150.75)}{859.6 \times 10^6} = 83.29 \text{ N/mm}^2$$

\therefore Total stress in steel = $73.2 + 83.29 = 156.5 \text{ N/mm}^2 < \text{allowable stress in steel}$

In a similar manner, the stress in concrete is found.

$$\frac{1}{30} \left\{ \frac{140 \times 10^6 \times 197.54}{721.9 \times 10^6} \right\} + \frac{1}{15} \left\{ \frac{168.75 \times 10^6 \times 150.75}{859.6 \times 10^6} \right\}$$

$$= 3.25 < \frac{(f_{ck})_{cu}}{3} = 10 \text{ N/mm}^2$$

The section is safe.

Step 9: Transverse Reinforcement

Shear force transferred per meter length

$$v_r = \frac{2 \times 58 \text{ kN}}{0.29 \text{ m}} \quad (n = 2, \text{ Since there are two shear studs})$$

$$= 400 \text{ kN/m}$$

$$v_r \leq 0.232 L_s \sqrt{(f_{ck})_{cu}} + 0.1 A_{sv} f_y n$$

Or

$$0.632 L_s \sqrt{(f_{ck})_{cu}}$$

$$L_s = 2 \times 125 = 250 \text{ mm}$$

$$f_y = 250 \text{ mm}$$

$$n = 2$$

$$\therefore 0.232 L_s \sqrt{(f_{ck})_{cu}} + 0.1 A_{sv} f_y n$$

$$= 0.232 \times 250 \sqrt{30} + 0.1 \times A_{sv} \times 250 \times 2 = 317.7 + 50 A_{sv}$$

Or

$$0.632 \times 250 \sqrt{30} = 865 \text{ kN/m}$$

$$\therefore 400 = 317 + 50 A_{sv} = 165 \text{ mm}^2/\text{m}$$

Minimum Reinforcement

$$= 250 v_{rf} / f_y \text{ mm}^2/\text{mm} = 400 \text{ mm}^2/\text{mm}$$

Provide 12Φ @ 280 mm c/c.

5.8 PROGRAM FOR COMPOSITE BEAMS

In the present work, a program is developed in Visual Basic for the design of composite beam with R.C.C. slab and design of composite beam with deck slab. A form shown in **Fig. 5.21** is startup screen for design of simply supported or continuous beam. User can tick mark the checkbox to specify the type of design of composite beam. Program is coded in such a way that the calculations of design of floor deck of previous chapter are transferred directly to the selected beam and loading and moments and shear forces are calculated at construction stage and composite stage. Form of **Fig. 5.22** gives the choice of section with available section database. Here whole steel table is interfaced so that the user can choose any section available in the market; even user can change the properties in boxes. Selected section properties are

automatically added in the boxes. Form of Fig. 5.23 calculates the loading for construction and composite stage. For calculation of bending moment and section classification, use of the form of Fig. 5.24 can be made. A form is also developed for checking the section for the ultimate limit state at the construction and composite stages for composite beam as shown in Figs. 5.25 and 5.26. By entering the diameter and height of shear connector, one can get the number of shear connectors required for the section as depicted in Fig. 5.27. For the serviceability check of deflection, use the form of Fig. 5.28. Check for stresses in material can be verified by using form of Fig. 5.29. Finally, Fig. 5.30 shows the calculation for requirement for transverse reinforcement. Similarly, design program is developed for the design of composite beam with solid slab for the simply supported and continuous beam. For design purpose, the analysis of composite section is made using Limit State of Collapse Method. As IS: 11384-1985 code deals with the design and construction of only simply supported composite beams, for continuous beam design criteria are considered as per EC 4. Various forms developed in the program of design of composite beam with solid slab are shown in Figs. 5.31 to 5.45 whereas forms developed in the program for the continuous beam are shown in Figs 5.46 to 5.54.

FORMS DEVELOPED FOR THE DESIGN OF COMPOSITE BEAMS WITH DECK SLAB

Composite beam

COMPOSITE BEAM

Span

Span of beam 9.0 m

Depth of slab 0.150 m

Distance between beams 3.5 m

TYPE

☒ SINGLE SPAN

☐ CONTINUOUS SPAN

< BACK OK NEXT >

Fig. 5.21 Form for Composite Beam Design

Composite beam

COMPOSITE BEAM

SECTIONAL PROPERTY | LOADING | BENDING MOMENT AND CLASSIFIC

SELECTION OF BEAM SECTION

☒ Single ☐ Continuous span

Depth of composite section 600 mm

Select the section having depth less than the depth of composite section

DESIGNA	WEIGHT	SECTION	DEPTH	WIDTH	THICKNE
ISMB 450	72.4	92.27	450	150	9.4

Sectional properties

ISMB 450

D	450	mm	Iyy	834	(cm) ⁴
A	92.27	(cm) ²	Zxx	1350.7	(cm) ³
Ix	17.4	mm	Zyy	111.2	(cm) ³
Iy	9.4	mm	Rxx	18.15	cm
W	150	mm	Ryy	3.01	cm
Sxx	30390	(cm) ⁴	W	72.4	Kg/m

Diagram of ISMB 450 section

Fig. 5.22 Form for Selection of Beam Section

Composite beam

COMPOSITE BEAM

SECTIONAL PROPERTY **LOADING** BENDING MOMENT AND CLASSIFIC.

CONSTRUCTION STAGE

Dead Load (kN/m)

Self Weight of Slab	8.44	Total Design Dead Load	12.36	kN/m
Self Weight of Beam	0.71	Total Design Live Load	7.87	kN/m
Total Dead Load	9.15			

Live Load (kN/m)

Construction Load	5.25	Total Design Load	20.23	kN/m
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COMPOSITE STAGE

Dead Load (kN/m)

Self Weight of Slab	8.44	Total Dead Load	10.90	kN/m
Self Weight of Beam	0.710	Total Design Dead Load	14.72	kN/m
From Floor Finish	1.75			

Live Load (kN/m)

Imposed Load	10.5	Total Design Live Load	21	kN/m
Partition Load	3.5	Total Design Load	35.72	kN/m

TOTAL DESIGN LOAD 55.96 kN/m

Fig. 5.23 Form for Calculating Loading

Composite beam

COMPOSITE BEAM

LOADING BENDING MOMENT AND CLASSIFICATION

CALCULATION OF BENDING MOMENT

Bending moment

Construction stage

Mid span moment 204.90 kN.m

Composite stage

Mid span moment 361.71 kN.m

CLASSIFICATION OF SECTION **CALCULATE**

0.5B/T	4.310	FyD	217.39	N/mm ²
D1/Tw	44.170	Z	1350.7	(cm) ³
Fy	250	Zp	1539.79	(cm) ³
D1	415.2	mm		

CLASS OF SECTION IS PLASTIC

<BACK NEXT>

Fig. 5.24 Form for Bending Moment and Classification of Section

construction stage

CHECK FOR THE ADEQUACY OF THE SECTION AT CONSTRUCTION STAGE

CHECK

Design Moment at Construction Stage 204.90 kN.m

Moment of Resistance of Steel Section

Moment of Resistance of Plastic Section 334.73 kN.m

decknew

SECTION IS SAFE IN BEANDING

CHECK

OK

<BACK NEXT>

Fig. 5.25 Form for Check at Construction stage

5. Development of Program for Composite Beams

composite stage

CHECK FOR ADEQUACY OF THE SECTION AT COMPOSITE STAGE

Position of Neutral axis

Effective width of slab 2250 mm

neutral axis lies in the slab

Depth of neutral axis(xu) 65.55 mm **CALCULATE**

Check for moment

Bending moment at composite stage 361.71 kN.m

Moment of resistance of the section 686.50 kN.m **check**

Check for shear

Design vertical shear 160.76 kN

Vertical shear resistance 275.86 kN **check**

decknew section is safe **OK**

<BACK **NEXT>**

Fig. 5.26 Form for Check at Composite Stage

shear connector

Design of shear connector

Diameter of connector 19 mm

Height of connector 100 mm

Reduction factor (kp) 1

Design strength of connector 52.73 kN

Longitudinal force 2005.86 kN

Number of shear connectors

Number of shear connectors required for half length

Numbers 38 Spacing 118 mm

Spacing for two connectors in row 236 mm

<BACK **CALCULATE** **NEXT**

Fig. 5.27 Form for Shear Connectors

Deflection

SERVICEABILITY CHECK

DEFLECTION

Modular ratio for dead load 30

Modular ratio for live load 15

Modulus of elasticity for steel (Es) 200000 N/mm²

Modulus of elasticity for concrete (Ec) 27386.12 N/mm²

FOR DEAD LOAD DEFLECTION IS CALCULATED BY USING M.I. OF STEEL BEAM

Moment of inertia of steel beam 303908000 mm⁴

Deflection due to Dead load 12.87 mm

FOR LIVE LOAD DEFLECTION IS CALCULATED BY USING M.I. OF COMPOSITE BEAM

Depth of neutral axis 155.19 mm

Moment of inertia of the composite section 676613561 mm⁴

Deflection due to live load 10.10 mm

TOTAL DEFLECTION 22.97 mm

ALLOWABLE DEFLECTION 27.96 mm

CALCULATE

SECTION IS SAFE

Main **<BACK** **NEXT>**

Fig. 5.28 Form for Check for Deflection

stress

CHECK FOR STRESS

composite stage

Due to Dead Load

Due to Live Load

Total dead load	10.90	kN/m	Total live load	14	kN/m
Moment	110.43	kN.m	Moment	141.75	kN.m
Depth of netural axis	200.58	mm	Depth of netural axis	155.19	mm
Moment of intertia	562423981	mm^4	Moment of intertia	676613561	mm^4
Stress in steel flange	64.68	N/mm^2	Stress in steel flange	78.52	N/mm^2

Stresses

TOTAL STRESS IN STEEL	143.20	N/mm^2
ALLOWABLE STRESS IN STEEL	217.5	N/mm^2
TOTAL STRESS IN CONCRETE	3	N/mm^2
ALLOWABLE STRESS IN CONCRETE	10	N/mm^2

decknew

SECTION IS SAFE

OK

CALCULATE

NEXT>

<BACK

Fig. 5.29 Form for Check for Stress

TRANSVERSE REINFORCEMENT

TRANSVERSE REINFORCEMENT

Reinforcement

Area of the steel required as transverse reinforcement

265.6 mm^2/m

Diameter of transverse reinforcement

10mm mm

Spacing of transverse reinforcement

220 mm

Area of the steel provided as transverse reinforcement

356.81 mm^2/m

CALCULATE

check

Longitudinal shear resistance

341.66 kN/m

Longitudinal design shear force

223.442 kN/m

CHECK

provided reinforcement is ok

Provide reinforcement of dia 10 mm @ 220 mm in two layer

Main

<Back

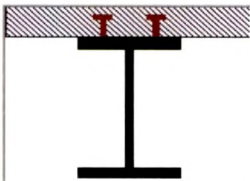
Exit


Fig. 5.30 Form for Check for Transverse Reinforcement


FORMS DEVELOPED FOR THE DESIGN OF COMPOSITE BEAMS WITH SOLID SLAB

DESIGN

DESIGN OF COMPOSITE STEEL CONCRETE BEAM



☐ SIMPLY SUPPORTED BEAM 

☐ CONTINUOUS BEAM 

DESIGN OF SIMPLY SUPPORTED BEAM IS ACCORDING TO IS:11384 AND IS 800

DESIGN OF CONTINUOUS BEAM IS ACCORDING TO EUROCODE4

Fig. 5.31 Form for Composite Beam

COMPOSITE BEAM

INPUTDATA SELECTION OF BEAM CALCULATION CHECKS SERVICEABILITY DESIGN RESULT

SPAN AND LOAD
MATERIAL

Fig. 5.32 Option Form for Composite Beam Design

DESIGN

LOADING AND SPAN OF COMPOSITE BEAM

Loading

Imposed load 3.0 kN/m²

Partition load 1.5 kN/m²

Floor finish load 0.5 kN/m²

Construction load 0.75 kN/m²

Span

Span of beam 10.0 m

Depth of slab 0.125 m

Distance between beams 3.0 m

OK NEXT>

Fig. 5.33 Form for Entering Loading Data

Material property

MATERIAL PROPERTY

STEEL

Yeild strength of steel (Fy) 250 N/mm²

Yeild strength of reinforcement (Fsk) 415 N/mm²

CONCRETE

Grade of concrete 30 N/mm²

Density of concrete 24 kN/m³

PARTIAL SAFETY FACTOR

Material factor Load factor

Steel 1.15 For LL 1.5

Concrete 1.5 For DL 1.35

Reinforcement 1.15

OK <BACK NEXT>

Fig. 5.34 Form for Entering the Material Property

5. Development of Program for Composite Beams

92.27

SELECTION OF BEAM SECTION

☒ Single ☐ Continuous span

Depth of Composite section 555.55 mm

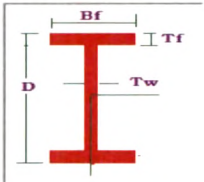
select the section having depth less than the depth of composite section

	DESIGNATION	WEIGHT PER METRE	SECTIONAL AREA	DEPTH	WIDTH
	ISMB 400	61.6	78.46	400	140
▶	ISMB 450	72.4	92.27	450	150
	ISMB 500	86.9	110.74	500	180

Sectional properties

ISMB 450

D	450	mm	I _{yy}	834	(cm) ⁴
A	92.27	(cm) ²	Z _{xx}	1350.7	(cm) ³
T _f	17.4	mm	Z _{yy}	111.2	(cm) ³
T _w	9.4	mm	R _{xx}	18.15	cm
B _f	150	mm	R _{yy}	3.01	cm
I _{xx}	30390.8	(cm) ⁴	W	72.4	Kg/m



<BACK NEXT>

Fig. 5.35 Form for Sectional Property

Loading

Load calculation

CONSTRUCTION STAGE

Dead Load (kN/m)

Self Weight of Slab 9 Total Design Dead Load 13.10 kN/m

Self Weight of Beam 0.71 Total Design Live Load 3.37 kN/m

Total Dead Load 9.71

Live Load (kN/m)

Construction Load 2.25 Total Design Load 16.48 kN/m

COMPOSITE STAGE

Dead Load (kN/m)

Self Weight of Slab 9 Total Dead Load 11.21 kN/m

Self Weight of Beam 0.71 Total Design Dead Load 15.13 kN/m

From Floor Finish 1.5

Live Load (kN/m)

Imposed Load 9 Total Design Live Load 20.25 kN/m

Partition Load 4.5 Total Design Load 35.38 kN/m

TOTAL DESIGN LOAD 51.86 kN/m <BACK NEXT>

Fig. 5.36 Form for Calculating the Factored Load

Bending moment

Bending moment calculation

Bending moment

Construction stage

Mid span moment 206.04 kN.m

Composite stage

Mid span moment 442.29 kN.m

CLASSIFICATION OF COMPOSITE SECTION

0.5B _f /T	4.31	F _y D	217.39	N/mm ²
D ₁ /T _w	44.17	Z	1350.7	(cm) ³
F _y	250	Z _p	1539.79	(cm) ³
D ₁	415.2			mm

CLASS OF SECTION IS PLASTIC

CALCULATE

<BACK NEXT>

Fig. 5.37 Form for Bending Moment and Classification of Section

CHECK AT CONSTRUCTION STAGE

CHECK FOR THE ADEQUACY OF THE SECTION AT CONSTRUCTION STAGE

CHECK

Design Moment at Construction Stage kN.m

Moment of Resistance of Steel Section

Moment of Resistance of Plastic Section kN.m

Moment of Resistance of Semicompact or Compact Section kN.m

CHECK

OK **<BACK** **NEXT>**

Fig. 5.38 Form for Check at Construction Stage

CHECK

CHECK FOR LATERAL BUCKLING OF THE TOP FLANGE

As the top flange Of the Steel Beam is unstrained and under compression stability of the top flange should be checked as per IS:800

Elastic Critical Stress(f_{cb}) N/mm²

k_1 = T/D = y = x =

k_2 = L/R = c_2/c_1 =

Bending Compressive Stress N/mm²

Maximum Stress at top flange N/mm²

composite beam and slab **×** **PROVIDE LATTERAL RESTRAINS**

REDUCE THE EFFECTIVE LENGTH OF BEAM

CALCULATE

OK **<BACK** **NEXT>**

Fig. 5.39 Form for Checking Lateral Buckling

CHECK AT COMPOSITE STAGE

CHECK FOR ADEQUACY OF THE SECTION AT COMPOSITE STAGE

Position of Neutral axis

Effective width of slab (b_{ef}) mm

a = $b_{ef}D_s$ = mm²

A_a = D_c = mm

D_s = mm

Neutral axis lies in the concrete slab

Depth of neutral axis(x_u) mm

CALCULATE

Check

Bending moment at composite stage kN.m

Moment of resistance of the section kN.m

check

composite beam and slab **×** **SECTION IS SAFE**

OK **<BACK** **NEXT>**

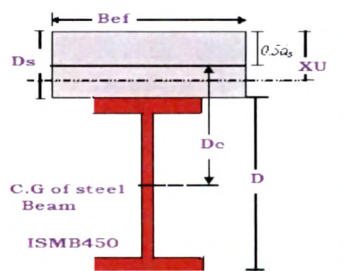



Fig. 5.40 Form for Check at Composite stage

5. Development of Program for Composite Beams

SHEAR CONNECTORS

DESIGN OF SHEAR CONNECTORS

TYPE OF CONNECTORS



Design Strength Of Connectors for Concrete Of Different Grade

TYPE OF CO	GRADE	SIZE	LOAD PER S	MATERIAL O	HEIGHT
HEADED ST	M-30	20 mm	58	IS:961-1975*	75

Type of connector: HEADED STUD 20 mm

Grade of concrete: M-30

Design strength of connector: 58 kN

Number of shear connectors

Number of shear connectors required for half length

Numbers: 35 Spacing: 143 mm

Spacing for two connectors in row: 286 mm

CALCULATE

<BACK NEXT>

Fig. 5.41 Form for Shear Connectors

SERVICEABILITY CHECK

SERVICEABILITY CHECK

DEFLECTION

Modular ratio for dead load: 30

Modular ratio for live load: 15

Modulus of elasticity for steel (Es): 200000 N/mm²

Modulus of elasticity for concrete (Ec): 27386.12 N/mm²

FOR DEAD LOAD DEFLECTION IS CALCULATED BY USING MOMENT OF INERTIA OF STEEL BEAM

Moment of inertia of steel beam: 303908000 mm⁴

Deflection due to Dead load: 20.80 mm

FOR LIVE LOAD DEFLECTION IS CALCULATED BY USING MOMENT OF INERTIA OF COMPOSITE BEAM

Depth of neutral axis: 150.74 mm

Moment of inertia of the composite section: 859601097 mm⁴

Deflection due to live load: 11.3606 mm

TOTAL DEFLECTION: 32.162 mm

ALLOWABLE DEFLECTION: 30.769 mm

CALCULATE

SELECT THE HIGHER SECTION

Main < >

Fig. 5.42 Form for Check for Deflection

CHECK FOR STRESS

composite stage

Due to Dead Load

Total Dead load: 11.2 kN/m

Moment: 140.12 kN.m

Depth of neutral axis: 197.54 mm

Moment of inertia: 721907734 mm⁴

Stress in steel flange: 73.26 N/mm²

Due to Live Load

Total Live load: 13.5 kN/m

Moment: 168.75 kN.m

Depth of neutral axis: 150.74 mm

Moment of inertia: 859601097 mm⁴

Stress in steel flange: 83.28 N/mm²

Stresses

TOTAL STRESS IN STEEL: 156.54 N/mm²

ALLOWABLE STRESS IN STEEL: 217.5 N/mm²

TOTAL STRESS IN CONCRETE: 3 N/mm²

ALLOWABLE STRESS IN CONCRETE: 10 N/mm²

composite beam and slab

SECTION IS SAFE

OK

CALCULATE

NEXT> <BACK

Fig. 5.43 Form for Check for Stress

TRANSVERSE REINFORCEMENT

TRANSVERSE REINFORCEMENT

Minimum Area required

405.59

mm²/m

Diameter of transverse reinforcement

10mm

mm

Spacing of transverse reinforcement

180

mm

Area of the steel provided as transverse reinforcement

436.11

mm²/m

calculate

check

shear force transferred per meter length

405.59

kN/m

Design shear resistance per meter length

535.73

kN/m

CHECK

provided reinforcement is ok

Provide transverse reinforcement of 10 mm @ spacing of 180 mm

NEXT>

<BACK

Fig. 5.44 Form for Check for Transverse Reinforcement

RESULTS

COMPOSITE BEAM DIMENSION

SPAN OF THE BEAM

=

10

m

C/C DIST BET BEAM

=

3

m

DEPTH OF I-SECTION

=

450

mm

DEPTH OF SLAB

=

.130

m

SHEAR CONNECTORS

TYPE

=

HEADED STUD

DIAMETER

=

20

mm

NUMBERS

=

36

HIEGHT

=

75

mm

SPACING

=

143

mm

TRANSVERSE REINFORCEMENT PER METER LENGTH

DIAMETER

=

10

mm

SPACING

=

180

mm

Fig. 5.45 Form for Displaying Result

STEPS FOR CONTINUOUS COMPOSITE BEAM

DESIGN

LOADING AND SPAN OF COMPOSITE BEAM

Loading

Imposed load

3.5

kN/m²

Partition load

1.0

kN/m²

Floor finish load

0.5

kN/m²

Construction load

0.5

kN/m²

Span

Span of beam

7.5

m

Depth of slab

0.130

m

Distance between beams

3.0

m

OK

NEXT>

Fig. 5.46 Form for Entering Loading Data

5. Development of Program for Composite Beams

SELECTION OF BEAM SECTION

☐ Single ☒ Continuous span

Depth of composite section: 340.9090909 mm

Select the section having depth less than the depth of composite section

	DESIGNATION	WEIGHT PER METRE	SECTIONAL AREA	DEPTH	WIDTH
▶	ISMB 250	37.3	47.55	250	125
	ISMB 300	44.2	56.26	300	140
<	ISMB 350	52.4	66.71	350	140

Sectional properties

ISMB 300

D	300	mm	Iyy	453.9	(cm) ⁴
A	56.26	(cm) ²	Zxx	573.6	(cm) ³
Tf	12.4	mm	Zyy	64.8	(cm) ³
Tw	7.5	mm	Rxx	12.37	cm
Bf	140	mm	Ryy	2.84	cm
Ixx	8603.6	(cm) ⁴	W	44.2	Kg/m

Diagram: I-beam with dimensions Bf, Tf, D, Tw.

<BACK NEXT>

Fig. 5.47 Form for Sectional Property

Loading

Load calculation

CONSTRUCTION STAGE

Dead Load (kN/m)

Self Weight of Slab: 9.36 Total Design Dead Load: 13.22 kN/m

Self Weight of Beam: 0.43 Total Design Live Load: 2.25 kN/m

Total Dead Load: 9.79

Live Load (kN/m)

Construction Load: 1.5 Total Design Load: 15.47 kN/m

COMPOSITE STAGE

Dead Load (kN/m)

Self Weight of Slab: 9.36 Total Dead Load: 11.29 kN/m

Self Weight of Beam: 0.43 Total Design Dead Load: 15.24 kN/m

From Floor Finish: 1.5

Live Load (kN/m)

Imposed Load: 10.5 Total Design Live Load: 20.25 kN/m

Partition Load: 3.0 Total Design Load: 35.49 kN/m

TOTAL DESIGN LOAD: 50.96 kN/m

<BACK NEXT>

Fig. 5.48 Form for Calculating the Factored Load

Bending moment

Bending Moment Calculation

Construction stage

Maximum positive moment: 74.63 kN.m

Maximum negative moment: 88.42 kN.m

Maximum shear force: 69.61 kN

Composite stage

Maximum positive moment: 185.34 kN.m

Maximum negative moment: 212.28 kN.m

Maximum shear force: 159.70 kN

CLASSIFICATION OF COMPOSITE SECTION

0.5Bf/T	5.64	FyD	217.39	N/mm ²
D1/Tw	36.69	Z	573.6	(cm) ³
Fy	250	Zp	653.90	(cm) ³
D1	275.2			

CLASS OF SECTION IS PLASTIC

CALCULATE

<BACK NEXT>

Fig. 5.49 Form for Bending moment and Classification

Form9 CONSTRUCTION STAGE

Check for moment

Plastic Moment Resistance Of the steel Section: 142.15 kN.m

Design Moment in construction stage: 88.43 kN.m

CHECK

Check for shear

Plastic Shear Resistance: 293.47 kN

Shear force at construction stage: 69.62 kN

CHECK

composite beam and slab SECTION IS SAFE UNDER SHEAR

OK

<BACK **NEXT>**

Fig. 5.50 Form for Check at Construction Stage

CHECK Check for Lateral torsional buckling of the steel beam

Torsion constant (It): 213164.07 mm⁴

Warping constant (Iw): 93859439160 mm⁴

Here span is more so provide lateral restrain at span/3 distance

Distance at restrain are provided: 2500 m

Elastic critical moment: 256.65 kN.m

Reduction factor: 0.79

Non dimensional slenderness ratio: 0.79

Design bulcking resistance moment: 113.26 kN.m

SECTION IS SAFE

CHECK

<BACK **NEXT>**

Fig. 5.51 Form for Check for Lateral Buckling

composite stage Composite Stage

1. Moment resistance of the section

Negative Bending Moment

Effective width of the concrete: 937.5 mm

Location of neutral axis: neutral axis lies in the web

Diametre of reinforcement: 12 mm Spacing: 100 mm

Number of bars: 9

Area of negative reinforcement: 1059.75 mm²

Negative Moment of Resistance of the Section: 263.62 kN.m

section is safe

positive Bending Moment

Effective width of the concrete flange: 1500 mm

Location of neutral axis: neutral axis lies in the slab

Positive Moment of Resistance of the Section: 305.78 kN.m

section is safe

2. Check for vertical shear, bending moment and shear force interaction

Plastic Shear Resistance: 293.47 kN

Vertical shear force: 159.7 kN

section is safe

3. Check for shear buckling

d/Tw: 36.69

section is safe

CHECK

<BACK **NEXT>**

Fig. 5.52 Form for Check at Composite stage

shear connector

Design of shear connectors

	TYPE OF CO	GRADE	SIZE	LOAD PER S	MATERIAL O	HEIGHT
▶	HEADED ST	M-30	22 mm	85	IS:961-1975*	100
	HEADED ST	M-30	20 mm	68	IS:961-1975*	100

TYPE OF CONNECTORS **HEADED STUD**

GRADE OF CONCRETE **M-30**

Design strength of connector **kN**

Position of connectors

1. Between simple end and point of maximum positive moment

Length **mm**

Numbers

Spacing **mm**

2. Between simple end and point of maximum positive moment

Length **mm**

Numbers

Spacing **mm**

Fig. 5.53 Form for Shear Connectors

REINFORCEMENT

TRANSVERSE REINFORCEMENT

Reinforcement

Area of the steel required as transverse reinforcement **mm²/m**

Diameter of transverse reinforcement **mm**

Spacing of transverse reinforcement **mm**

Area of the steel provided as transverse reinforcement **mm²/m**

check

Longitudinal shear force **kN/m**

Longitudinal design shear force **kN/m**

section is safe

Provide the reinforcement of 8mm dia in two layer @ spacing of 190 mm

Fig. 5.54 Form for Check for Transverse Reinforcement