IS 11384 (1985): Code of Practice for Composite Construction in Structural Steel and Concrete [CED 38: Special Structures]

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Indian Standard

CODE OF PRACTICE FOR COMPOSITE CONSTRUCTION IN STRUCTURAL STEEL AND CONCRETE

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INDIAN STANDARDS INSTITUTION
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
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Indian Standard

CODE OF PRACTICE FOR COMPOSITE CONSTRUCTION IN STRUCTURAL STEEL AND CONCRETE

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Indian Standard
CODE OF PRACTICE FOR COMPOSITE CONSTRUCTION IN STRUCTURAL STEEL AND CONCRETE

0. FOREWORD

0.1 This Indian Standard was adopted by the Indian Standards Institution on 30 September 1985, after the draft finalized by the Prefabricated and Composite Construction Sectional Committee had been approved by the Civil Engineering Division Council.

0.2 Composite construction consists in the use of prefabricated structural units like steel beams, precast reinforced or prestressed concrete beams in combination with *in-situ* concrete. The construction should ensure monolithic action between the prefabricated and *in-situ* components so that they act as a single structural unit. This code deals only with steel-to-concrete composite construction, that is, one in which the prefabricated components is a steel beam, either rolled or built up. It is intended to issue a separate code dealing with concrete-to-concrete composite construction. Again because of the special nature of bridge structures where dynamic loadings are expected, this code is restricted to buildings. This code will replace the existing IS : 3935-1966*. The code incorporates important changes including the introduction of limit state design concept to bring it in line with other major structural codes issued by the Indian Standards Institution.

0.3 Whilst the common methods of design and construction of steel-concrete composite structures have been covered in this code, special systems of design and construction not covered by this code may be permitted on production of satisfactory evidence regarding their adequacy and safety by analysis or test or both.

0.4 In this code it has been assumed that design of composite construction is entrusted to a qualified engineer and the execution of the work is carried out under the direction of an experienced supervisor.

0.5 All requirements of IS : 456-1978† and IS : 800-1984‡ in so far as they apply, shall be deemed to form part of this code except where otherwise laid down in this code.

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*Code of practice for composite construction.

†Code of practice for plain and reinforced concrete (*third revision*).

‡Code of practice for general construction in steel (*second revision*).

0.6 The Sectional Committee responsible for the preparation of this standard has taken into consideration the need for international coordination among standards prevailing in different countries of the world. These considerations led the Sectional Committee to derive assistance from the following:

a) Code of practice CP 117 : Part I - 1965 Composite construction in structural steel and concrete: Part I Simply supported beams in building. British Standards Institution.

b) DIN 4239 : 1956 Specification for the design and development of Composite Building Structures, Deutosches Institut Für Normung.

c) Manual of Steel Construction, New York 1966. American Institute of Steel Construction.

0.7 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS : 2 - 1960*. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

1. SCOPE

1.1 This standard deals with the design and construction of Composite beams (simply supported) made up of structural steel units and cast *in-situ* concrete.

2. TERMINOLOGY

2.0 For the purpose of this standard, the following definitions shall apply:

2.1 Composite Members — Structural members consisting of steel structural units, rolled or built up and cast *in-situ* concrete connected together in such a manner that they act monolithically.

2.2 Shear Connectors — Steel elements, such as stud, bar, spiral or any other similar device welded to the top flange of the steel section and intended to transmit the horizontal shear between the steel beam and the cast *in-situ* concrete, and also to prevent vertical separation at the interface.

3. SYMBOLS

3.1 For the purpose of this code and unless otherwise defined in the test, the following symbols shall have the meanings noted against each:

A_f = area of top flange of steel beam of a composite section

A_s = cross sectional area of steel beam of a composite section

*Rules for rounding off numerical values (*revised*).

A_t = cross-sectional area of transverse reinforcement in composite beams in cm^2/m.

b = breadth of flange in T-section

b_f = width of top flange of steel sections

d_c = vertical distance between centroids of concrete slabs and steel beam in a composite section

d_s = thickness of concrete slab

E_s = modulus of elasticity of steel

E_c = modulus of elasticity of concrete

f_{ck} = characteristic strength of concrete in N/mm^2

F_{cc} = total concrete compressive force in composite beams

f_y = characteristic strength of steel in N/mm^2

L_s = length of shear surface in mm

M_u = ultimate bending moment

n = number of times each transverse reinforcement crosses the shear surface

N_c = number of mechanical shear connectors at a cross-section

P_c = design ultimate strength of shear connector in kN

Q = horizontal shear force in kN/m

t_f = average thickness of the top flange of the steel section

X_u = depth of neutral axis at ultimate limit state of flexure

$$a = \frac{0{\cdot}87\, fy}{0{\cdot}36\, fck}$$

4. MATERIALS AND WORKMANSHIP

4.1 For structural steel, the materials and workmanship should comply with IS : 800-1984*. For concrete and reinforcing steel, the materials and workmanship should be in accordance with IS : 456-1978†.

5. BASIS OF DESIGN

5.1 The aim of structural design may be stated as the achievement of acceptable probabilities that the structure being designed will not become unfit for the use for which it is required during its intended life.

*Code of practice for general construction in steel (*second revision*).

†Code of practice for plain and reinforced concrete (*third revision*).

5.2 A composite structure or part of it, is considered unfit for use when it exceeds a particular state called the limit state, beyond which it infringes one of the criteria governing its performance or use. The limit states can be classified into categories:

a) the ultimate limit states, which are those corresponding to the maximum load-carrying capacity; and

b) the serviceability limit states, which are related to the criteria governing normal use and durability.

5.2.1 In steel-concrete composite structures used in buildings, the significant ultimate limit states to be considered are listed below:

a) collapse due to flexural failure of one or more critical sections,

b) collapse due to horizontal shear failure at the interface between the steel beam and the concrete slab, and

c) collapse due to vertical separation of the concrete slab from the steel beam.

5.2.2 The important serviceability limit states to be considered are:

a) limit state of deflection, and

b) limit state of stresses in concrete and steel.

6. LIMIT STATE DESIGN

6.1 Steel-concrete composite structures shall be designed by the limit state method using the partial safety factor (γ_f for loads and γ_m for the material strengths) as given in **35.4** of IS : 456-1978*.

7. ANALYSIS OF STRUCTURE

7.1 The overall analysis of structure to find the action effects shall be done as per **21** of IS : 456-1978*.

7.2 Analysis of Sections for Ultimate Limit States — This is done taking account of in elastic properties of concrete and steel as given in **8.**

7.3 Analysis of Sections for Serviceability Limit States — This is done by elastic theory assuming the values of Young's modulus for concrete and steel as given in IS : 456-1978* and neglecting the tensile stresses in concrete.

8. LIMIT STATE OF COLLAPSE : FLEXURE

8.1 Assumptions — Design for the limit state of collapse in flexure shall be based on the assumptions given below:

a) Plane sections normal to the axis remain plane after bending;

*Code of practice for plain and reinforced concrete (*third revision*).

b) The maximum strain in concrete at the outermost compression fibre is taken as 0·003 5 in bending;

c) The stress-strain curve for concrete may be taken to be the same as in Fig. 20 of IS : 456-1978*. The total compressive force in concrete is given by $F_{cc} — 0{\cdot}36 f_{ck} b X_u$ and this acts at a depth of $0{\cdot}42 X_u$ with the value restricted to maximum of *ds*;

d) The tensile strength of the concrete is ignored; and

e) The stress-strain curve for the steel section shall be assumed to be the same as in Fig. 22B of IS : 456-1978*.

8.2 For determining the position of plastic neutral axis and ultimate moment of resistance the Appendix A may be followed.

9. LIMIT STATE OF COLLAPSE : HORIZONTAL SHEAR AT THE INTERFACE BETWEEN STEEL BEAM AND THE CONCRETE SLAB

9.1 Mechanical shear connectors should be provided to transmit the horizontal shear between the steel beam and the concrete slab, ignoring the effect of any bond between the two.

9.2 The number of connectors should be calculated to resist the maximum value of the total horizontal shear force to be transmitted at collapse between points of maximum and zero moment. This force is taken as the force in the concrete F_{cc} at ultimate moment, formulae for which are given in **8**.

9.3 Table 1 gives design values for a range of commonly used types of connectors illustrated in Fig. 1. The values for other type of connectors may be determined experimentally by shear tests carried out in accordance with **9.9**. The design value of a shear connector is taken at 67 percent of the ultimate capacity.

9.4 Where there is a concrete haunch with a slope steeper than 1 vertical to 3 horizontal between the top flange of the steel beam and the underside of the concrete slab, the value of the shear connector should in all cases be based on shear tests in accordance with **9.9** incorporating the proposed haunch and reinforcement.

9.5 The number of connectors as determined above may normally be uniformly spaced between each end of the beam and the section of maximum moment. Where the composite beam supports heavy concentrated loads, the procedure laid down in Appendix B may be followed.

9.6 The spacing of connectors should not be greater than four times the slab thickness nor greater than 600 mm. The distance between the edge of the connector and the edge of the plate or flange to which it is connected shall not be less than 25 mm.

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*Code of practice for plain and reinforced concrete (*third revision*).

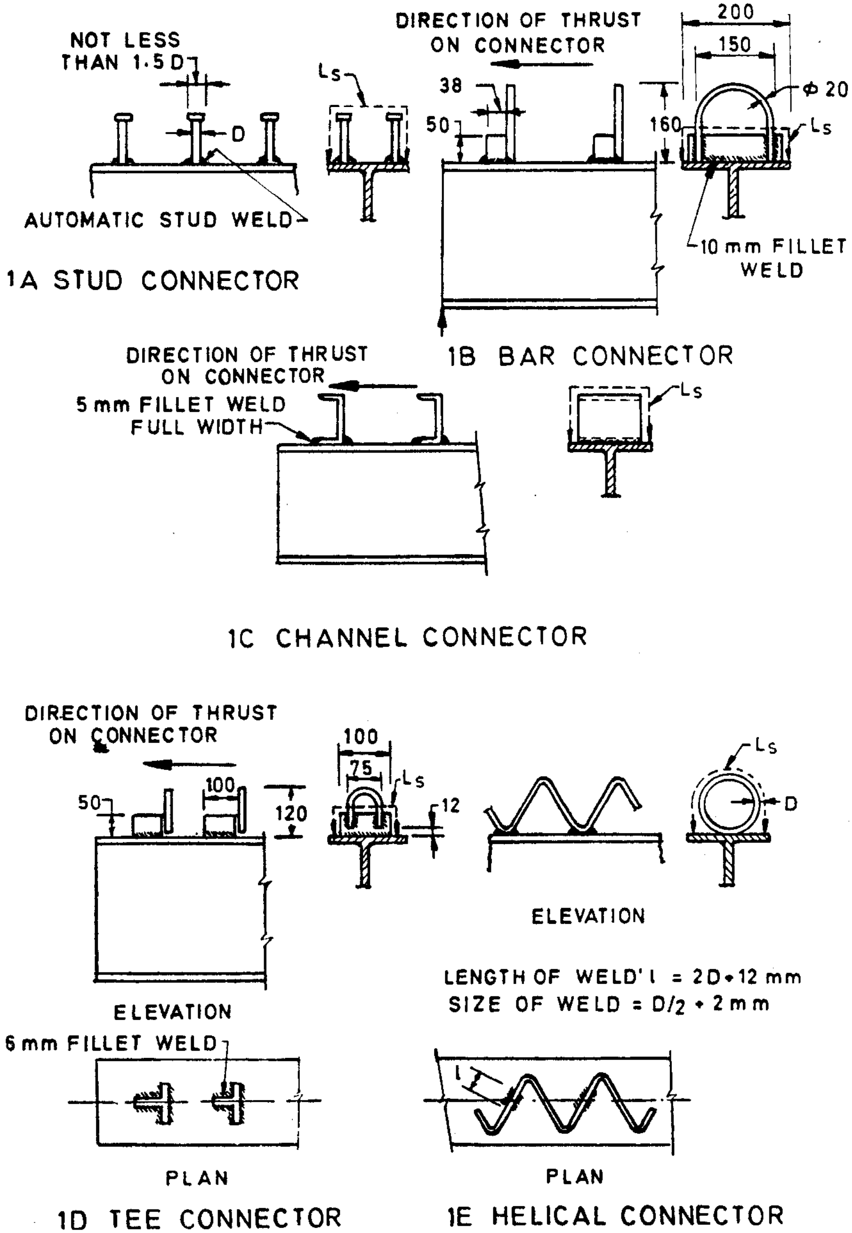
TABLE 1 DESIGN STRENGTH OF SHEAR CONNECTORS FOR DIFFERENT CONCRETE STRENGTHS

(*Clause* 9.3)

Type of Connector		Connector Material	Welds	Design Strength of Connector for Concrete of Grade		
				M-20	M-30	M-40
(1)		(2)	(3)	(4)	(5)	(6)
I. Headed stud		IS : 961-1975* Fe 540-HT	*See* Fig. 1A	Load per stud	(P_c), kN	
Diameter mm	Height mm					
25	100			86	101	113
22	100			70	85	94
20	100			57	68	75
20	75			49	58	64
16	75			47	49	54
12	62			23	28	31
II. Bar connector		IS : 226-1975†	*See* Fig. 1B	Load per bar	kN	
50 mm × 38 mm × 200 mm				318	477	645
III. Channel connector		IS : 226-1975†	*See* Fig. 1C	Load per channel	(P_e)kN	
125 mm × 65 mm × 12·7 kg × 150 mm				184	219	243
100 mm × 50 mm × 9·2 kg × 150 mm				169	204	228
75 mm × 40 mm × 6·8 kg × 150 mm				159	193	218
IV. Tee connector		IS : 226-1975†	*See* Fig. 1D	Load per connector	(P_e)kN	
100 mm × 100 mm × 10 mm Tee × 50 mm				163	193	211
V. Helical connector		IS : 226-1975†	*See* Fig. 1E	Load per pitch	(P_e)kN	
Bar diameter mm	Pitch circle diameter mm					
20	125			131	154	167
16	125			100	118	96
12	100			70	83	90
10	75			40	48	52

*Specification for structural steel (high strength) (*second revision*).

†Specification for structural steel (standard quality) (*fifth revision*).



All dimensions in millimetres.

FIG. 1 TYPICAL SHEAR CONNECTORS

9.7 The shear force in kN/m of beam

$$Q = \frac{N_c \times \text{load in kN on one shear connector at ultimate load } (P_c)}{\text{Longitudinal spacing of connectors in m should not exceed either}}$$

The shear resistance per metre run of beam

$$= 0{\cdot}232 L_s \sqrt{f_{ck}} \quad + 0{\cdot}1 A_t f_y n$$

or

$$= 0{\cdot}623 L_s \sqrt{f_{ck}}$$

where

N_c = number of shear connectors at a cross section

f_{ck} = characteristic strength of concrete in N/mm^2

L_s = the length (in mm) of the shear surface at the shear connectors

This length is to be taken as the peripheral distance (in mm) around the connectors at cross-section as shown in Fig. 1 but not to be taken greater than the thickness of the slab in the case of L-beams or twice the thickness of the slab in the case of T-beams. Where haunches having a slope not steeper than 1 vertical to 3 horizontal are provided, the thickness of the slab may be taken as the depth of the slab plus haunch when calculating this limiting value of L_s.

A_t = area in cm^2 per metre run of beam

n = number of times each lower transverse reinforcing bar is intersected by a shear surface. Generally, for T-beams $n = 2$ and for L-beams $n = 1$

f_y = yield stress in N/mm^2 with a maximum value of 425 N/mm^2

9.8 The amount of transverse steel in the bottom of the slab should not be less than $\frac{2{\cdot}5Q}{f_y}$ cm^2/m run of beam.

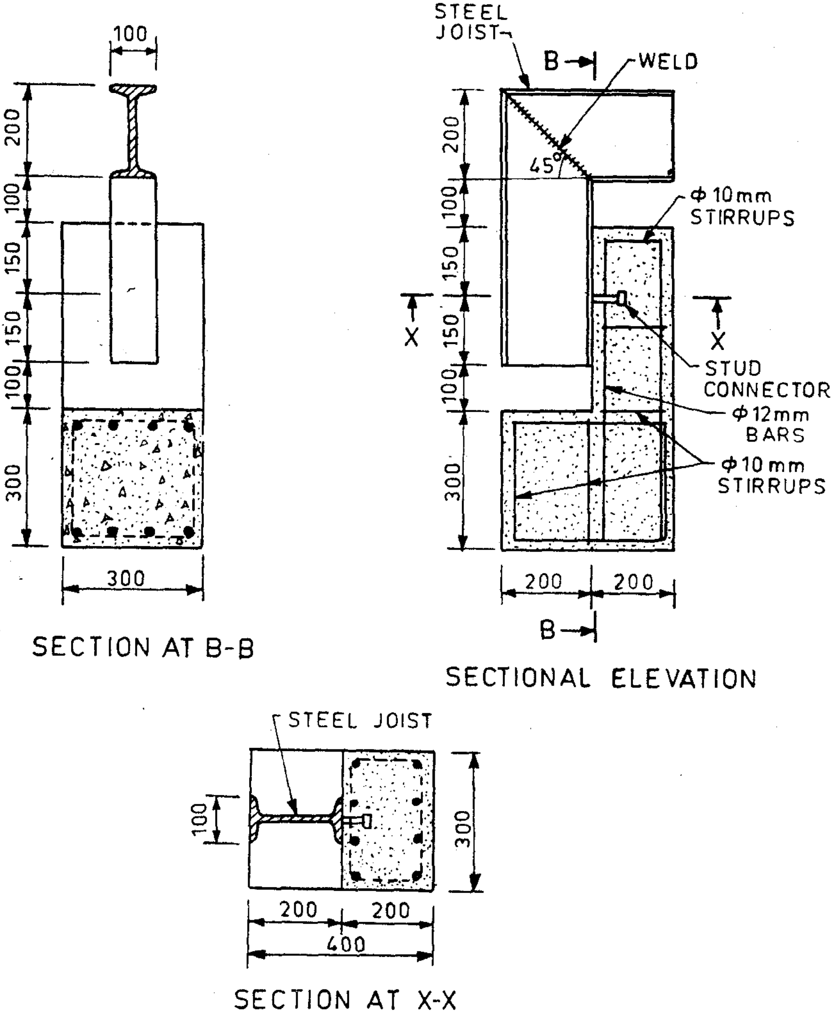
9.9 Tests on Shear Connectors

a) The dimensions of the standard test-piece are shown in Fig. 2.

b) While preparing the test-piece, the bond at the steel-concrete interface should be prevented by greasing the flanges or by any other suitable method.

c) The rate of increase of load should be uniform and such that the collapse load is reached in not less than 10 minutes.

d) The thickness of slab and detailing of reinforcement should be either (i) as given in Fig. 2 or (ii) as in the beams for which the test is designed.



All dimensions in millimetres.

FIG. 2 STANDARD TEST FOR SHEAR CONNECTORS

e) The characteristic strength of the concrete at the time of testing should not exceed the characteristic strength of the concrete in the beams for which the test is designed.

f) A minimum of three tests should be made and the design values should be taken as 67 percent of the lowest ultimate capacity.

10. LIMIT STATE OF COLLAPSE : VERTICAL SEPARATION OF THE CONCRETE SLAB FROM THE STEEL BEAM

10.1 This is usually taken care of by proper detailing of the shear connectors. The overall height of the connector, that is, the length of stud, diameter of helix, height of channel, hoop, etc, should not be less than 50 mm nor project less than 25 mm into the compression zone of the concrete slab. The thickness of the compression zone should be that at the section of maximum bending moment at the limit state of collapse by flexure. The diameter of the head of a stud should not be less than 1·5 times the diameter of the stud and the thickness of the head shall not be less than 0·4 times the shank diameter.

11. METHOD OF CONSTRUCTION (PROPPED OR UNPROPPED) AND ITS EFFECT ON CALCULATIONS FOR SERVICEABILITY LIMIT STATES

11.1 The stressed and strain at serviceability limit state depend on the method of construction, that is, whether the steel beam is propped or unpropped during construction. In unpropped construction, the steel beam has to carry the construction load of the shuttering, wet concrete and its own weight. Only the live load is resisted by the composite section. In propped construction both the dead and live load are resisted by the composite section. This difference in method of construction does not, however, effect the ultimate limit load.

11.2 When props are used, they should be kept in place until the *in-situ* concrete has attained a characteristic strength equal to at least twice the stress to which the concrete may be subjected shortly after the time of removing the props.

12. LIMIT STATE OF SERVICEABILITY : DEFLECTION

12.1 In this case the beam is analysed using the elastic theory adopting a modular ratio of 15 for live load and 30 for the dead load, and neglecting any tensile stress in concrete. The deflection should not exceed the value for steel structures as $\frac{L}{325}$.

13. LIMIT STATE OF SERVICEABILITY : STRESSES IN STEEL AND CONCRETE

13.1 The total elastic stress considering the different stages of construction in the steel beam should not exceed $0{\cdot}87\,f_y$ nor the stress in concrete exceed one-third of the characteristic strength.

APPENDIX A

(*Clause* 8.2)

POSITION OF PLASTIC NEUTRAL AXIS AND ULTIMATE MOMENT OF RESISTANCE

A-1. DETERMINATION OF POSITION OF PLASTIC NEUTRAL AXIS AND ULTIMATE MOMENT OF RESISTANCE

A-1.1 In a section of homogenous material, the plastic neutral axis coincides with the equal area axis of the section, that is, the axis which divides the section into two equal areas on either side. The same concept can be used in the case of composite beams also, provided the steel area is converted into equivalent concrete area by multiplying it with the stress ratio.

$$a = \frac{0{\cdot}87 f_y}{0{\cdot}36 f_{ck}}$$

Case (i) *Plastic Neutral Axis within Concrete Slab* (Fig. 3)

This happens when $bd_x \geqslant aA_s$

$bX_u = aA_s \qquad X_u = aA_s$ ... (1)

Compressive force in concrete $F_{cc} = 0{\cdot}36 bX_u f_{ck}$ ... (2)

Taking moment about centre of concrete compression,

$M_u = 0{\cdot}87 A_x f_y\,(\,d_c + 0{\cdot}5 d_s - 0{\cdot}42 X_u\,)$ ... (3)

Case (ii) *Plastic Neutral Axis within Top Flange of Steel Beam* (Fig. 4)

$$[\,d_s < X_u < (\,d_s + t_f\,)\,]$$

This happens when

$$bd_s < aA_s < (\,bd_s + 2\,aA_f\,)$$

This stress distribution at ultimate limit state is shown in Fig. 4(b). The derivation of the formulae will be simplified by adding equal and opposite forces to the steel beam above the neutral axis giving the equivalent stress distribution shown in Fig. 4(c).

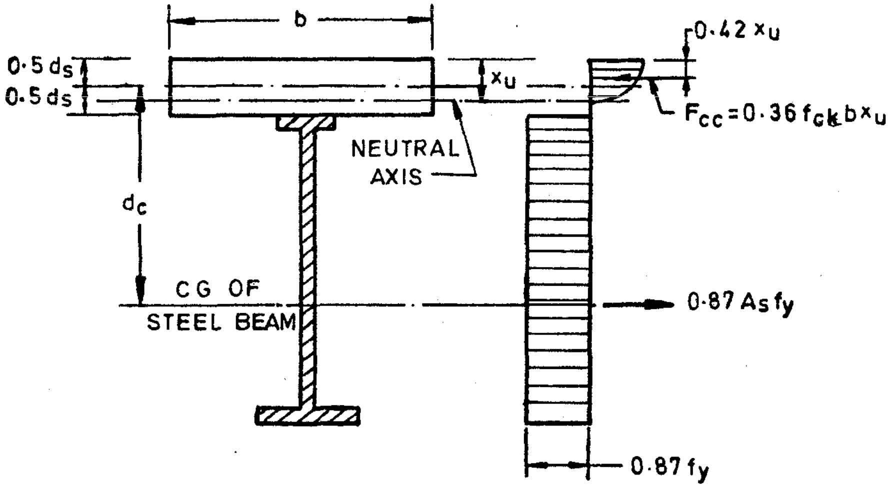


FIG. 3 STRESS DISTRIBUTION IN A COMPOSITE BEAM WITH NEUTRAL AXIS WITHIN CONCRETE SLAB

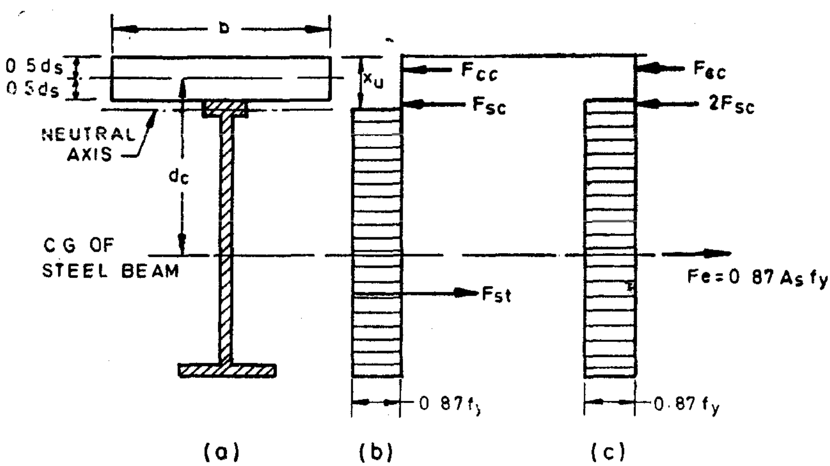


FIG. 4 STRESS DISTRIBUTION IN A COMPOSITE BEAM WITH NEUTRAL AXIS WITHIN FLANGE OF STEEL BEAM

Thus the steel beam is assumed to be stressed in tension to yield through its full depth, the total equivalent tensile force F_c being balanced by the compressive force F_{cc} in the concrete plus twice the compressive force F_{sc} in the steel section above the neutral axis.

$$F_c = 0.87 A_s f_y \quad \ldots \quad (4)$$

$$F_{cc} = \frac{bd_s}{a} 0.87 f_y \quad \ldots \quad (5)$$

$$2F_{sc} = 2\,(\text{area of steel in compression}) \times 0.87 f_y \quad \ldots \quad (6)$$

$$F_c = F_{cc} + 2F_{sc} \quad \ldots \quad (7)$$

Substituting (4), (5) and (6) in (7)

$$\text{Area of steel in compression} = \tfrac{1}{2} A_s - \frac{bd_s}{a} \quad \ldots \quad (8)$$

In this case area of steel in compression $= (X_u - d_x)\, b_f$

$$\therefore \quad (X_u - d_s)\, b_f = \tfrac{1}{2}\left(A_s - \frac{bd_s}{a}\right)$$

$$X_u = b_f d_s + \tfrac{1}{2}\left(A_s - \frac{bd_s}{a}\right)$$

$$X_u = d_s + \frac{aA_s - bd_s}{2\, b_f a} \quad \ldots \quad (9)$$

Taking moment about centre of concrete compression it can be shown that

$$M_u = 0.87 f_y \,[\, A_s\,(d_c + 0.08\, d_s) - b_f\,(X_u - d_s)\,(X_u + 0.1 ċ d_s)\,] \quad \ldots \quad (10)$$

Case (iii) *Plastic Neutral Axis within the Web of Steel Beam* (Fig. 5) $(X_u > d_s + t_f)$

This occurs when

$$a\,(A_s - 2A_f) > bd_s$$

$$bd_s + 2aA_f + 2a\,(X_u - d_s - t_f)\, t_w = aA_s$$

$$X_u - d_s - t_f = \frac{A_s}{2t_w} - \frac{bd_s}{2a\,t_w} - \frac{A_f}{t}$$

$$\therefore X_u = d_s + t_f + \frac{a\,(A_s - 2A_t) - bd_s}{2at_w} \quad \ldots \quad (11)$$

$$F_{cc} = 0.36\, bd_s f_{ck} \quad \ldots \quad (12)$$

Taking moment about centre of concrete compression,

$$M_u = 0.87 f_y A_s\,(d_c + 0.08 d_s) - 2A_t\,(0.5 t_f + 0.58 d_s) - 2t_w\,(X_u - d_s - t_f)\,(0.5 \times X_u + 0.08\, d_s + 0.5\, t_f) \quad \ldots \quad (13)$$

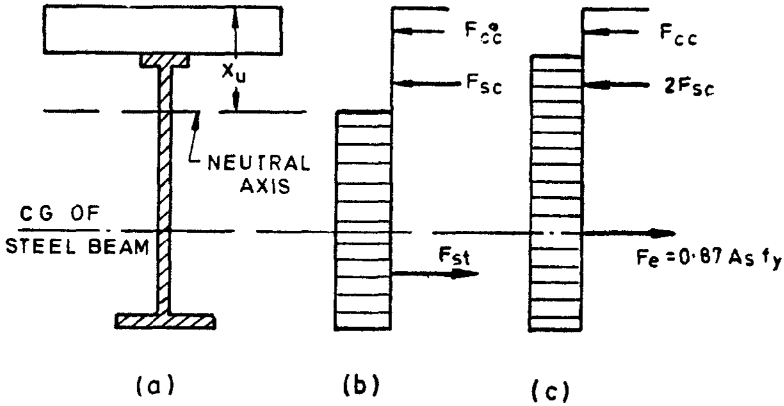


FIG. 5 STRESS DISTRIBUTION IN A COMPOSITE BEAM WITH NEUTRAL AXIS WITHIN THE WEB OF STEEL BEAM

APPENDIX B

(*Clause* 9.5)

DISTRIBUTION OF SHEAR CONNECTORS FOR HEAVY CONCENTRATED LOADS

B-1. DISTRIBUTION OF SHEAR CONNECTORS

B-1.1 In the case of composite beams carrying heavy concentrated loads, the distribution of shear connectors may be varied as given in **B-1.2**. In such cases, there will be sharp discontinuities in the shear force diagram as shown for example, in Fig. 6.

B-1.2 The number of connectors based on the concrete force F_{cc} for the section of maximum moment should be distributed between that section and the section of zero moment according to the respective areas of the shear force diagram between the points of discontinuity.

If the total number of connectors required between the section of zero and maximum moments is $N = n_1 + n_2 + \ldots\ldots\ldots$

then the number of connectors in length $l_1 = n_1 = N \left(\dfrac{a_1}{a_1 + a_2 + \ldots\ldots} \right)$

and the number of connectors in length $l_2 = n_2 = N \left(\dfrac{a_2}{a_1 + a_2 + \ldots\ldots} \right)$

The spacing of connectors over the lengths l_1, l_2, etc, may be uniform.

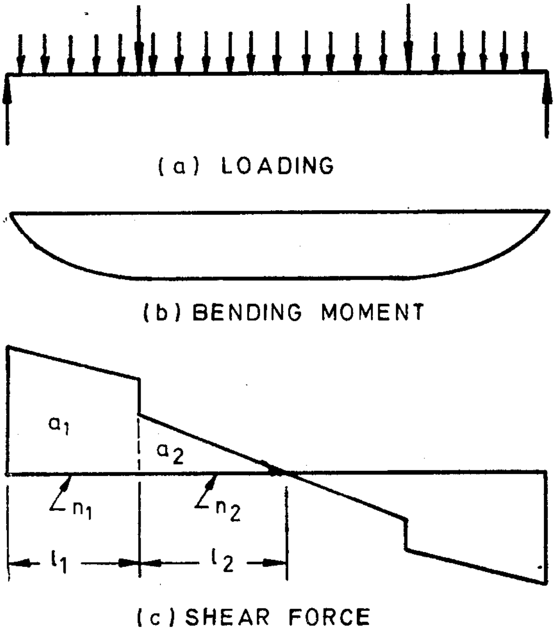


FIG. 6 BEAM WITH HEAVY CONCENTRATED LOADS

(*Continued from page* 2)

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