IS 3935 (1966): Code of practice for composite construction [CED 38: Special Structures]

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Indian Standard

CODE OF PRACTICE FOR
COMPOSITE CONSTRUCTION

(Fifth Reprint MAY 1993)

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B U R E A U   O F   I N D I A N   S T A N D A R D S
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

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Indian Standard
CODE OF PRACTICE FOR
COMPOSITE CONSTRUCTION

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CONTENTS

Indian Standard
CODE OF PRACTICE FOR
COMPOSITE CONSTRUCTION

0. F O R E W O R D

0.1 This Indian Standard was adopted by the Indian Standards Institution on 23 November 1966, after the draft finalized by the Composite Construction Sectional Committee had been approved by the Civil Engineering Division Council.

0.2 Though composite construction is not a very new technique, its importance in structural construction is of recent realization in this country. With the advancement in the manufacture of structural units, composite construction has assumed great importance. This technique essentially consists in providing the required monolithic action between the prefabricated units, such as steel beams, precast reinforced or prestressed concrete beams and cast-*in-situ* concrete and thereby increasing the structural efficiency of the whole section. Prefabricated construction and cast-*in-situ* construction have their own advantages and disadvantages; and composite construction seeks to combine the advantages and minimize the disadvantages of these methods of construction. For example, in the conventional type of steel beam and slab construction, each beam carries the entire load transmitted to it by the slab, but if sufficient shear connection is provided between the beam and the slab, they will act together as a composite section to carry the load and their action will be similar to that of a tee beam. For a given condition, considerably more variation in depth of the section is possible with composite construction than with the conventional construction. Composite construction has also the advantages that the prefabricated units can act as formwork for *in-situ* concrete and the units requiring to be transported and erected are lighter than those in case of fully precast and prefabricated construction. In this code, it is attempted to provide a general guidance to designers and field engineers for the design and construction of composite structures. This code may be applied to both dynamically and statically loaded structures.

0.2.1 Basically there are two methods of assembly in composite construction, namely, (a) the unproped method, wherein the prefabricated units are made sufficiently strong to carry the dead weight of wet concrete and constructional live load together with any incidental formwork which may be required; and (b) the proped method, wherein the prefabricated units are supported during the laying and curing of *in-situ* concrete so that when

3

the props are removed the whole of the section is monolithic and carries the total dead weight of the concrete as well as live load.

0.3 The provisions of this code apply mainly to the composite beams for buildings and bridges made up of prefabricated structural units and cast-*in-situ* concrete. Whilst the common methods of design and construction have been covered in this code, special systems of design and construction of composite beams not covered by this code may be permitted on production of satisfactory evidence regarding their adequacy and safety by analysis or tests or both.

0.4 All requirements of IS : 456-1964*, IS : 1343-1960† and IS : 800-1962‡ in so far as they apply, shall be deemed to form part of this code except where otherwise laid down in this code.

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

0.6 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.

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1. SCOPE

1.1 This standard deals with the design and construction of composite structures made up of prefabricated structural units and cast-*in-situ* concrete. The prefabricated units may consist of steel members or prestressed or reinforced concrete precast members.

2. TERMINOLOGY

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

2.1 Castellations — Protrusions or recesses on the top surface of the prefabricated concrete units to provide the necessary monolithic action between the cast-*in-situ* concrete and prefabricated units.

2.2 Composite Members — Structural members comprising prefabricated structural units of steel, prestressed concrete, or reinforced concrete and cast-*in-situ* concrete connected together in such a manner that they act monolithically.

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

†Code of practice for prestressed concrete.

‡Code of practice for use of structural steel in general building construction (*revised*).

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

2.3 Shear Connectors — Structural elements, such as anchors, studs, channels and spirals, intended to transmit the horizontal shear between the prefabricated member and the cast-*in-situ* concrete and also to prevent vertical preparation at the inter-face

3. SYMBOLS

3.1 For the purpose of this standard and unless otherwise defined in the text, the following symbols shall have the meanings indicated against each:

b = width of the steel flange of the rigid connector at surface of contact

d = the diameter of the stud connector in cm

h = maximum thickness of the flange of a channel connector in cm measured at the face of the web

H = height of the stud connector in cm

I = moment of inertia of the transformed composite section

L = length of the channel shear connector in cm

m_s = the statical moment of the transformed area on the slab side of the contact surface about the neutral axis of the composite section or the statical moment of area of reinforcement embedded in the concrete slab for negative moment

q = permissible shear stress measured as inclined tension in concrete

Q = the safe shear resistance in kg of one shear connector or one pitch of a spiral shear connector

S_h = the horizontal shear per linear cm at the plane of contact of the *in-situ* concrete slab and the prefabricated beam at the cross-section of the composite beam under consideration

t = thickness of the web of a channel shear connector in cm

V = the total external (vertical) shear due to the superimposed load acting on the composite section

σ_{cu} = crushing strength of 150 mm concrete cube at 28 days

σ_{st} = permissible tensile stress in the anchor bar

4. MATERIALS

4.1 Concrete — *In-situ* concrete and concrete for plain and reinforced concrete prefabricated structural units shall conform to the requirements of IS : 456-1964*.

4.1.1 Concrete for prestressed concrete structural units shall conform to the requirements of IS : 1343-1960†.

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

†Code of practice for prestressed concrete.

4.2 Steel

4.2.1 *Structural Steel* — Structural steel shall comply with IS : 226-1962*, IS : 961-1962†, IS : 2062-1962‡, or Designation St 440 of IS : 1977-1962§, whichever is appropriate.

4.2.2 *Shear Connectors* — Steel for shear connectors shall comply with IS : 226-1962*, IS : 432 (Part I)-1966¶, IS : 961-1962†, Designation St 440 of IS : 1977-1962§, or IS : 2062-1962‡, whichever is appropriate.

4.2.3 *Steel for Rivets, Bolts and Nuts, and Washers* — Steel for rivets, bolts and nuts, and washers shall conform to IS : 800-1962∥.

4.2.4 *Steel for Concrete Reinforcement* — The steel reinforcement for reinforced concrete shall conform to IS : 432 (Part I)-1966¶, IS : 432 (Part II)-1966**, IS : 1139-1966††, IS : 1786-1966‡‡, or IS : 1566-1960§§, whichever is appropriate.

4.2.5 *Prestressing Steel* — The prestressing steel for prestressed concrete structural units shall comply with IS : 1785 (Part I)-1966¶¶, or IS : 2090-1962∥∥, whichever is appropriate.

5. GENERAL DESIGN CONSIDERATIONS

5.1 Basic Requirements — The general provisions related to the design and construction of plain and reinforced concrete, prestressed concrete and steel structures as laid down in IS : 456-1964***, IS : 1343-1960†††, and IS : 800-1962∥, respectively shall apply together with the additional requirements specified herein for composite sections.

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*Specification for structural steel (standard quality) (*third revision*).

†Specification for structural steel (high tensile) (*revised*).

‡Specification for structural steel (fusion welding quality).

§Specification for structural steel (ordinary quality).

¶Specification for mild steel and medium tensile steel bars and hard-drawn steel wire for concrete reinforcement: Part I Mild steel and medium tensile steel bars (*second revision*).

∥Code of practice for use of structural steel in general building construction (*revised*).

**Specification for mild steel and medium tensile steel bars and hard drawn steel wire for concrete reinforcement: Part II Hard drawn steel wire (*second revision*).

††Specification for hot rolled mild steel and medium tensile steel deformed bars for concrete reinforcement (*revised*).

‡‡Specification for cold twisted steel bars for concrete reinforcement (*revised*).

§§Specification for hard drawn steel wire fabric for concrete reinforcement.

¶¶Specification for plain hard drawn steel wire for prestressed concrete: Part I Cold drawn stress relieved wire (*revised*).

∥∥Specification for high tensile steel bars used in prestressed concrete.

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

†††Code of practice for prestressed concrete.

5.1.1 In any composite structure provisions shall be made for all conditions of stresses that may occur in accordance with principles of mechanics, recognized methods of design and sound engineering practice. Before taking up the detailed design, the engineer-in-charge should satisfy himself on the correct estimation of all loads and on the adequate static equilibrium of the structure, particularly, in regard to safety against overturning of overhanging members. The anchorages or counterweights provided for overhanging members (during construction and service) should be such that static equilibrium should remain even when the overturning moment is doubled.

5.2 Composite Action — For the purpose of design, if the prefabricated unit is adequately supported before placing of the *in-situ* concrete, it shall be designed to sustain self-load only. If the load of the formwork, constructional live load and the *in-situ* concrete is carried directly by the prefabricated unit without adequate props, this additional load shall also be accounted for in addition to self-load. The composite section shall be designed for all the loads imposed on the member taking note of the fact that the composite action of the member is effective only for the loads imposed after the composite action has started to function.

5.2.1 In prescribing the requirements of this code, full composite action has been assumed between the prefabricated member and the *in-situ* concrete. For such full composite action to be considered effective, the *in-situ* concrete shall have attained at least 75 percent of the designed 28-day strength of 15 cm cubes.

5.2.2 The composite section should preferably be proportioned in such a way that the neutral axis of the composite section is generally located below the *in-situ* concrete slab.

If the neutral axis is located inside the *in-situ* concrete slab, the portion of the slab below the neutral axis shall not be considered effective for computing moments of inertia or resisting moments except for deflection calculations.

5.3 Equivalent Section — For prefabricated units in prestressed concrete or reinforced concrete, consideration shall be given to the different moduli of elasticity of the concrete of the precast and of the *in-situ* portions.

For prefabricated units in steel, the effective gross area of concrete slab shall be converted into the corresponding equivalent area of steel. This shall be done by dividing the effective area of the concrete slab by the modular ratio.

5.4 Modulus of Elasticity — The values of moduli of elasticity of steel and concrete shall be taken in accordance with requirements of the relevant Indian Standard codes. The modular ratio shall be also calculated on the·

7

basis of these moduli of elasticity except where otherwise laid down in the relevant design codes, such as in IS : 456-1964*.

5.4.1 The modular ratio between precast concrete and cast-*in-situ* concrete shall be determined on the basis of values of moduli of elasticity for the two concretes.

5.5 Loads

5.5.1 *Dead Loads* — Dead loads shall be calculated on the basis of the unit weights taken in accordance with IS : 1911-1961†. In all calculations of loading, unless otherwise established or specified, the weight of reinforced and prestressed concrete shall be taken as 2 400 kg/m³ and that of plain concrete as 2 300 kg/m³.

5.5.2 *Live Loads, Snow Loads and Wind Loads* — In general building construction, live loads, snow loads and wind loads shall be assumed in accordance with IS : 875-1964‡. In the case of structures of other types, live loads, wind loads, snow loads and other loads shall be taken as specified by the appropriate authority.

5.5.3 *Earthquake Loads* — Effect of earthquake loads shall be taken in accordance with IS : 1893-1966§.

5.6 Permissible Stresses

5.6.1 *Permissible Stresses in Concrete*

5.6.1.1 *For reinforced concrete members* — The permissible stresses shall be in accordance with the requirements of IS : 456-1964*.

5.6.1.2 *For prestressed concrete members* — The permissible stresses shall be in accordance with the requirements of IS : 1343-1960¶.

5.6.2 *Permissible Stresses in Steel Reinforcement*

5.6.2.1 *For reinforced concrete members* — The permissible stresses shall be in accordance with the requirements of IS : 456-1964*.

5.6.2.2 *For prestressed concrete members* — The permissible stresses in steel shall be in accordance with the requirements of IS : 1343-1960¶.

5.6.3 *Permissible Stresses in Structural Steel* — The permissible stresses in structural steel members shall be in accordance with the requirements of IS : 800-1962‖.

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*Code of practice for plain and reinforced concrete (*second revision*).
†Schedule of unit weights of building materials.
‡Code of practice for structural safety of buildings: Loading standards (*revised*).
§Recommendations for earthquake resistant design of structures (*revised*).
¶Code of practice for prestressed concrete.
‖Code of practice for use of structural steel in general building construction (*revised*).

5.7 Differential Shrinkage and Creep of Concrete — The effects of shrinkage and creep of the cast-*in-situ* concrete on the prefabricated member shall be considered. It shall be ensured that the stresses in the prefabricated member do not exceed the permissible stresses by more than 25 percent when these effects are superimposed on the stresses caused by the worst combination of other loads.

5.8 Deflection

5.8.1 *Live Load Deflections* — Live load deflections shall be calculated on the basis of the moment of inertia of the transformed composite section using the full value of the moduli of elasticity of the concretes.

5.8.2 *Dead Load Deflections*

5.8.2.1 For beams shored during construction, the dead load deflections shall be calculated on the basis of the moment of inertia of the transformed composite section using one-half the value of moduli of elasticity of concretes.

5.8.2.2 For beams not shored during construction, the dead load deflections shall be calculated on the basis of the moment of inertia of the prefabricated beam alone except that deflections due to dead loads applied after the concrete slab has attained 75 percent of the specified 28-day strength shall be calculated according to **5.8.2.1**.

5.8.2.3 Steps, such as giving a reverse camber to compensate for the full dead load plus half the live load deflections shall be taken in design and construction in order to prevent excessive:

    a) dishing of the slabs and beams built with shores,

    b) thickening of slabs and beams built without shores, and

    c) deflection of beams in service.

5.8.3 *Limiting Deflections* — For simply supported beams the total deflection due to dead load, live load and impact should preferably not exceed 1/600 of the span, or the deflection due to live load and impact should preferably not exceed 1/800 of the span. The deflection of cantilever arms due to dead load, live load and impact shall not exceed 1/300 of the cantilever arms and due to live load and impact shall not exceed 1/400 of the cantilever arm.

5.9 Design of Slabs

5.9.1 In continuous spans, the effective span of slab shall be:

    a) central distance between the outstand of supporting flanges of the steel prefabricated units (*see* Fig. 1); and

    b) clear distance between the webs of precast reinforced concrete or prestressed concrete units, reduced by two-thirds of the total thickness of the slab and flange of the precast unit at the face of the web (*see* Fig. 2).

FIG. 1 EFFECTIVE SPAN OF SLAB SUPPORTED ON STEEL
PREFABRICATED UNITS

5.9.2 The slabs shall be designed in accordance with requirements of
IS : 456-1964*. In the design of slabs the stress caused by composite
action need not be added to the bending stresses in the slabs.

5.10 Flange Width of Composite Beams

5.10.1 *Beams Having Flanges on Both Sides* — The width of flange (slab)
considered effective in the design of the composite tee beam except in the
case of edge beam shall not exceed the least of the following:

a) One-fourth the span length of the beam;

b) Distance, centre-to-centre, of the beam; and

c) The web (or rib) thickness plus twelve times the least thickness
of the slab plus, in the case of slabs resting on wide flange
(*see* Fig. 2), two-thirds the total thickness of slab and the flange of
the prefabricated unit at the face of the web (or rib).

5.10.2 *For Edge Beams* — The effective flange (slab) width for inner
and outer parts (measured from the centre line of the beam) to be taken
in the case of an edge beam shall not exceed least of the following:

a) One-twelfth the span of the beam (for both the inside and the
outside parts);

b) Half the distance to the adjoining beam (for the inside part) and
the actual width (for the outside part); and

c) Six times the least thickness of the slab plus half the web (or rib)
thickness plus, in the case of slabs resting on wide flanges (*see*
Fig. 2), one-third the total thickness of the slab and the flange, at the
face of the web (or rib) (for both the inside and the outside parts).

5.10.3 *Allowance for Openings* — Any permanent openings which exist
shall be deducted from the calculated width of the flange (slab) at the
section under consideration. The loss of section due to the openings may,
however, be compensated by other suitable provisions, such as trimmer
beams, in which case the full flange width shall be taken into account.

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

$$\frac{1}{3}(x+t)$$
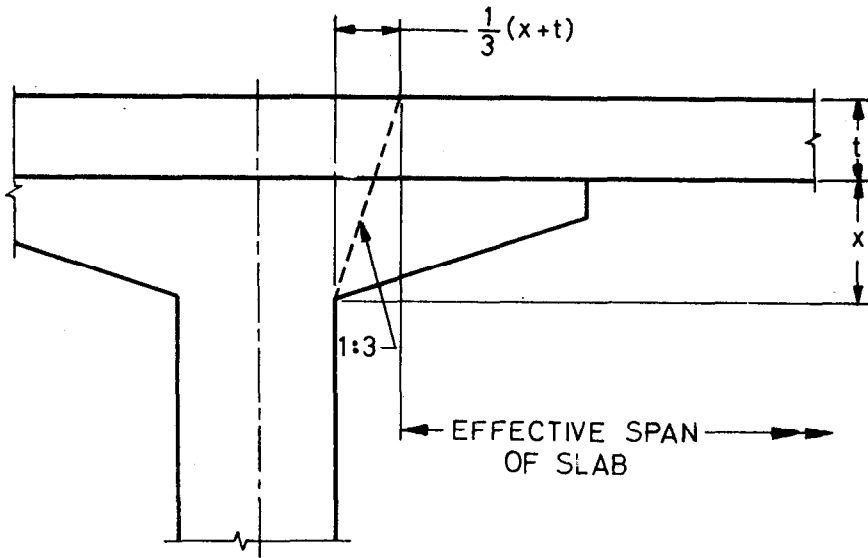
1:3

EFFECTIVE SPAN
OF SLAB

FIG. 2 EFFECTIVE SPAN OF SLAB SUPPORTED ON PRECAST
CONCRETE UNITS

6. PREFABRICATED STEEL AND *IN-SITU* CONCRETE COMPOSITE MEMBERS

6.1 Steel Structural Members — The steel structural members may be of rolled steel joists or any other built-up sections. The structural members shall preferably be symmetrical about the vertical axis. The top flanges and web plates shall be able to absorb and transmit the forces from the connectors. The minimum thickness of the free overhang shall not be less than one-tenth of the free overhang (*see* Fig. 3) so that heavy distortion at the junction with the connectors does not occur.
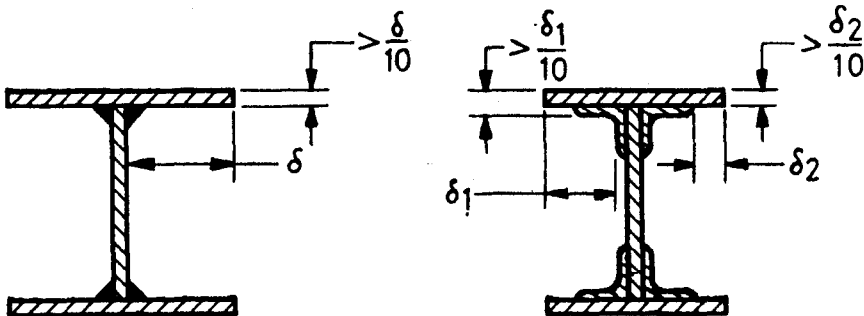

$$>\frac{\delta}{10} \qquad >\frac{\delta_1}{10} \qquad >\frac{\delta_2}{10}$$

FIG. 3 MINIMUM FLANGE THICKNESS FOR STEEL PREFABRICATED ·UNITS

11

6.2 With steel prefabricated units, the depth of the steel section should preferably be not less than 1/30th of the span and the depth of the composite section should be not less than 1/25th of the span. If depths smaller than these are used, the sections should be adequate to limit deflections to the values obtained with the limiting depths specified above.

6.3 Slab and Haunch

6.3.1 The minimum thickness of the concrete above the steel structural member shall be not less than 100 mm and, therefore, haunches should necessarily be provided where thinner slabs are used. The slope of the haunches shall not be greater than one vertical to three horizontal for slabs thinner than 100 mm.

6.3.2 The depth of the haunch shall be chosen so that the depth of the composite structural member is not greater than one and a half times the depth of the steel structural member and further the depth of the haunch shall not be greater than one and a half times the thickness of the slab.

6.3.3 Where a supporting fillet is provided between the prefabricated steel section and the concrete slab, its section shall be ignored in computing the total composite section.

6.4 Shear Connectors

6.4.1 In case of connections between *in-situ* concrete and the prefabricated steel unit, resistance to horizontal shear shall be provided by mechanical shear connectors at the junction of the concrete slab and the steel beam or girder. The connectors shall be capable of resisting the shear force between the slab and the structural steel member and at the same time prevent the vertical separation of the slab from the structural steel member at the inner face (*see* **6.4.2**). The shear connectors shall be of the type which permit a thorough compaction of concrete in order to ensure that their entire surfaces are in contact with concrete.

6.4.1.1 The shear connectors shall be of weldable steel and shall be end welded to the structural members. The capacity of the welds at permissible stress shall be not less than the shear resistance of the connectors. Welding shall be in accordance with the requirements of the relevant Indian Standard.

NOTE — In the case of studs, specialized fusion welding will be necessary and hence expert advice and necessary equipment should be available. To permit satisfactory welding of studs, the gap between the heads of two adjacent connectors should not be less than 15 mm.
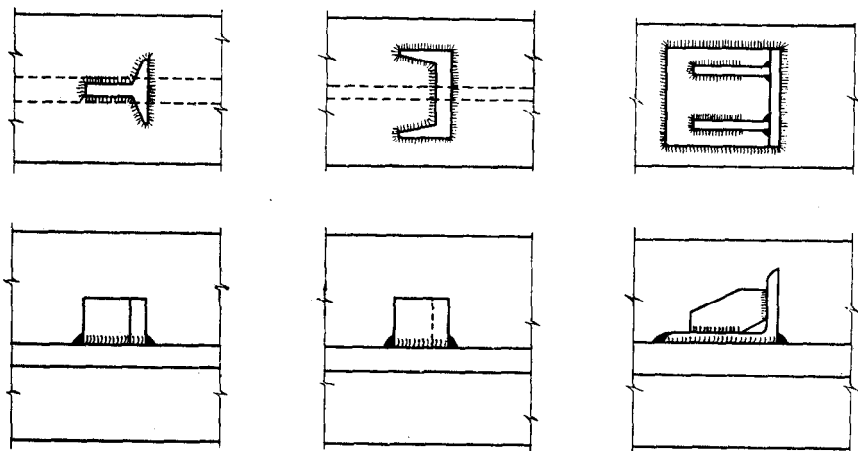
6.4.1.2 Studs and channel shear connectors shall not be spaced further apart than 600 mm. The clear distance between the edge of the beam flange and edge of the connectors shall not be less than 25 mm. The concrete cover over the shear connectors in all directions shall not be less than 25 mm.

6.4.1.3 To ensure that the concrete slab is adequately tied down to the steel flange, the overall height of the shear connector (that is, the length of stud, diameter of the helix, height of the 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 shall be that at the section of maximum bending moment.
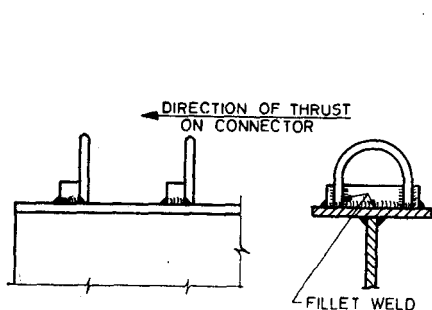
6.4.2 Shear connectors shall consist of any or a combination of the following types:

a) Rigid connectors consisting of short lengths of bars, angles or tees welded on to the flange of the steel fabricated units (*see* Fig. 4). These connectors derive their resistance to horizontal shear from the bearing pressure of the concrete. Failure or slip is generally associated with the crushing of concrete. Some suitable means (anchors) capable of preventing the separation of the *in-situ* concrete from the prefabricated units in the direction perpendicular to the contact surface should be introduced with these connectors.

b) Flexible connectors, such as studs (*see* Fig. 5) and channels (*see* Fig. 6) welded to the contact surface of the prefabricated unit. These derive their resistance essentially through the bending of the connectors.

c) Bond or anchorage connectors consisting of (*see* Fig. 7):

1) mild steel bars welded to the flange of the prefabricated unit in the form of vertical or inclined loop stirrups, or

2) inclined bars with one end welded to the flange of the steel unit and the other end suitably bent, or

3) bar stirrups welded to the flange of the steel unit at each loop. These derive their resistance through bond and/or anchorage action.

d) Any other mechanical device to resist horizontal shear and to prevent vertical separation of *in-situ* concrete from prefabricated unit.

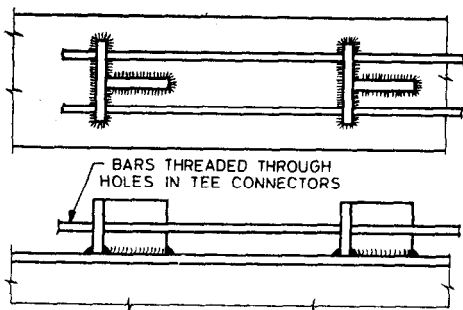**6.4.3** Connectors, such as channels, tees and angles, more closely spaced with smaller faces are preferable to those with larger faces and widely placed, since the former arrangement induces a uniform distribution of shear stress in the concrete. The spacing of the connectors shall not exceed three times the thickness of the slab. Connectors should be as stiff as possible so that an even distribution of stress on the surface is achieved. Channels and tees should be preferred to angles. Welding seams should be taken around the connectors as continuous welds.

13

4A Typical Rigid Connectors

DIRECTION OF THRUST
ON CONNECTOR

BARS THREADED THROUGH
HOLES IN TEE CONNECTORS

FILLET WELD

4B Typical Bar Rigid Connector

4C Typical Rigid Tee Connector with Anchorage Device to Hold Down the Concrete Slab Against Uplift (Concrete .not Shown)

FIG. 4 TYPICAL RIGID CONNECTORS

6.5 Design Requirements of Shear Connectors

6.5.1 The connection between the steel prefabricated unit and the *in-situ* concrete slab shall be checked for integral action of the composite structure at all loads so that:

a) shear along the contact surface is transferred without slip, and

b) separation of the prefabricated unit and the *in-situ* slab in a direction perpendicular to the slab is prevented.
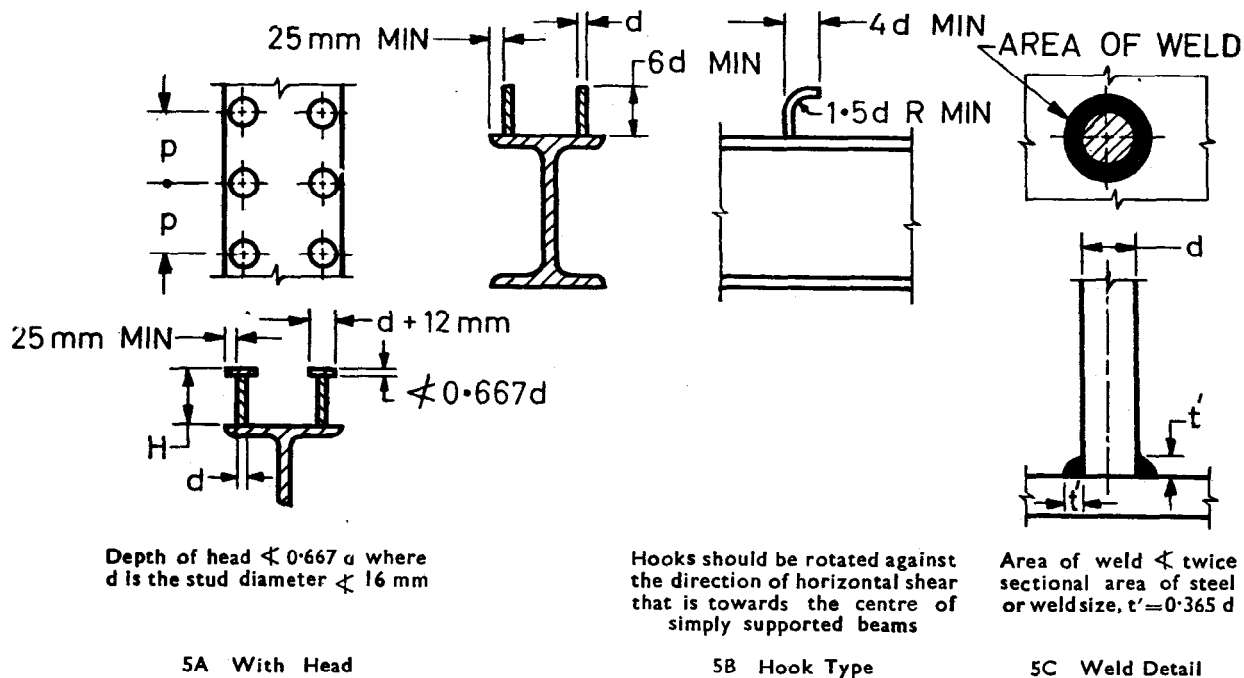
14

25 mm MIN

d

6d MIN

4d MIN

1·5d R MIN

AREA OF WELD

p

p

25 mm MIN

d + 12 mm

t ≮ 0·667d

H

d

d

t'

t'

Depth of head ≮ 0·667 d where
d is the stud diameter ≮ 16 mm

Hooks should be rotated against
the direction of horizontal shear
that is towards the centre of
simply supported beams

Area of weld ≮ twice
sectional area of steel
or weld size, t'=0·365 d

5A With Head

5B Hook Type

5C Weld Detail
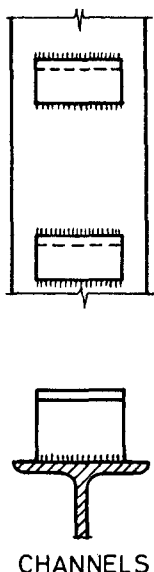
Fig. 5 Typical Stud Shear Connectors

CHANNELS

FIG. 6   TYPICAL FLEXIBLE CHANNEL CONNECTOR

6.5.2 *Horizontal Shear Force* — The horizontal shear to be transferred by the shear connectors, that is, horizontal shear at the plane of contact of the prefabricated and *in-situ* unit shall be computed from the equations:
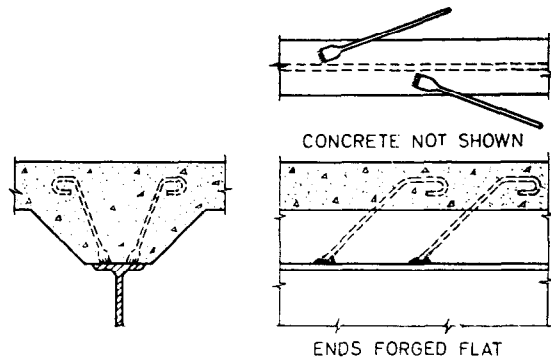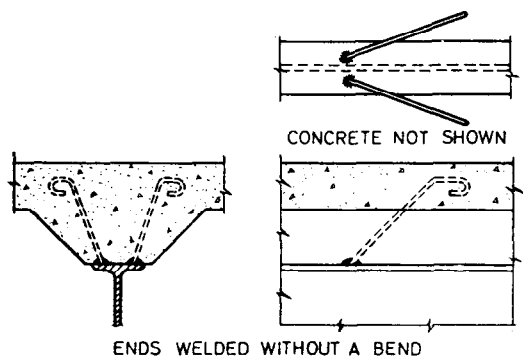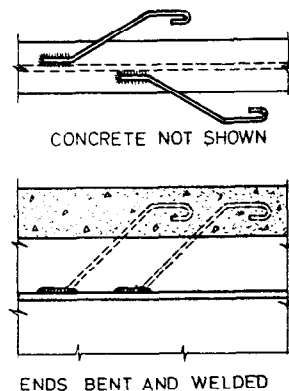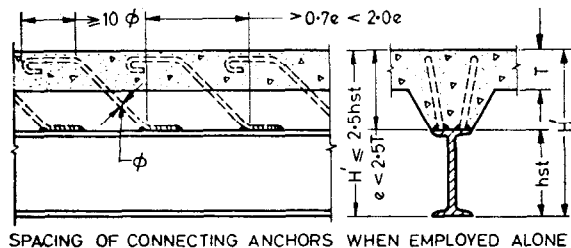
$$S_h = \frac{V\, m_s}{I}$$

NOTE 1 — For beams erected without temporary props the total external shear V is the total external shear from live load and impact plus any shear from the dead load added after the concrete has attained a strength compatible to the composite action assumed (*see* **5.2**). For beams provided with properly designed props during construction, V is the external shear from dead load, live load and prop removal loads.

NOTE 2 — The compressive concrete area is transformed into an equivalent area of steel by dividing the effective concrete area with the modular ratio m.

6.5.3 When negative moments are to be resisted by the prefabricated section alone, shear connection between the prefabricated section and the slab need not be provided in the regions of negative bending moments.

6.5.4 When negative moments are to be resisted by the composite section, shear connection should be provided throughout the full length of the beam, but the concrete on the tension side of the neutral axis shall not be taken as effective except as a device to develop the full stress in the reinforcing steel embedded in.

16

≥10 φ   >0·7e < 2·0e

SPACING OF CONNECTING ANCHORS WHEN EMPLOYED ALONE

$H' \leq 2·5h_{st}$
$e < 2·5T$

CONCRETE NOT SHOWN

ENDS BENT AND WELDED

CONCRETE NOT SHOWN

ENDS WELDED WITHOUT A BEND

CONCRETE NOT SHOWN

ENDS FORGED FLAT

7A   Typical Bond Type Connectors

IS : 3935 - 1966

17

18

CONCRETE NOT SHOWN   CONCRETE NOT SHOWN
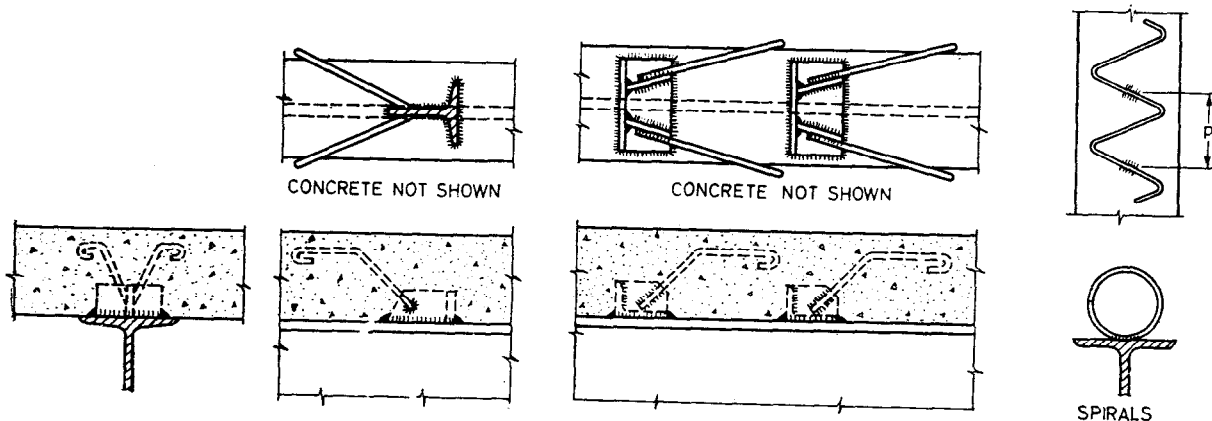
SPIRALS

7B Typical Composite Dowel and Anchor
Connectors

7C Typical Spiral
Connector

FIG. 7   TYPICAL BOND OR ANCHORAGE CONNECTORS

6.5.5 *Shear Resistance of Connectors* — Shear resistance values of any connector devices may be calculated by a rational method after duly taking into account the stress conditions, the permissible bearing pressure of concrete, the permissible bond stress in concrete, the structural properties in the steel used for the connectors and the strength of the weld. The design requirements for different types of shear connectors are given in **6.5.6** to **6.5.9**.

6.5.6 *Rigid Connectors* — The safe shear resistance capacity of a rigid connector is given by the equation:

$$Q = Fb \ Ab$$

where

$Fb =$ the permissible bearing pressure on concrete found by the expression:

$0.25 \ \sigma_{cu} \sqrt[3]{\dfrac{A}{Ab}}$, this value being limited to $0.6 \ \sigma_{cu}$

$A =$ the area to which the bearing force is transmitted, that is $a' \ b' \ c' \ d'$, being equal to the product of width of the top flange of steel unit at surface of contact and the depth of concrete slab including the haunch (*see* Fig. 8).

$Ab =$ the bearing area of the connector, that is area of the transmitting face of the connector, say $a \ b \ c \ d$ (*see* Fig. 8).

6.5.6.1 The spacing and size of the rigid connectors shall satisfy the following requirements:

a) The bearing pressure on the face of the connector should not exceed the permissible value Q.

b) The longitudinal shear stress along the shearing surface between two successive connectors should not be greater than two and a half times the permissible shear stress for concrete. This condition shall be deemed to be satisfied if $2.5 \ bq = S_h$.

c) The projected area along a slope of 1 to 5 from one rigid connector on to another should be at least three times the area of the face of the connector (*see* Fig. 9).

6.5.6.2 The following precautions are necessary with rigid connectors:

a) Angular or wedge shaped placing of the connectors will tend to split the concrete slab and shall, therefore, be prohibited.

b) The area of the bearing face of the connector shall not be less than one-fifth of the area to which the bearing force is transmitted.

c) As far as possible, rigid connectors shall be associated with anchors (*see* Fig. 4B and 4C) so that shear is resisted partly by bond of the concrete and partly by the bearing pressure of the concrete against the face of the rigid connectors.
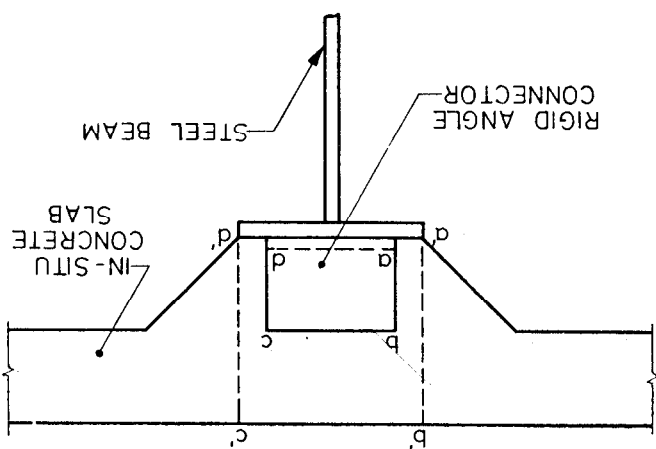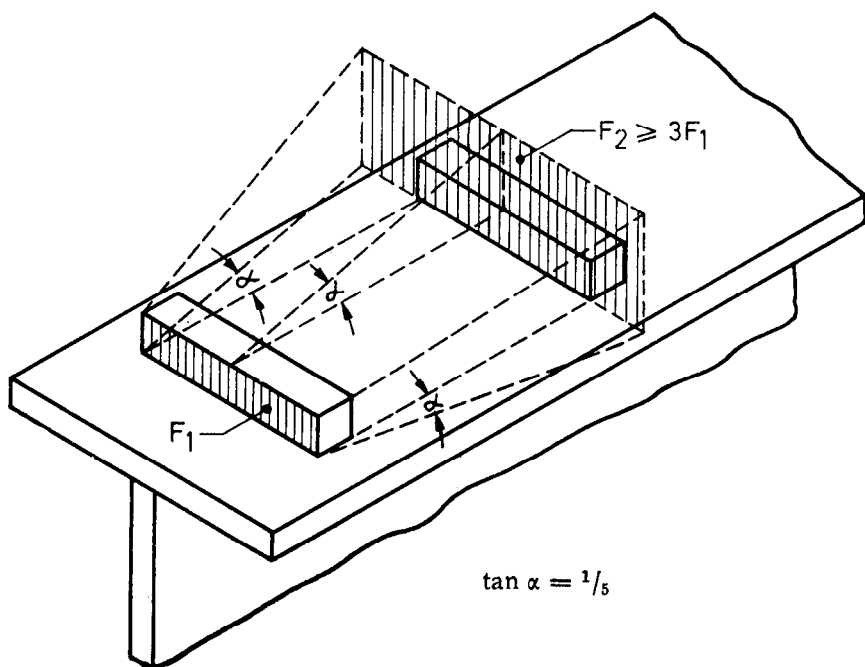
19

FIG. 8

$$\tan \alpha = {}^1/_5$$

FIG. 9 RULE FOR DETERMINING THE MINIMUM SPACING OF RIGID CONNECTORS

6.5.7 *Anchor Connector* — Anchor connectors are either used alone or are used in conjunction with rigid connectors. The safe shear resistance of an anchor connector is given by the following equation:

$$Q = K \, \sigma_{st} \, A_t$$

where

A_t = cross-sectional area of the anchor bar, and

K = coefficient having following values:

Value of K

Anchors with bond length of not less than 40 times the diameter of the bar including the hook in the compression zone of the concrete	1·0
Looped anchors with diameter of loop greater than 15 times the diameter of bar	1·0
Looped anchor usually used in combination with rigid connectors with diameter of loop less than 15 times the diameter of the bar	0·7
Hooked anchors usually used in combination with rigid connectors where the ends of the straight anchors are hooked but the bond length in the compression zone of the concrete is less than 40 times the diameter of the bar	0·5

The above equation for shear resistance of the anchor bar is independent of the angle of inclination of the bar. But anchors may generally be either vertical or inclined at about 45°.

6.5.7.1 Spacing of anchors when used alone shall not be less than 0·7 times the depth of the slab and shall not be greater than two times the depth of slab.

6.5.7.2 Spacing of anchors when associated with rigid connectors shall not be greater than two and a half times the depth of slab. The minimum spacing of anchors associated with rigid connectors shall be governed by the design conditions of rigid connectors.

6.5.7.3 The anchors may be welded to the beam or the ends bent over and well placed completely around. The anchors shall be brought up to the top surface of the flange, then bent over and ends hooked. The bond length should be adequate in accordance with the provisions of IS : 456-1964* with further provision that the portion from the upper bend to the hook is at least ten times the diameter of the bar.

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

6.5.8 *Flexible Connectors*

6.5.8.1 *Welded stud connector* — The safe shear resistance or welded connectors (*see* Fig. 5) with minimum stud head diameter of $d + 12$ mm and stud head height of 12 mm, and of steel with minimum ultimate strength of 4 600 kg/cm², yield point of 3 500 kg/cm² and an elongation of 20 percent is given by the following equation:

a) For a ratio of H/d less than 4·2:

$$Q = 4\cdot8\ H\ d\ \sqrt{\sigma_{cu}}\ \text{kg}$$

b) For a ratio of H/d equal to or greater than 4·2:

$$Q = 19\cdot6\ d^2\ \sqrt{\sigma_{cu}}\ \text{kg}$$

6.5.8.2 *Channel flexible connector* — For channel connectors made of steel with minimum ultimate strength of 4 200 to 5 000 kg/cm², yield point of 2 300 kg/cm² and an elongation of 21 percent, the safe shear resistance is given by the equation (*see* Fig. 6):

$$Q = 10\cdot7\ (\ h + 0\cdot5\ t\ )\ L\ \sqrt{\sigma_{cu}}\ \text{kg}$$

NOTE — Flange shall be oriented against the direction of horizontal shear, that is, towards the centre, in case of simply supported beams.

6.5.8.3 *Spiral connectors* (*see* Fig. 7C) — For spiral connectors, the shear resistance shall be given by the equation:

$$Q = 315\ d\ \sqrt[4]{\sigma_{cu}}\ \text{kg}$$

where

Q = the safe shear resistance in kg of one pitch of a spiral bar, and

d = the diameter of the round bar used in spiral connectors in cm.

The diameter of the spiral bars shall preferably be between 12 and 20 mm, smaller diameter bars may be used but care shall be exercised in welding as the welding heat is likely to impair the ductility of small bars. In all composite beams the spirals shall extend at least half way in the slab. The ratio of the pitch of the spiral to the diameter shall be between 0·5 and 4·0. The developed length of the spiral per pitch shall not be less than 20 times the diameter of the bar. From fabrication consideration, the spiral pitch shall be within the limits of 100 mm and 400 mm.

6.5.9 *Spacing of Connectors* — The aggregate capacity of all connectors located at a transverse section of a beam shall be equal to the horizontal shear divided by the pitch. Thus the required pitch or spacing parallel to

the beam axis of the connectors may be determined by the equation:

$$P = \frac{NQ}{S_h}$$

where

P = spacing or pitch of connectors in the direction of the axis, and

N = number of connectors at one transverse section of beam.

6.5.10 *End Shear Connectors* — At each end of a simply supported girder in composite construction in steel and concrete, an end connector shall be provided to counteract the effects of temperature, shrinkage and creep in addition to the external shear forces. The shear resistance of such an end connector shall have the following values unless otherwise determined by rational analysis:

$$\text{Shear resistance of each end connector} = \frac{M\,m_s}{I}$$

where

M = maximum bending moment on the composite beam due to additional loads operating after the composite action has been effected.

6.5.10.1 The end shear connector shall consist of mechanical device having adequate shear resistance as calculated in **6.5.10**. Such mechanical device may consist of cut piece of rolled steel with the bearing face directed towards the centre of the beam or it may consist of anchor bars spreading out into the slab away from the centre of the beam (*see* Fig. 10 and 11).

7. PREFABRICATED PRESTRESSED OR REINFORCED CONCRETE AND *IN-SITU* CONCRETE COMPOSITE MEMBERS

7.1 Composite structures in which the *in-situ* concrete is assumed to act integrally with the precast beam shall be inter-connected to transfer the horizontal shear along the contact surfaces and to prevent the vertical separation of these units. Transfer of shear shall be by shear bars, castellations and by bond. The units shall further be tied together by the extension of web reinforcement.

7.1.1 *Ties* — Separation of the component elements in the direction perpendicular to the contact surface shall be prevented by ties adequately embedded on each side of the contact surface. The spacing of such ties shall not exceed four times the thickness of the slab or 60 cm whichever is less. The minimum cross-sectional area of the ties, in each metre of the span shall not be less than 0·15 percent of the contact area or 130 sq mm. All web reinforcement of the prefabricated unit shall be extended into the cast-*in-situ* concrete.
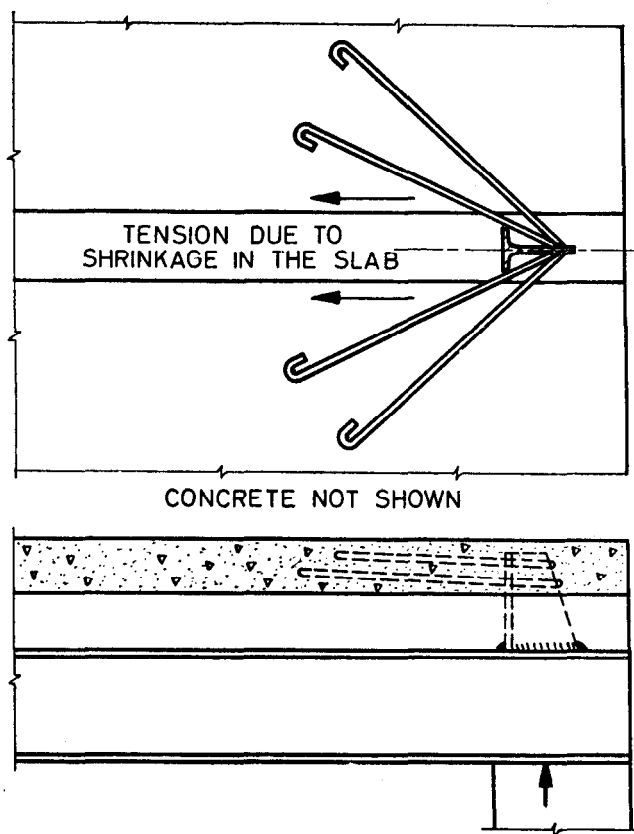
Fig. 10   Typical End Connector with Anchoring Rod

In the case of either dynamically or statically loaded structures where the horizontal shear at the inter-face at ultimate load is less than $\frac{\sigma_{cu}}{40}$ it is not necessary to provide vertical ties.

7.2 Bond Strength at the Inter-face — The bond strength at the inter-face shall be checked for ultimate load.   The inter-face shall always be made rough for effective bonding.

7.2.1 The ultimate values of the horizontal shear stress at the inter-face shall be calculated by using the formula given in **6.5.2**.   If the calculated shear stresses are more than the values given under no slip condition in Table 1 for strength of the *in-situ* concrete, it shall be taken that the slip
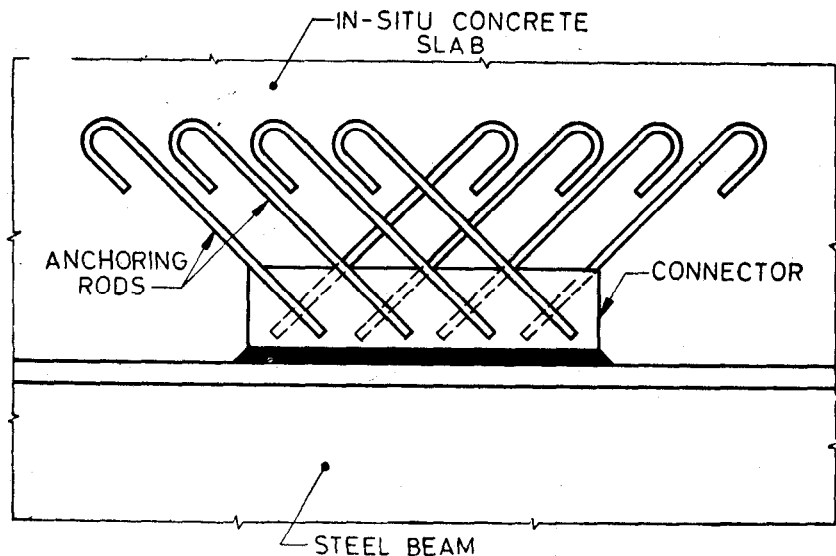
FIG. 11 ALTERNATIVE ARRANGEMENT OF END CONNECTORS, SHOWING ANCHORING RODS IN OPPOSITE DIRECTION

has occurred. The design shall then be made taking a frictional shear resistance of 10 kg/cm² and the balance stress to be resisted by steel shear connectors stressed to a maximum of 1 340 kg/cm². The inter-face shear shall not, however, exceed the value given under the maximum permissible shear stress in Table 1.

TABLE 1 PERMISSIBLE SHEAR STRESS IN THE INTER-FACE AT ULTIMATE LOAD

(All values in kg/cm².)

150 mm CUBE STRENGTH OF *IN-SITU* CONCRETE AT 28 DAYS	PERMISSIBLE SHEAR AT NO SLIP	PERMISSIBLE SHEAR AT SLIP	MAXIMUM PERMISSIBLE INTER-FACE SHEAR
(1)	(2)	(3)	(4)
150 200 250	12	10	14
300 350 400	14	10	20

7.3 Shear Bars — The shear bars at the ends of the girders to a length of one-half to three-fourth depth of the girder shall be spaced closer and designed to take full shear force under ultimate conditions.

7.4 Castellation — Castellations may be provided as a means of transferring horizontal shear. Whilst generally the rectangular type of castellation is recommended, it is important to ensure that whatever type of castellation is adopted, it has been successfully tried out. The castellations should be so designed that they are capable of resisting the horizontal shear in accordance with the requirements of IS : 456-1964*.

7.4.1 The depth of the castellation should not, however, be in any case less than 25 mm and the length of the castellation should be about four times the depth. The centre-to-centre spacing of the castellations should not be greater than the lever arm or 60 cm, whichever is less.

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