CONNECTION IN STEEL FRAMED STRUCTURES

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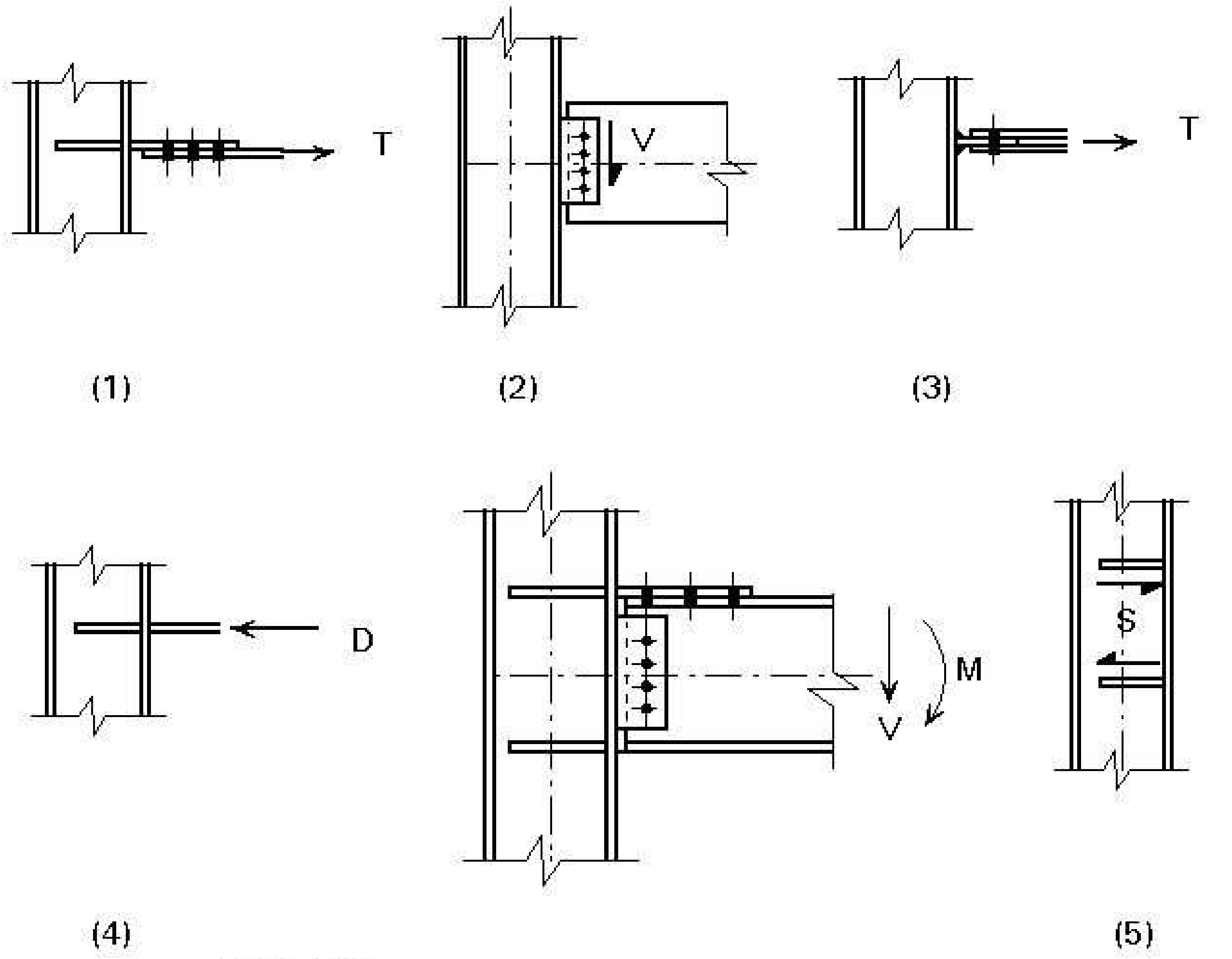
CONNECTIONS IN STEEL FRAME BUILDINGS

INTRODUCTION

❖ In current construction practice, steel members are joined by either bolting or welding.

❖This helps simplify shipping and makes erection faster.

❖Welding that may be required on a connection is preferably performed in the more-easily controlled environment of the fabrication shop. If a connection is bolted on one side and welded on the other, the welded side will usually be the shop connection and the bolted connection will be the field connection.



(1) Axial force
(2) Shear force
(3) Introduction of tensile force
(4) Introduction of compression force
(5) Shear panel

FIG. 1 BASIC FORCE TRANSFERS IN CONNECTION

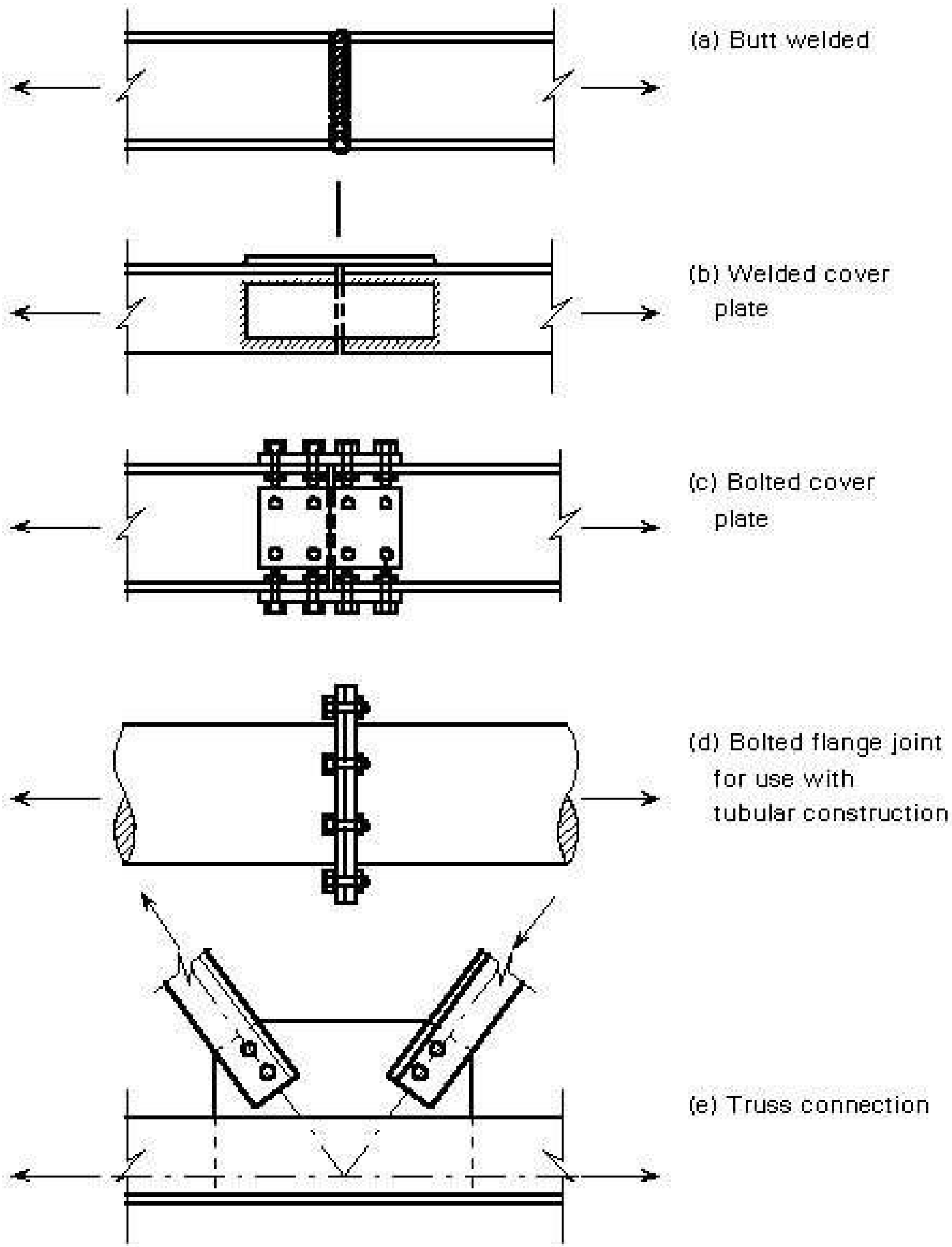


FIG. 2 EXAMPLE OF TRANSFER OF TENSILE OR COMPRESSIVE AXIAL MEMBER FORCE

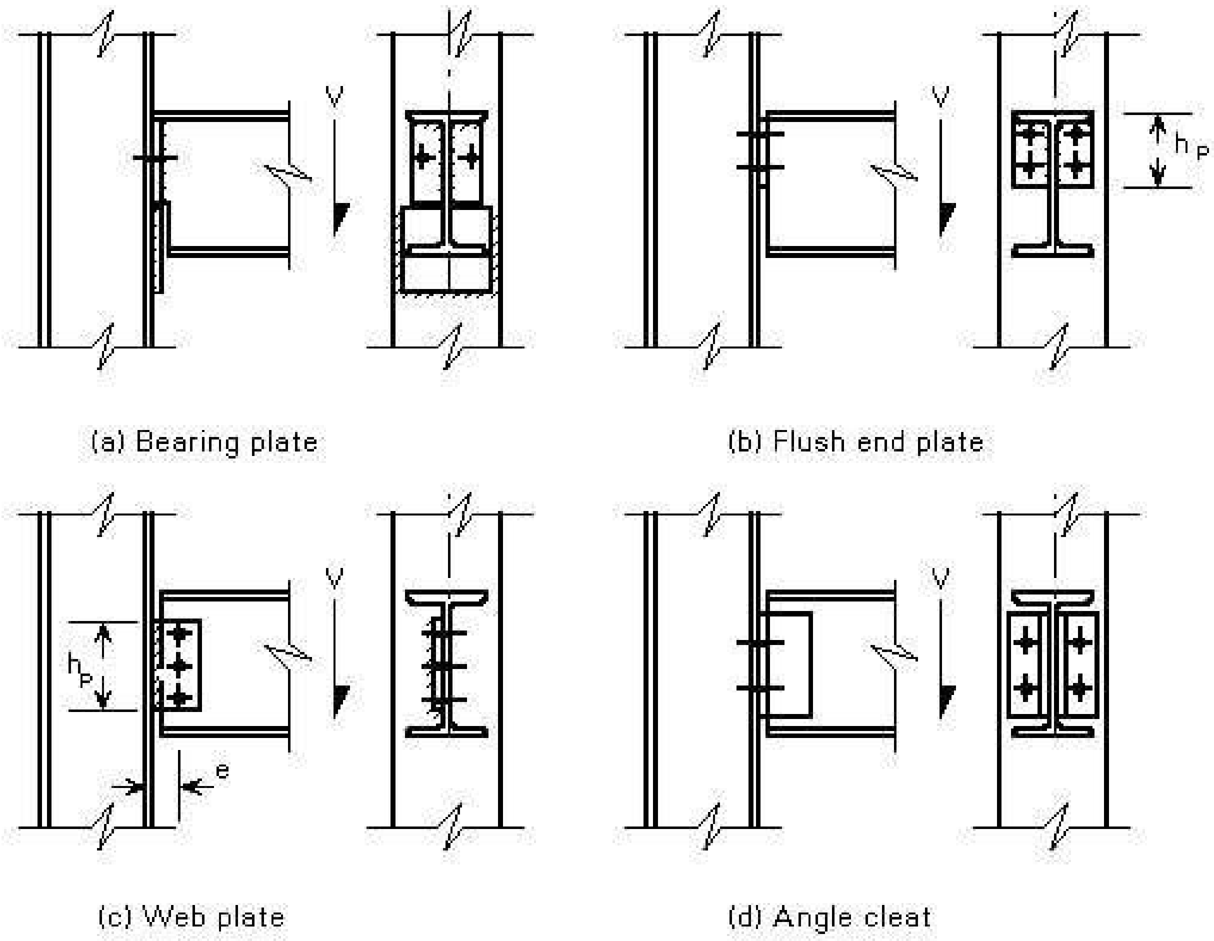


FIG. 3 EXAMPLE OF TRANSFER OF SHEAR FORCE

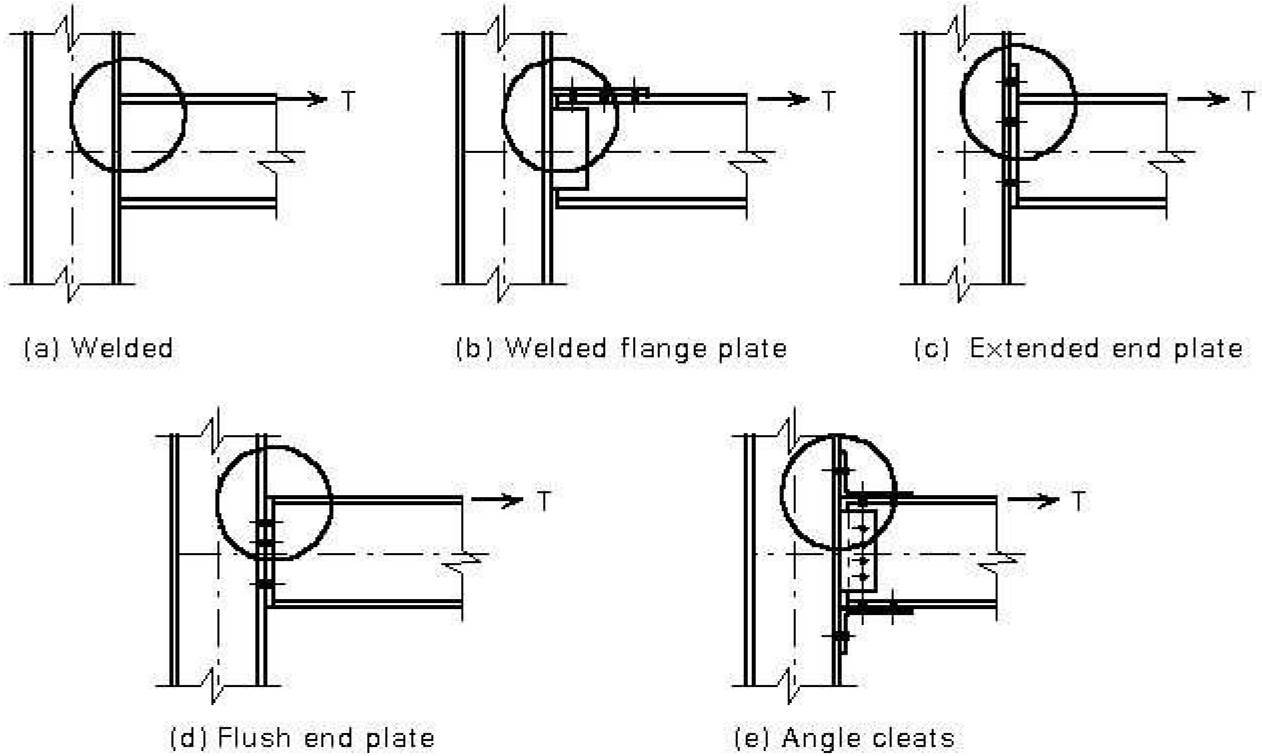


FIG. 4 EXAMPLE OF TRANSFER OF LOCAL TENSILE FORCE

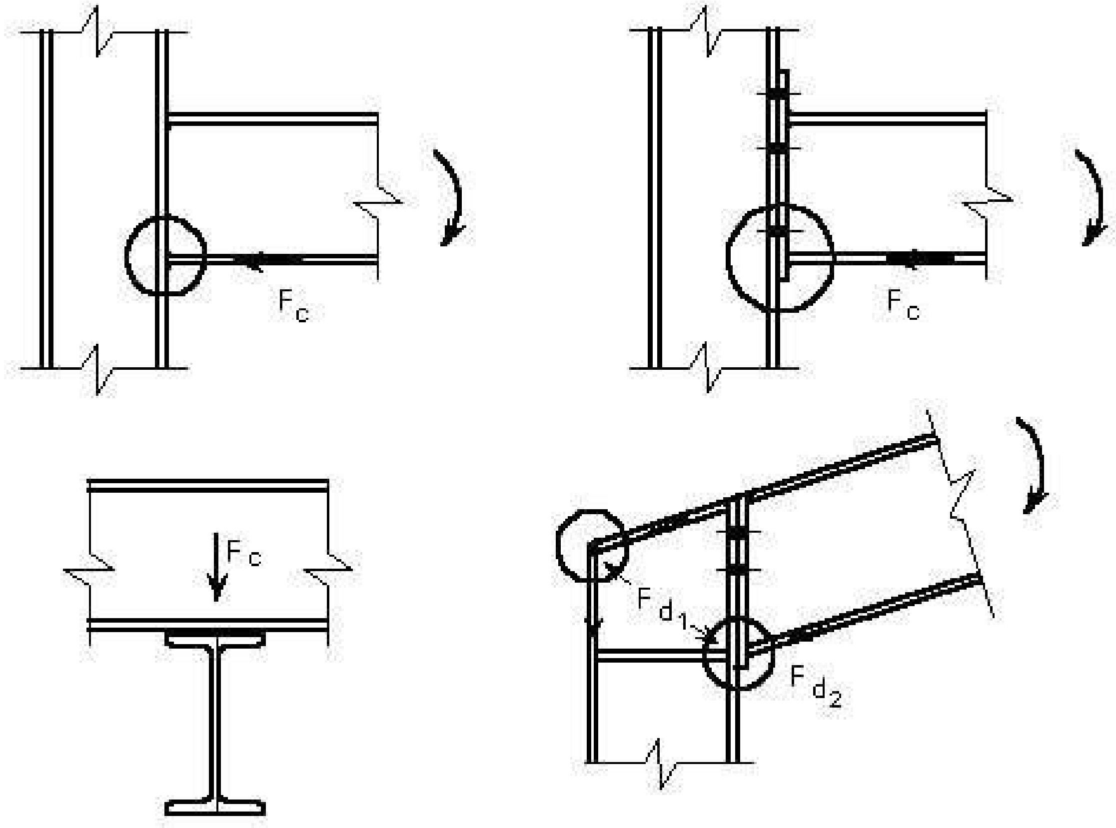


FIG. 5 EXAMPLE OF TRANSFER OF LOCAL COMPRESSIVE FORCE

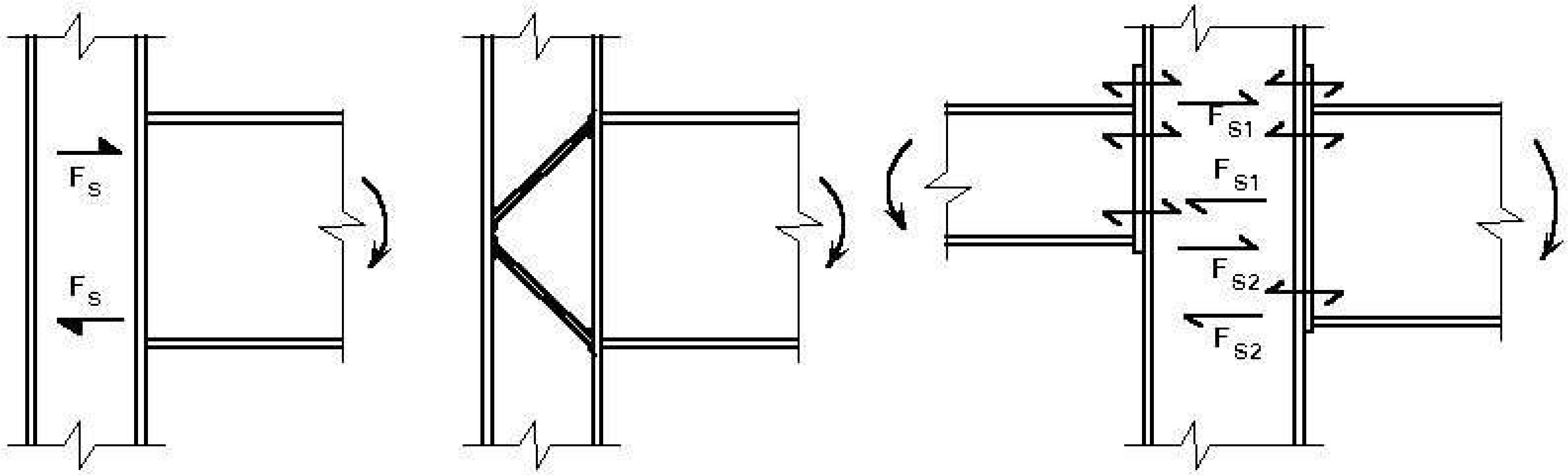


FIG. 6 EXAMPLE OF TRANSFER OF SHEAR FORCE THROUGH A SHEAR PANEL

•The principal structural requirement of a connection is that it be capable of safely transferring load from the supported members to the supporting member.

•The above requirement implies that three properties of the connection needs to be considered: strength, stiffness and deformation capacity.

•Beam-to-column connections can be classified by their stiffness as nominally pinned, semi-rigid or rigid. For their capability to transfer moments, they can be classified as nominally pinned, partial-strength and full-strength connections.

•The analysis of connections implies the assumption of a realistic internal distribution of forces that are in equilibrium with the external forces, where each element is capable of transferring the assumed force and the deformations are within the deformation capacity of the elements.

•In the analysis of connections, a number of basic load transfers can generally be identified.

BEAM-TO-BEAM CONNECTIONS

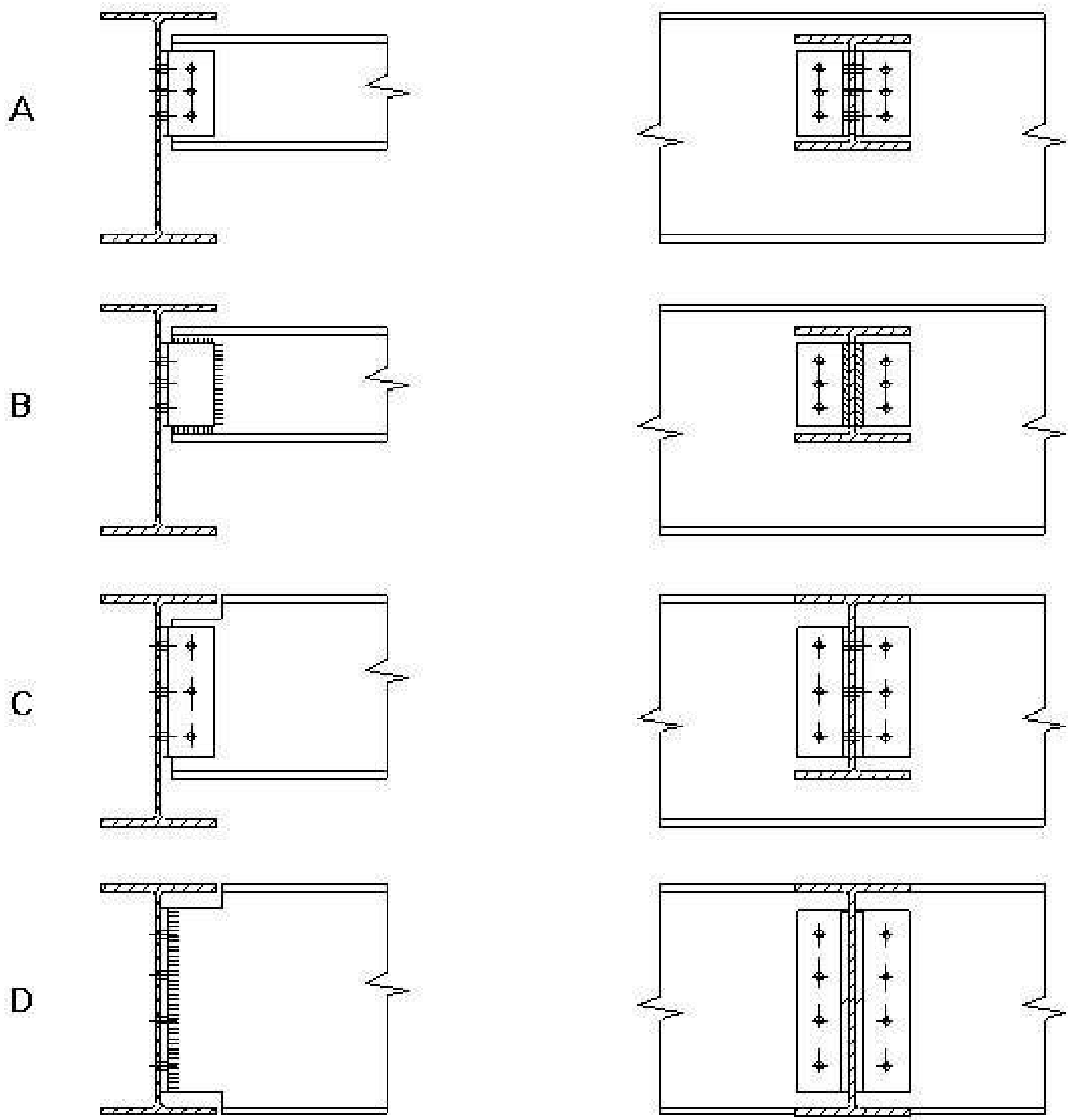


FIG. 7a BEAM TO BEAM CONNECTIONS

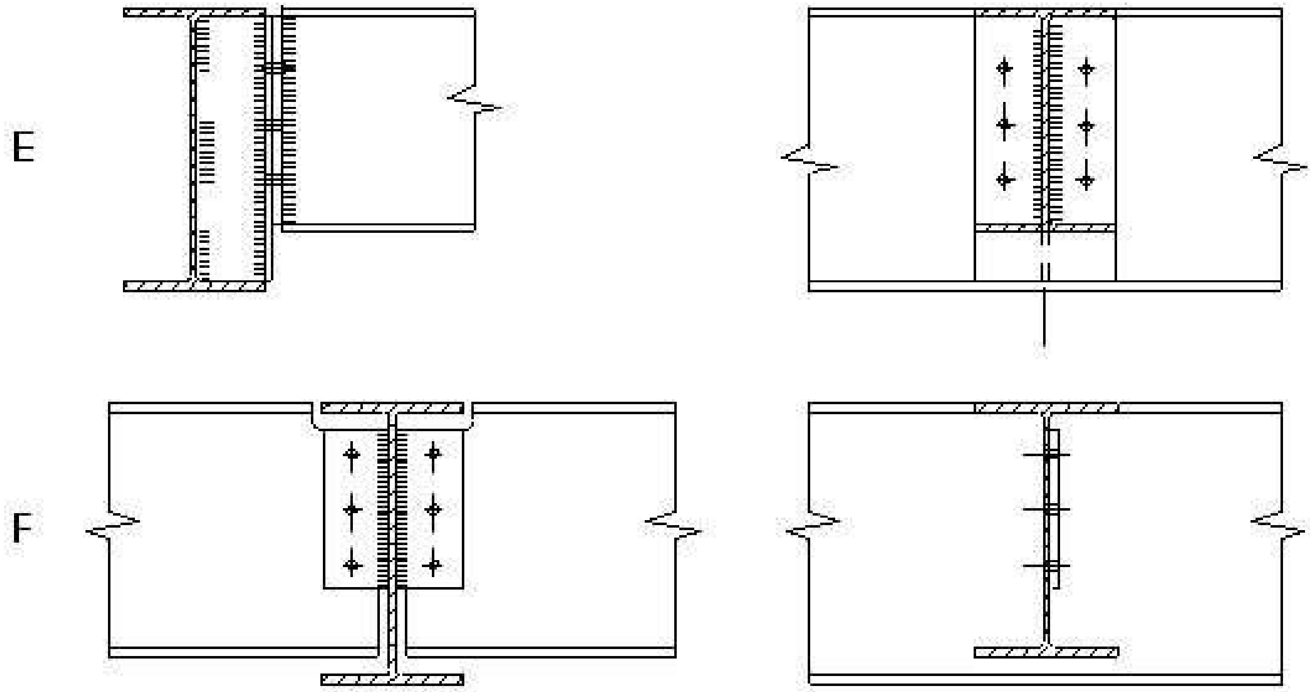


FIG. 7b BEAM TO BEAM CONNECTIONS

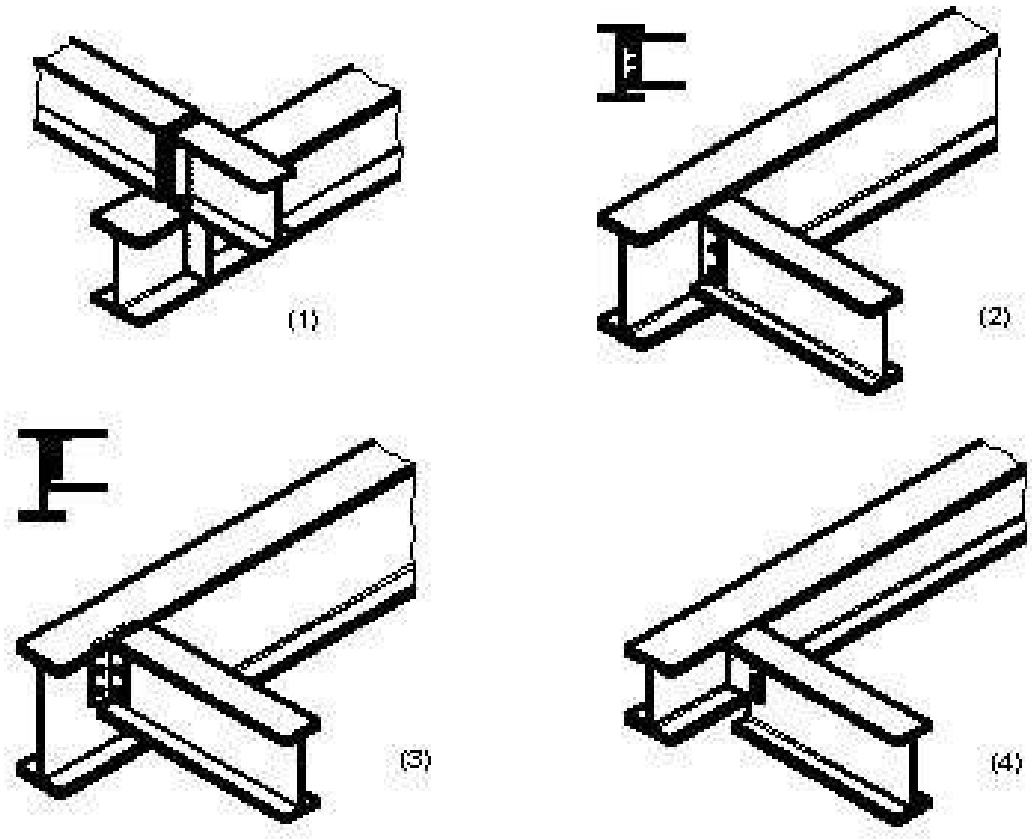


FIG. 7c BEAM TO BEAM CONNECTIONS

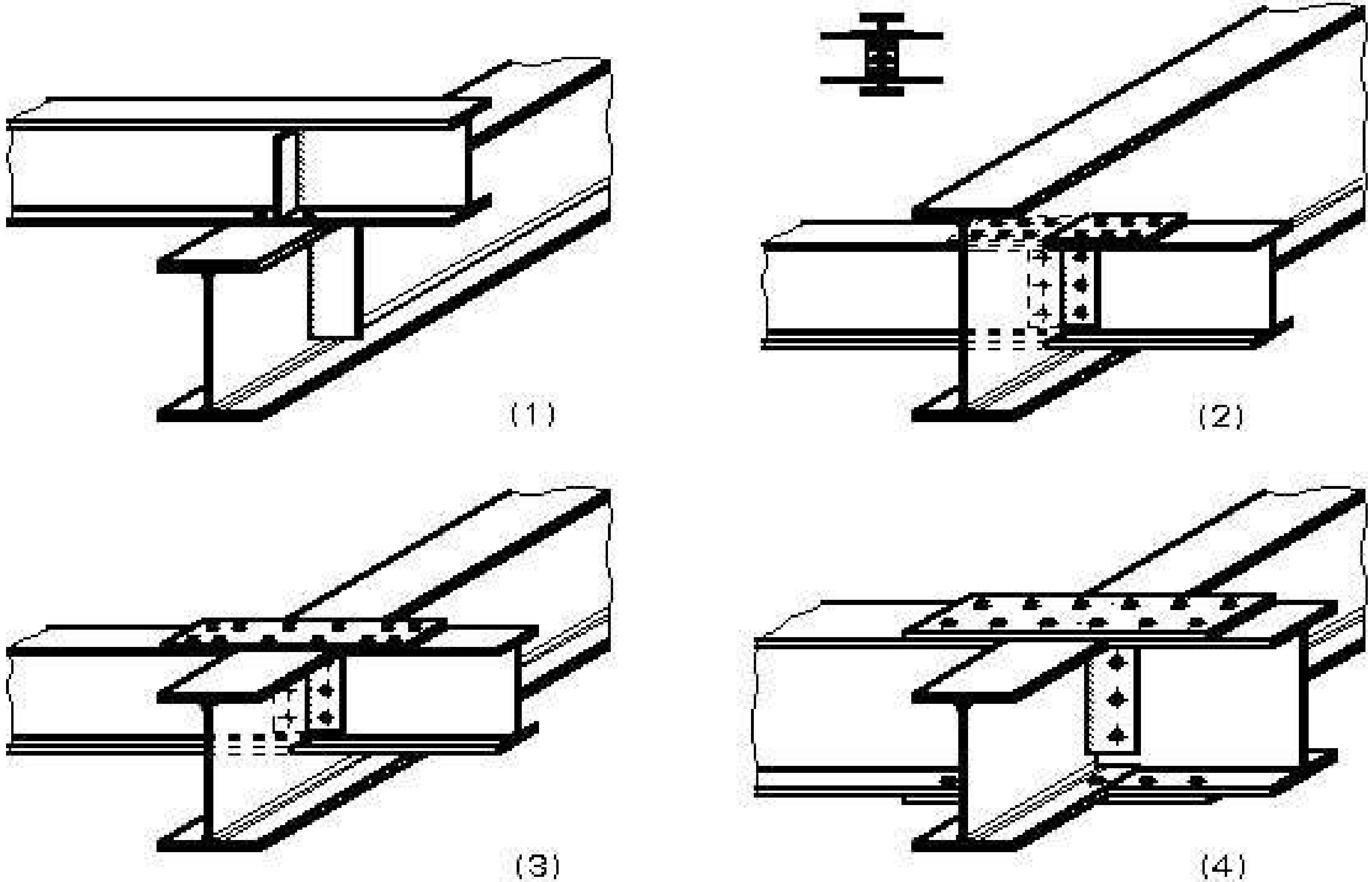


FIG. 7d BEAM TO BEAM CONNECTIONS

BEAM-TO-COLUMN CONNECTIONS

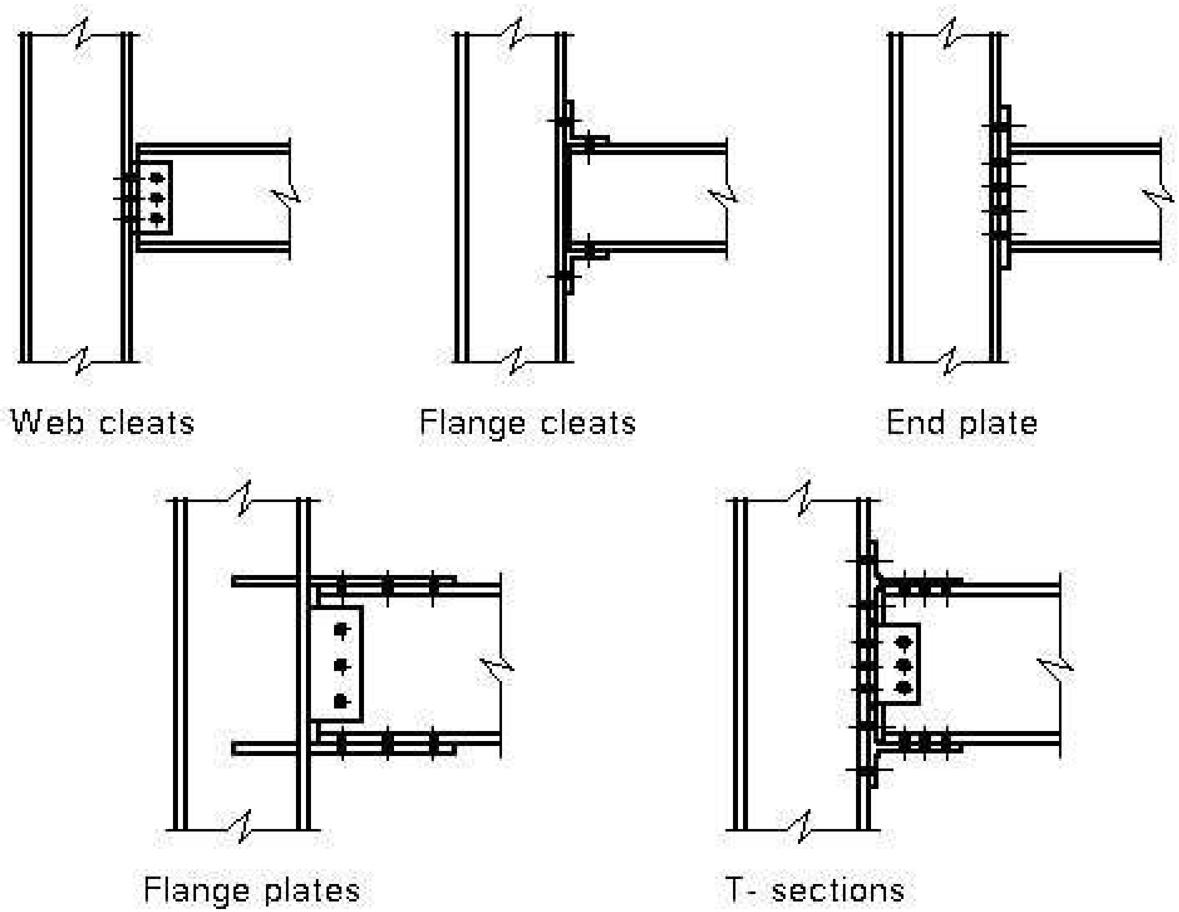


FIG. 8a BEAM TO COLUMN CONNECTIONS

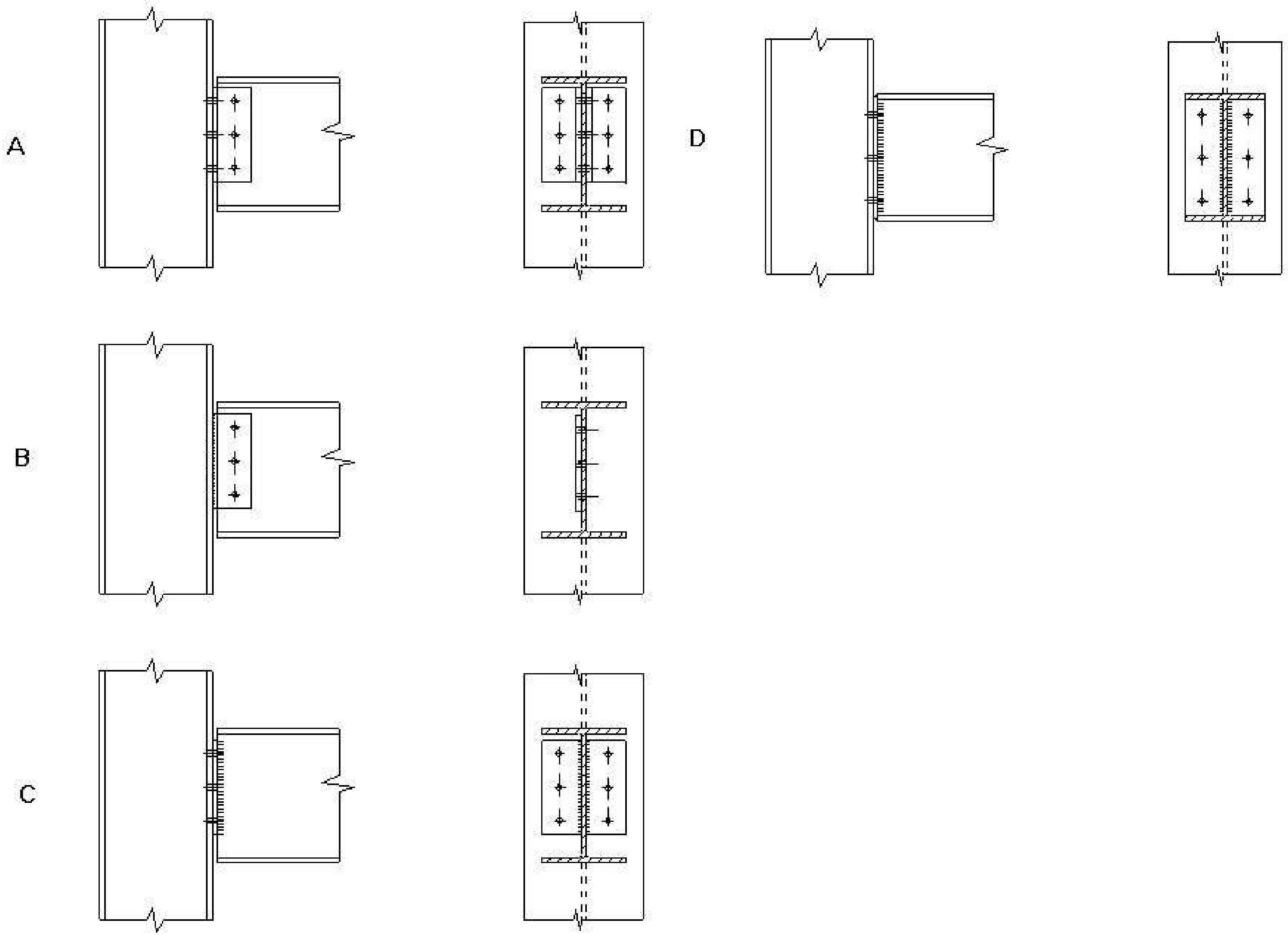


FIG. 8b BEAM TO COLUMN CONNECTIONS

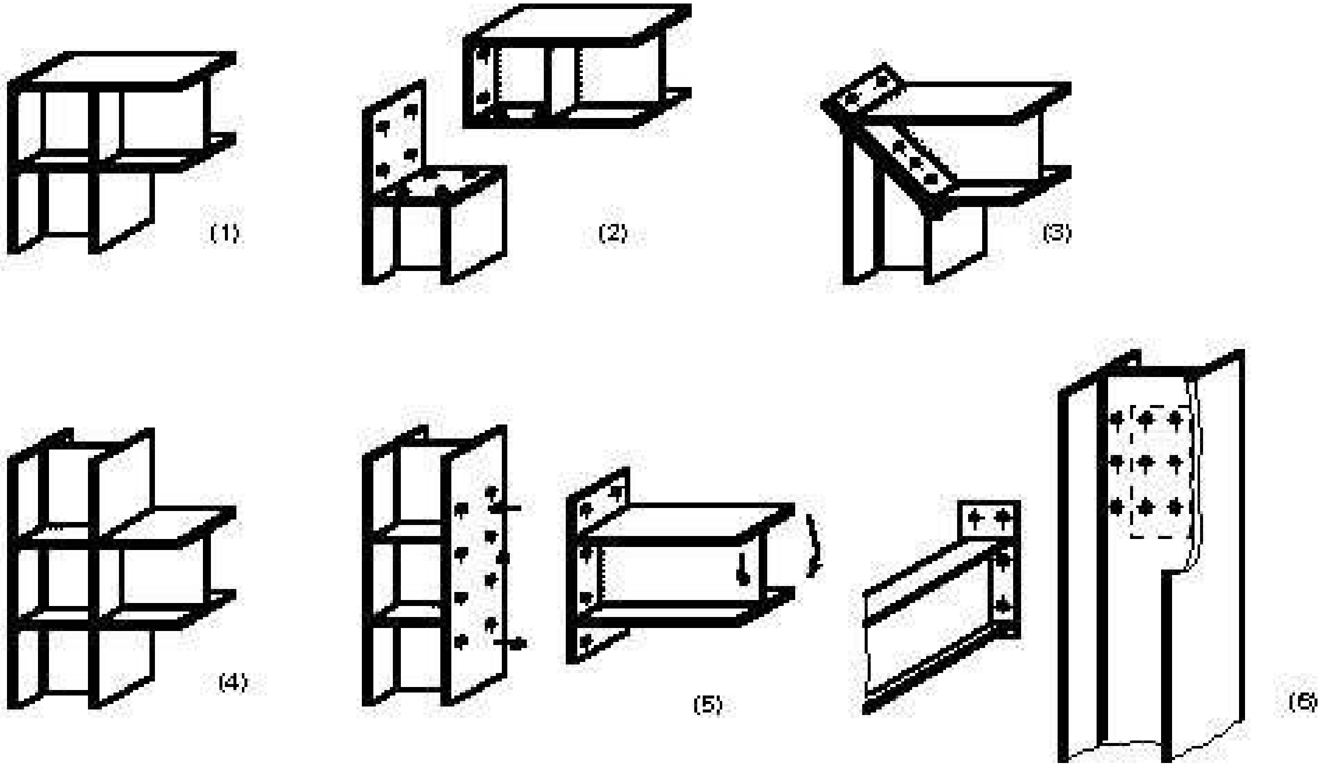


FIG. 8c BEAM TO COLUMN CONNECTIONS

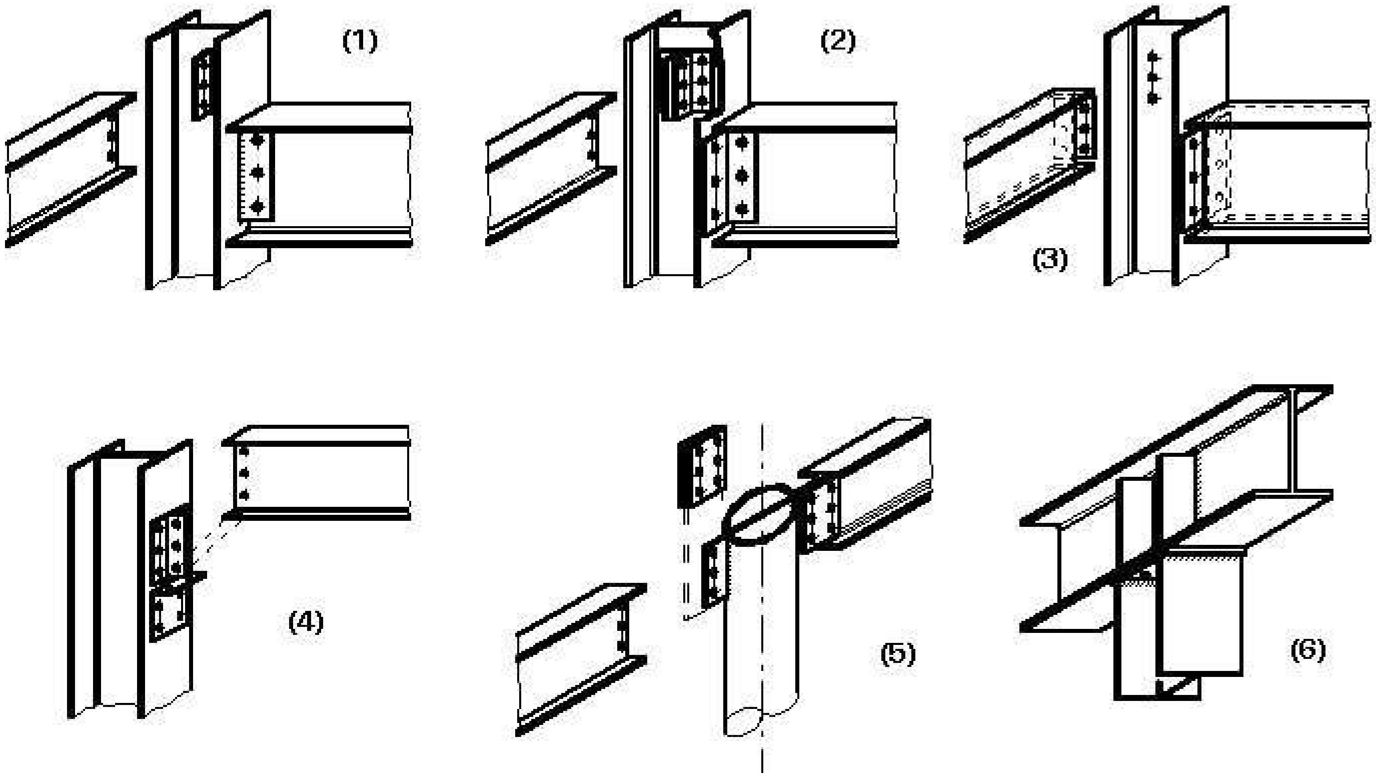


FIG. 8d BEAM TO COLUMN CONNECTIONS

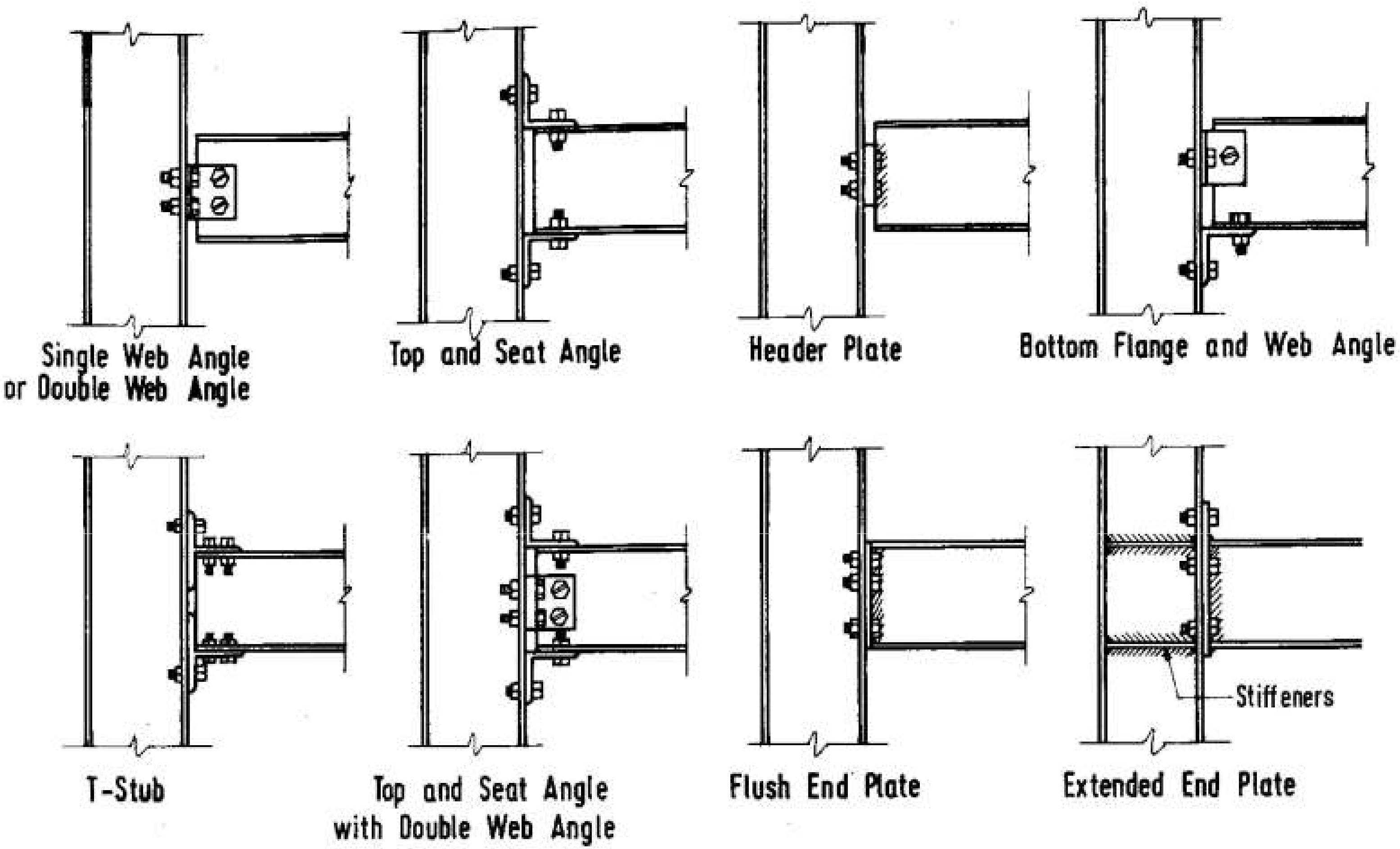


FIG. 8e BEAM TO COLUMN CONNECTIONS

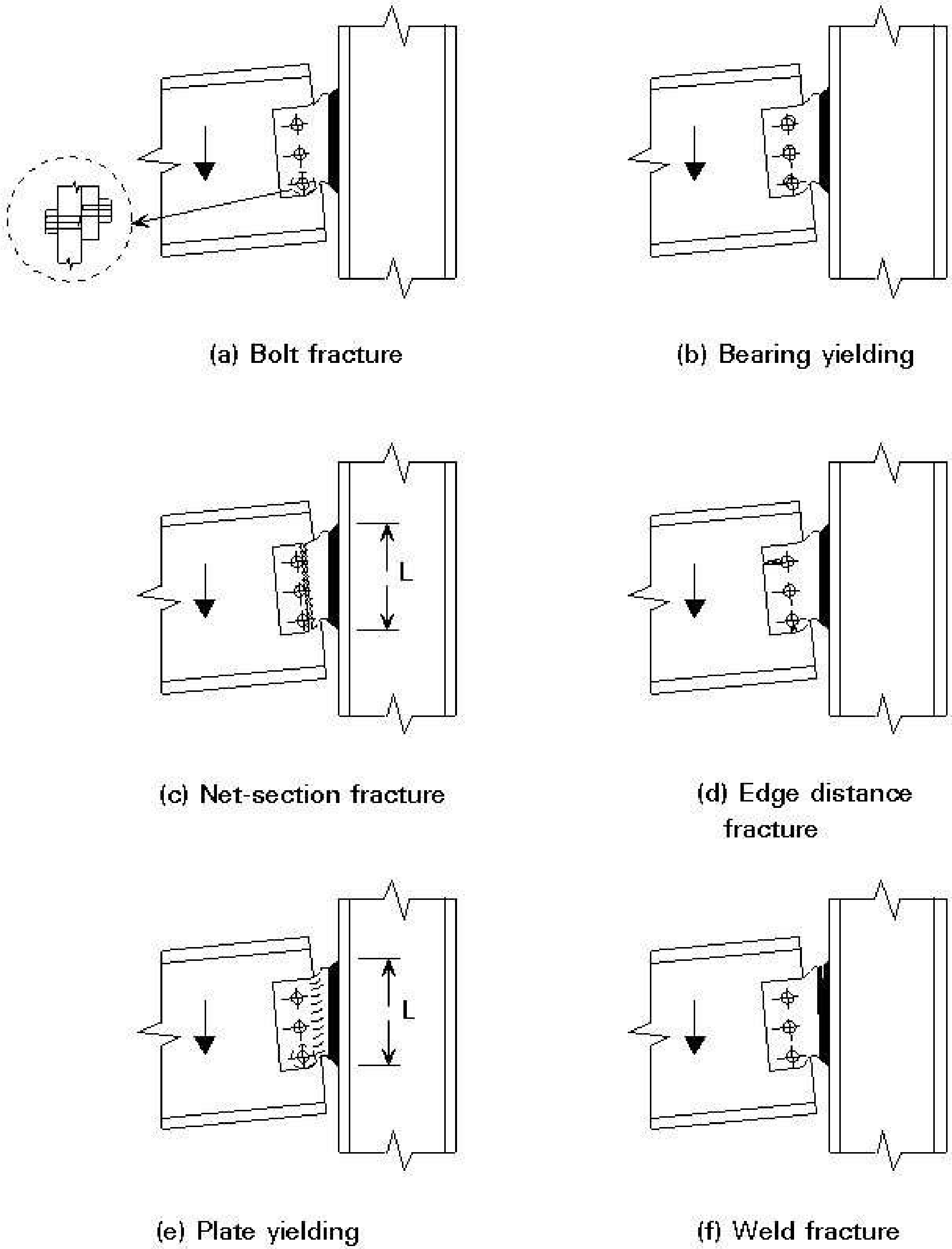


FIG. 9 MODE OF FAILURE FOR FIN PLATES

COLUMN SPLICES

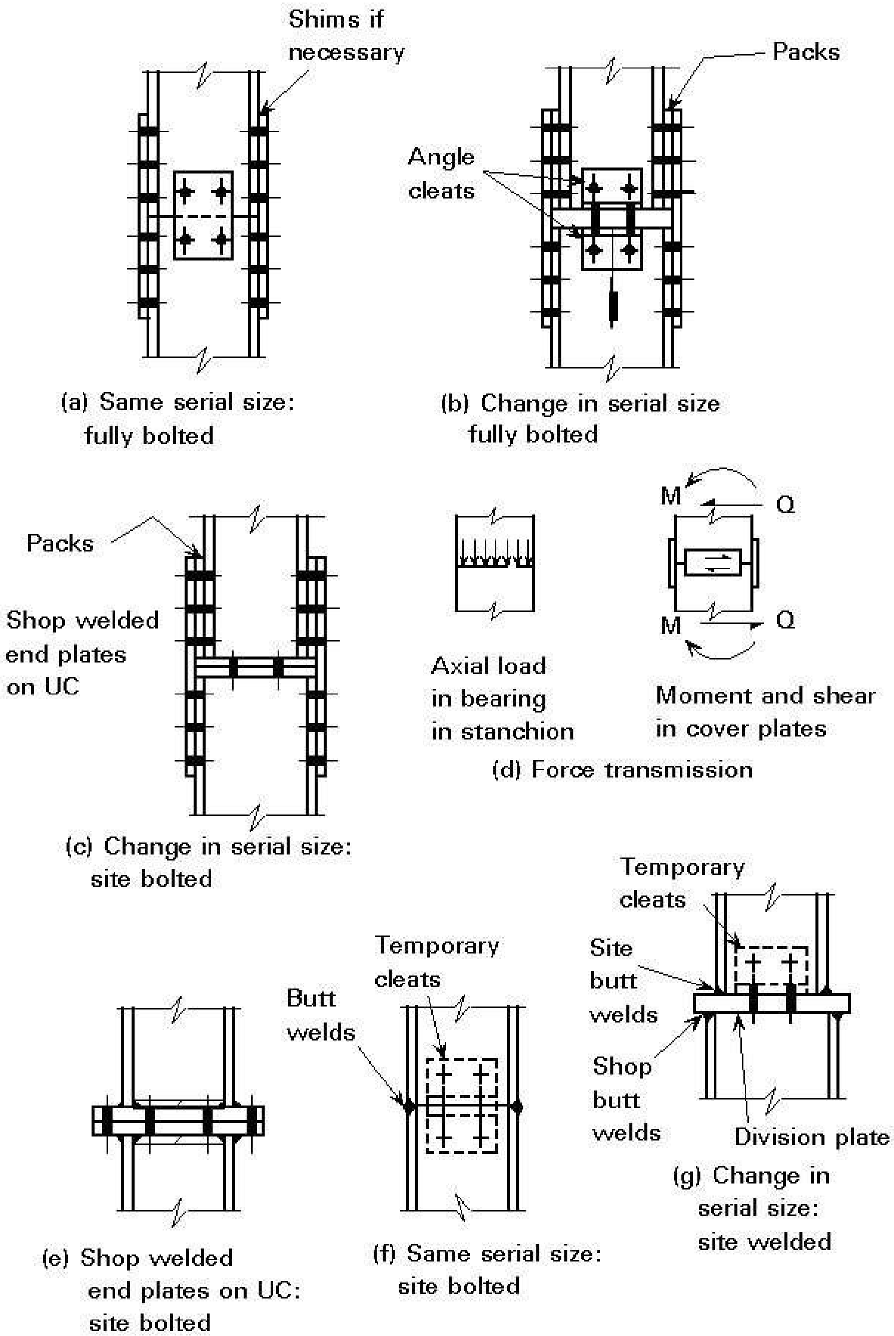


FIG. 10a COLUMN SPLICES

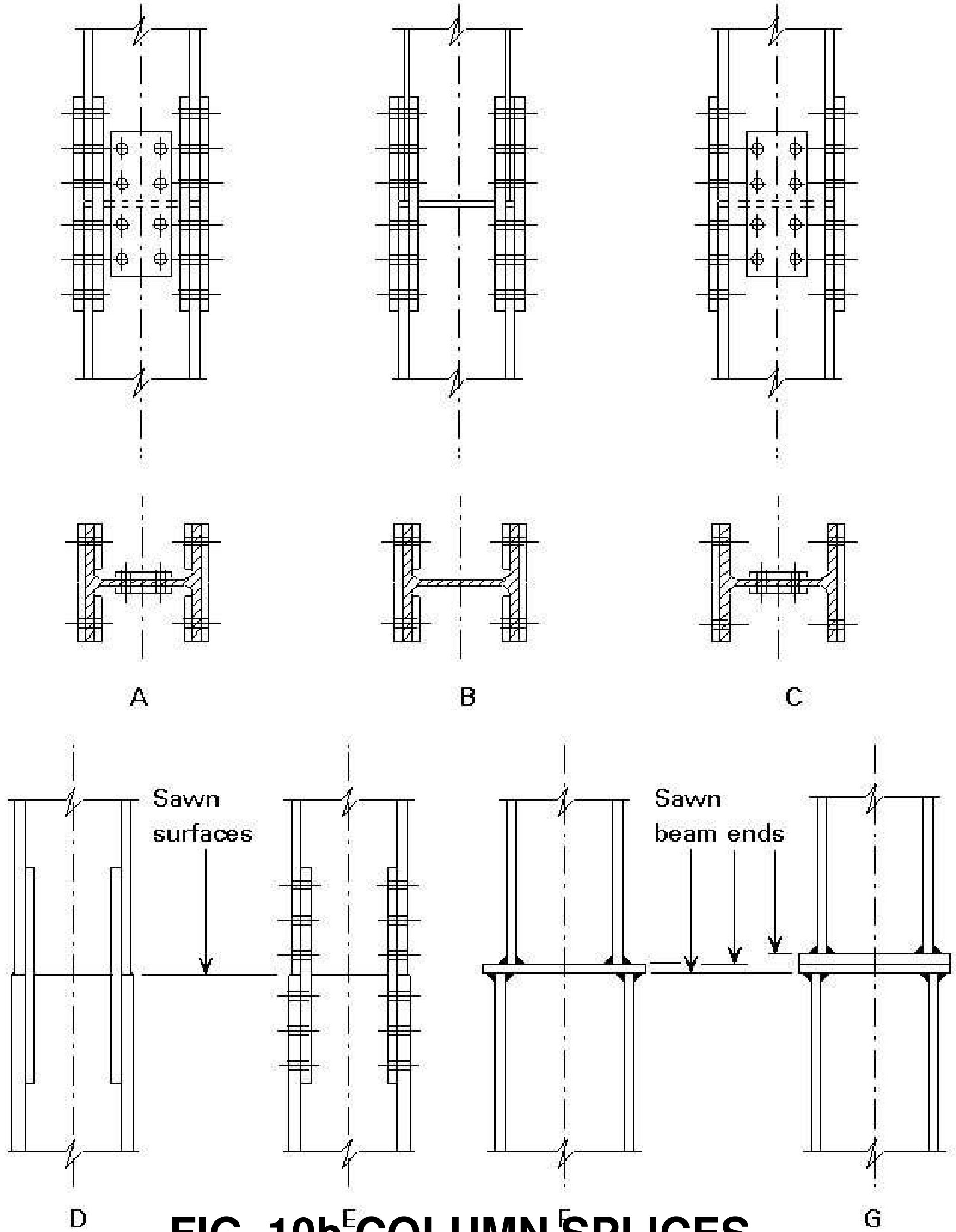


FIG. 10b COLUMN SPLICES

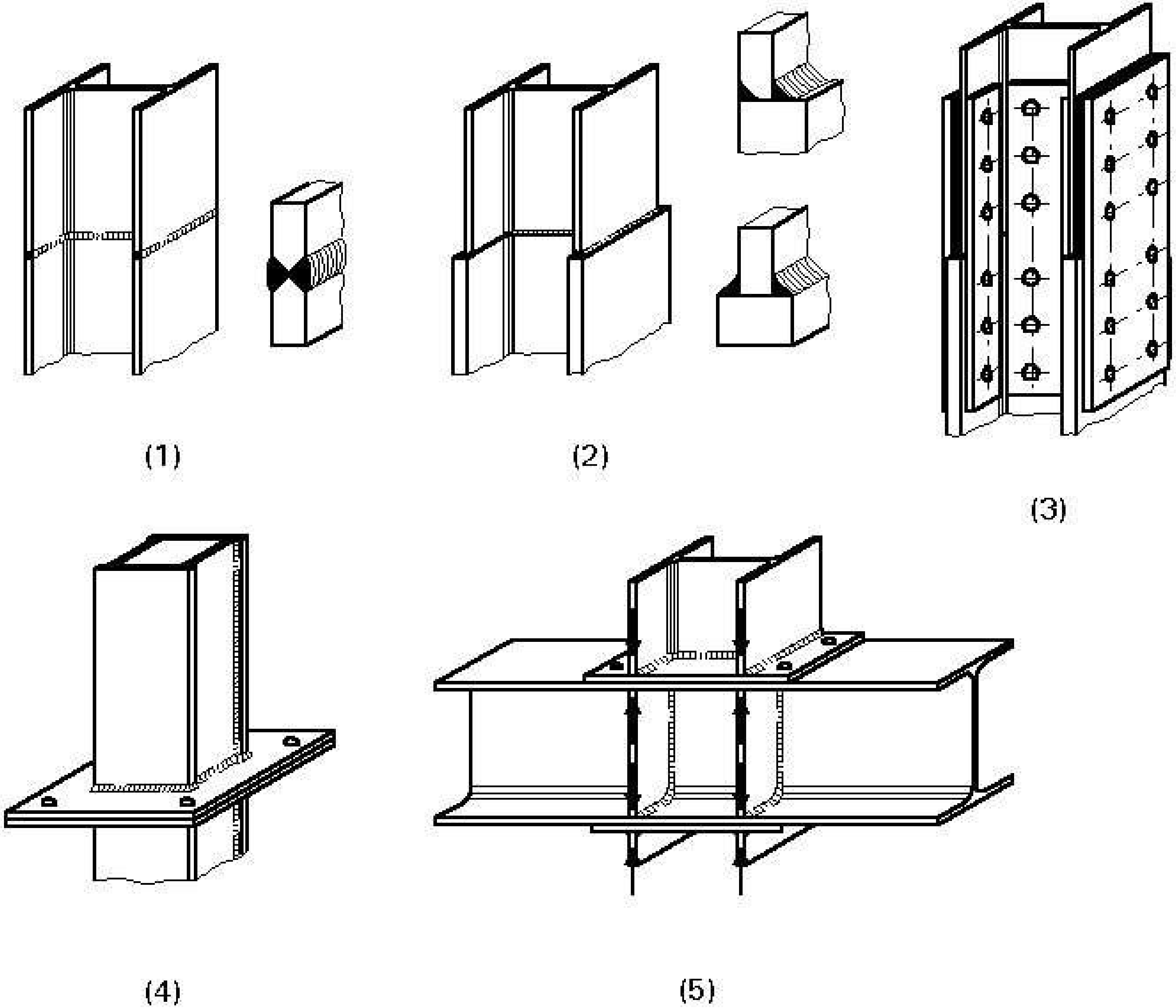


FIG. 10c COLUMN SPLICES

BRACING CONNECTIONS

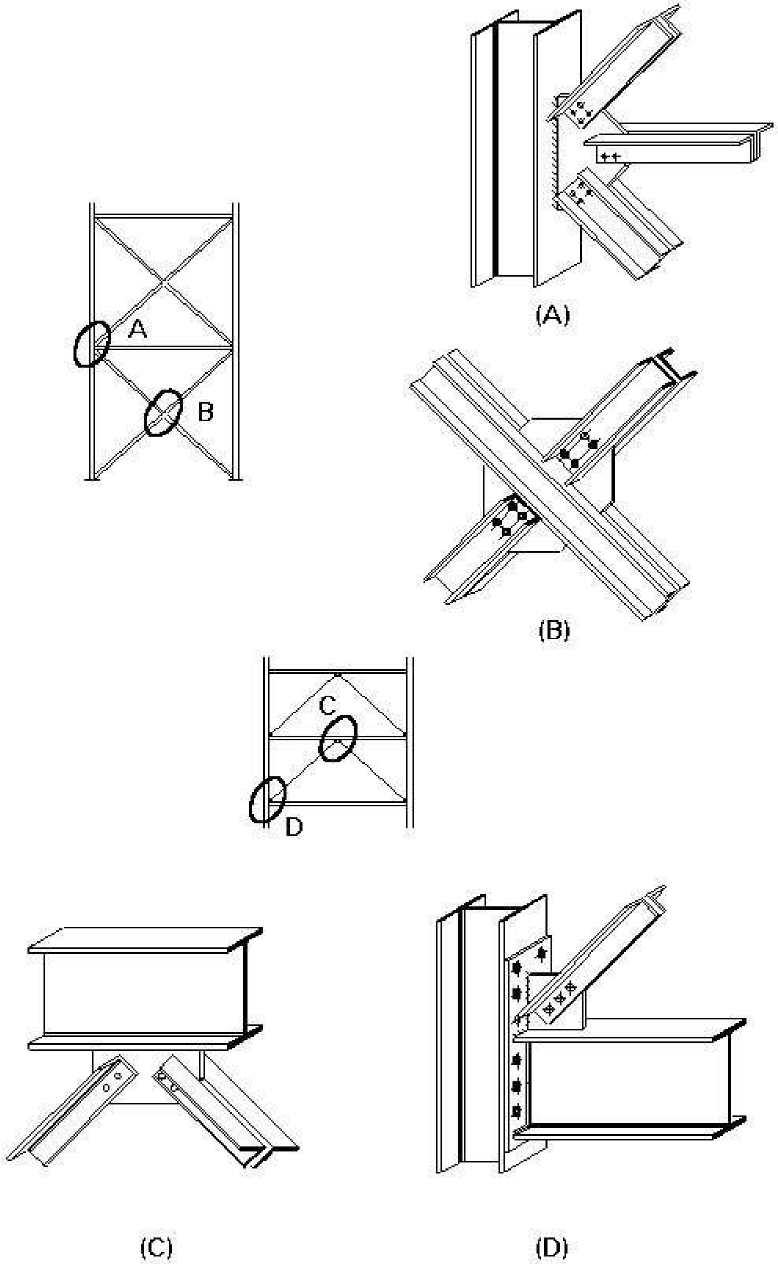


FIG. 11a BRACING CONNECTIONS

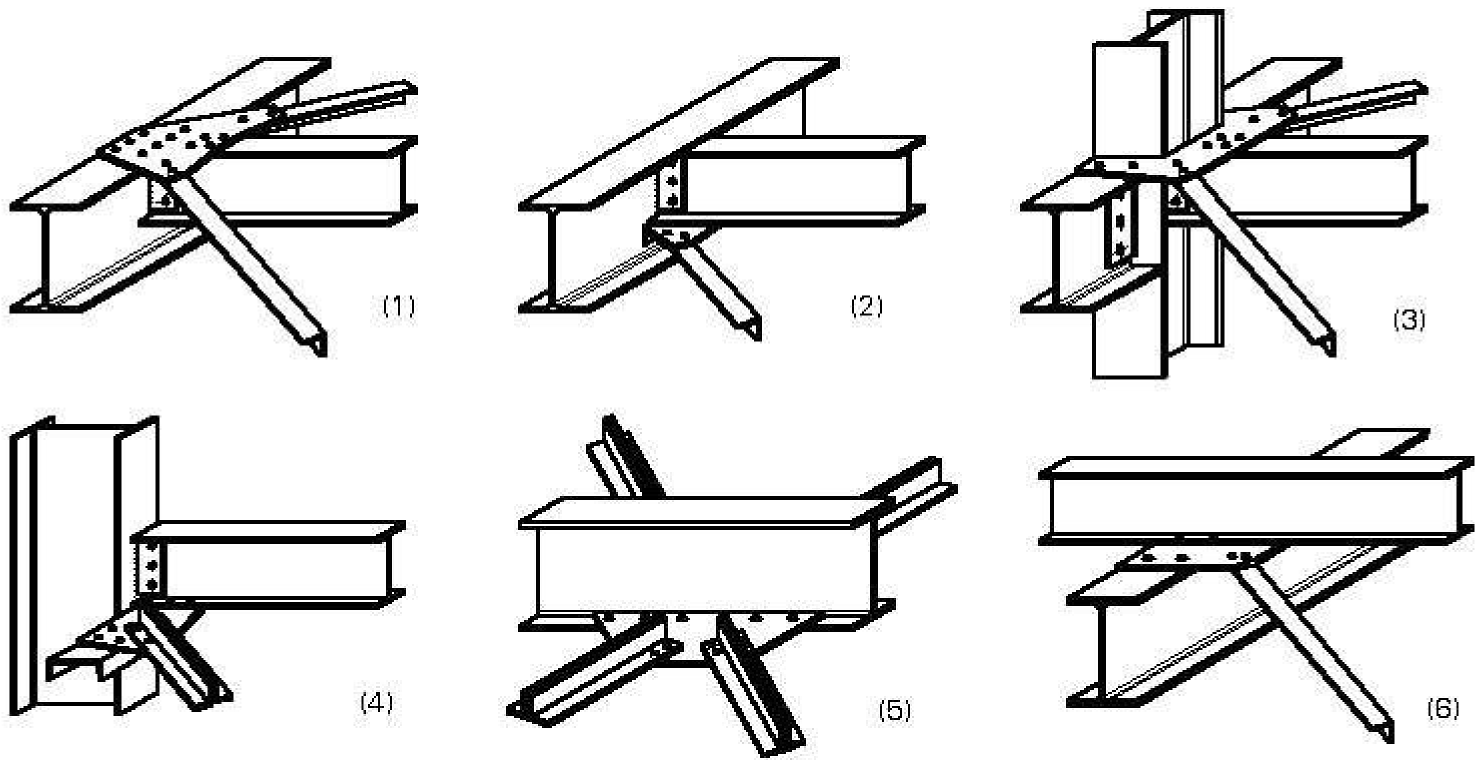


FIG. 11b HORIZONTAL BRACING CONNECTIONS

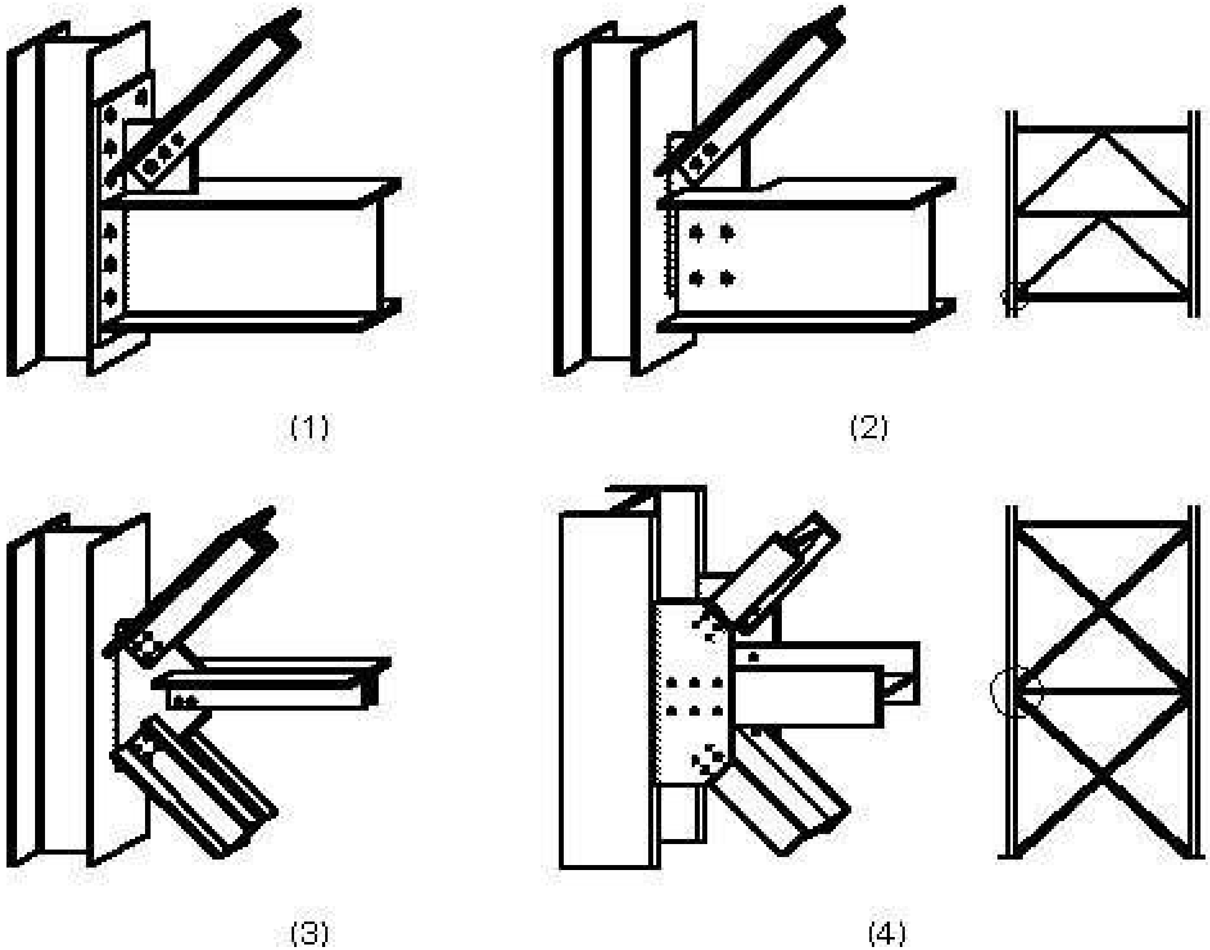


FIG. 11c VERTICAL BRACING CONNECTIONS

COLUMN BASES

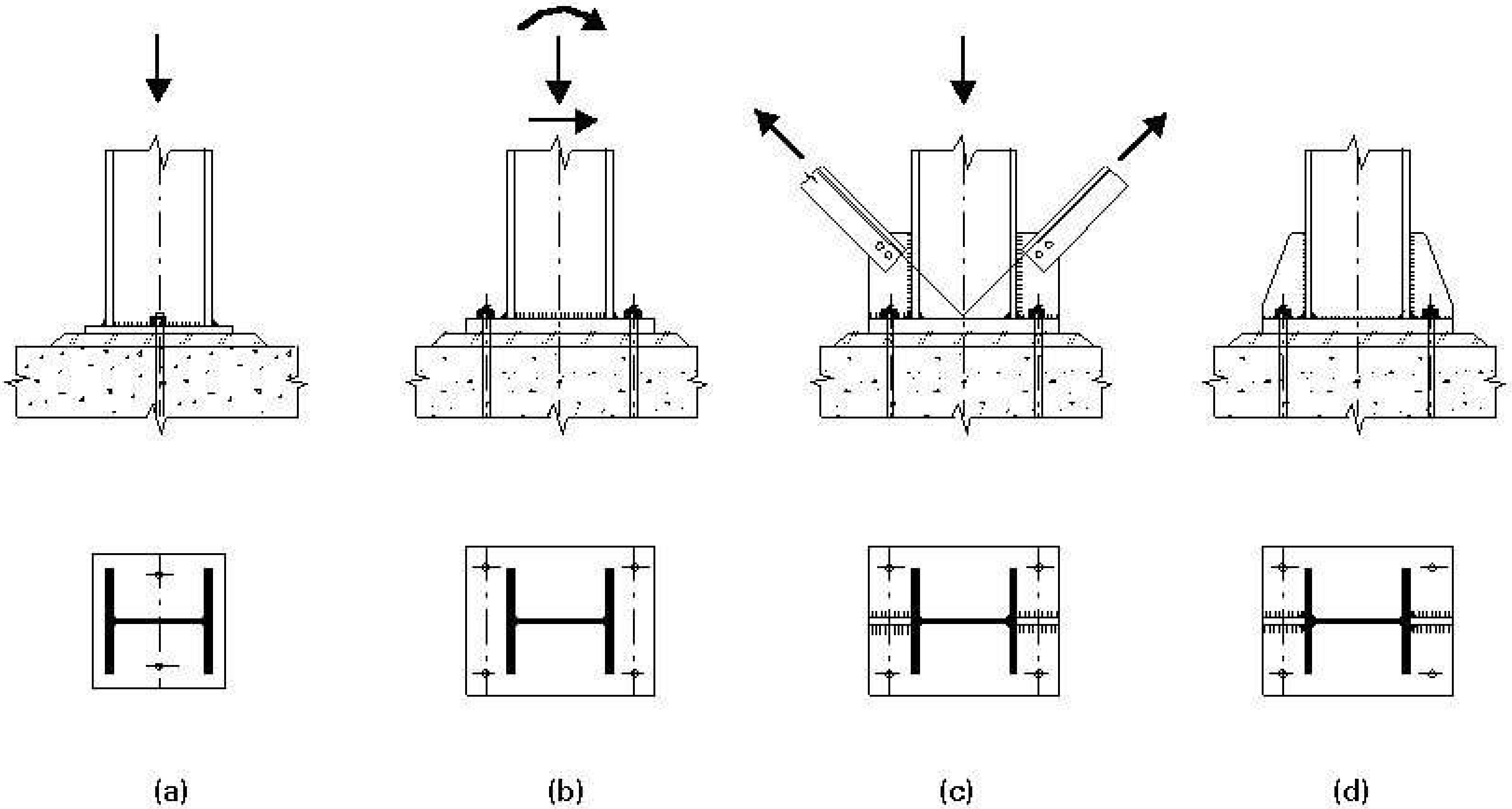


FIG. 12a COLUMN BASES

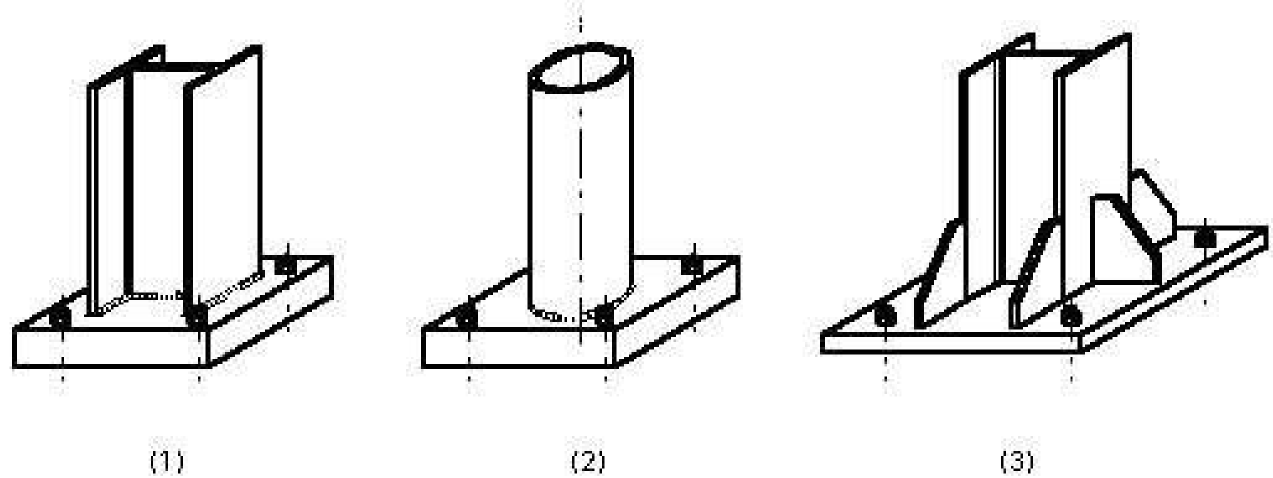


FIG. 12b COLUMN BASES

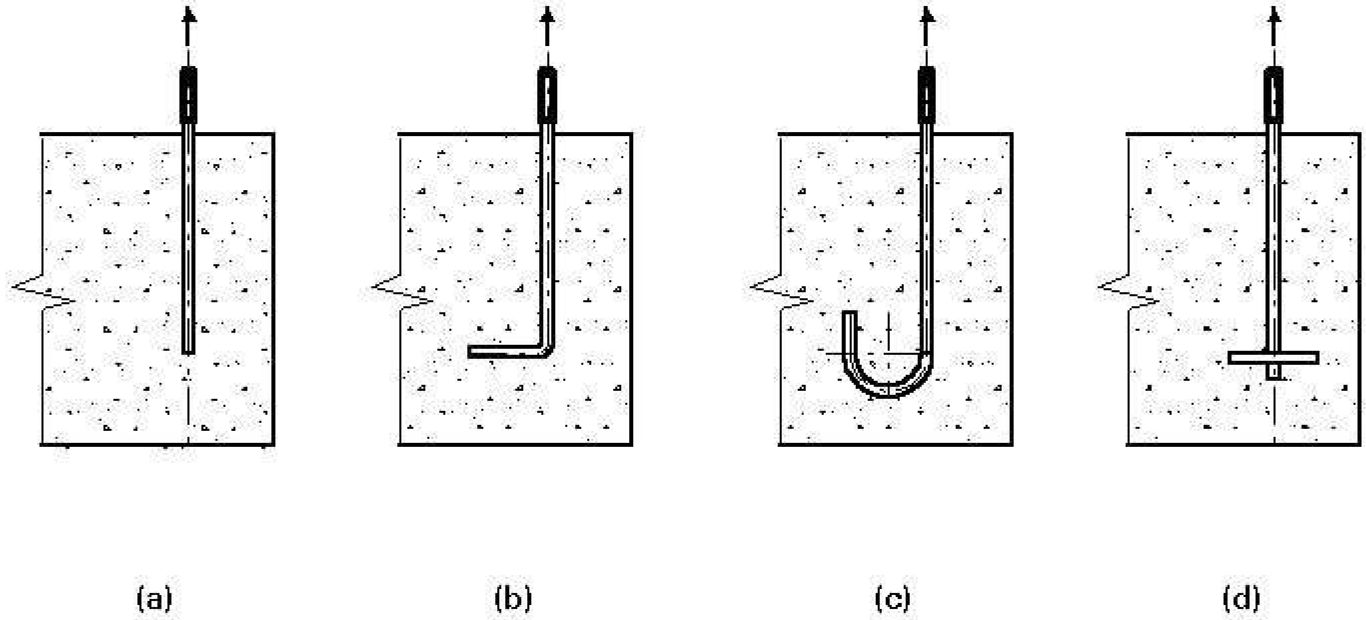


FIG. 12c ANCHORAGES OF HOLDING DOWN BOLTS

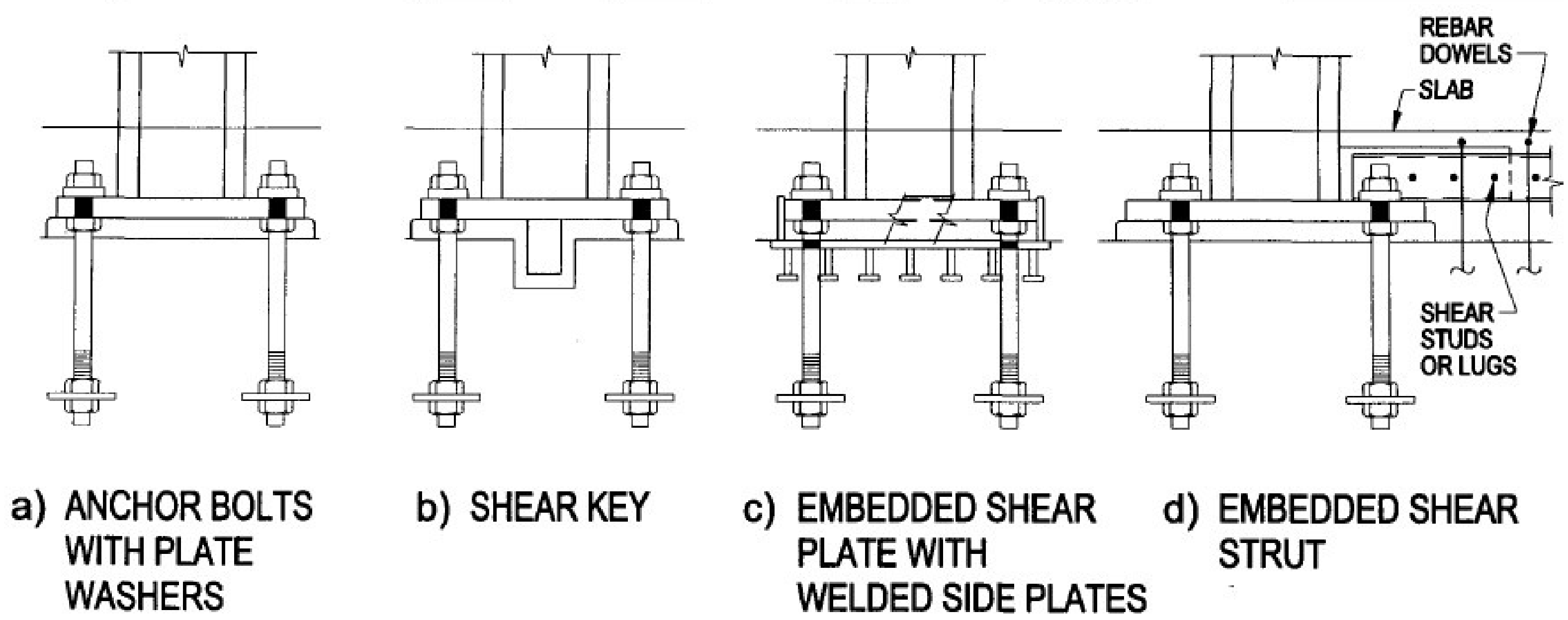
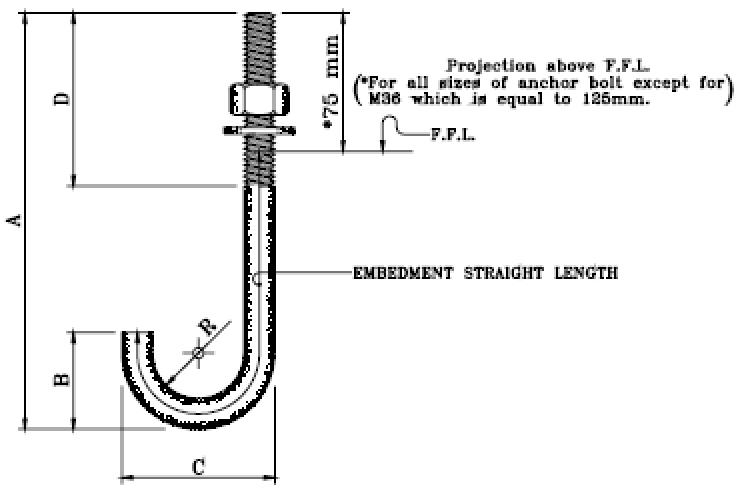


FIG. 12d ANCHORAGES OF HOLDING DOWN BOLTS



DIMENSIONAL PROPERTIES

BOLT		WEIGHT	A	B	C	D	RADIUS "R"	TOTAL STRAIGHT LENGTH	EMBEDMENT STRAIGHT LENGTH
NOMINAL DIAMETER	THREAD PITCH	(Kg)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
M16	2.00	0.80	400	90	80	100	24	511	436
M20	2.50	1.56	500	110	100	125	30	636	561
M24	3.00	2.73	600	140	128	125	40	775	700
M30	3.50	6.15	900	170	160	150	50	1114	1039
M36	4.00	10.04	1000	210	192	200	60	1263	1138

ALLOWABLE LOADS

BOLT NOMINAL DIAMETER	TENSION (kN)	SHEAR (kN)	PULL-OUT STRENGTH (kN)
M16	26.54	13.67	30.21
M20	41.47	21.36	40.55
M24	59.72	30.76	50.65
M30	93.31	48.07	75.15
M36	134.36	69.22	82.3

Moment Connections

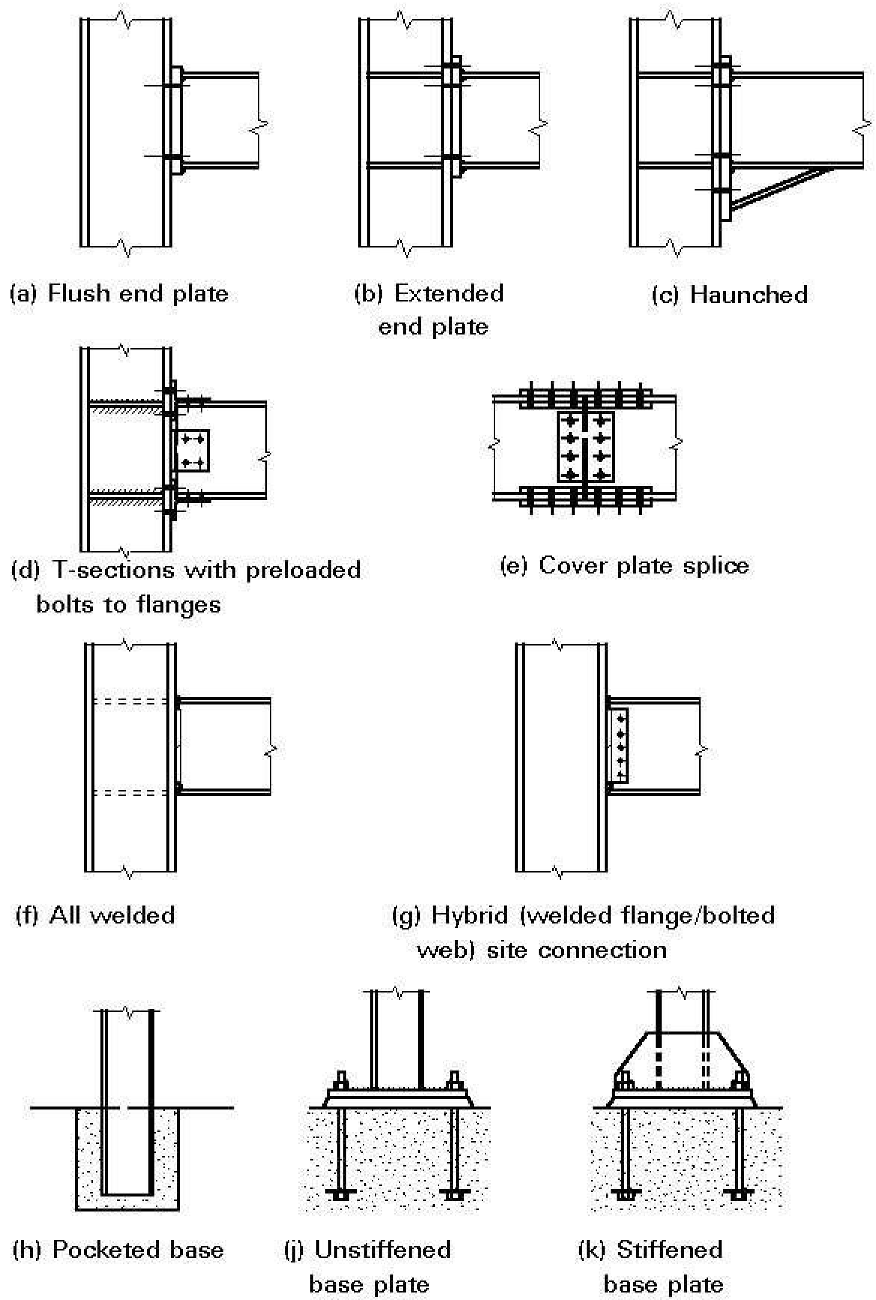
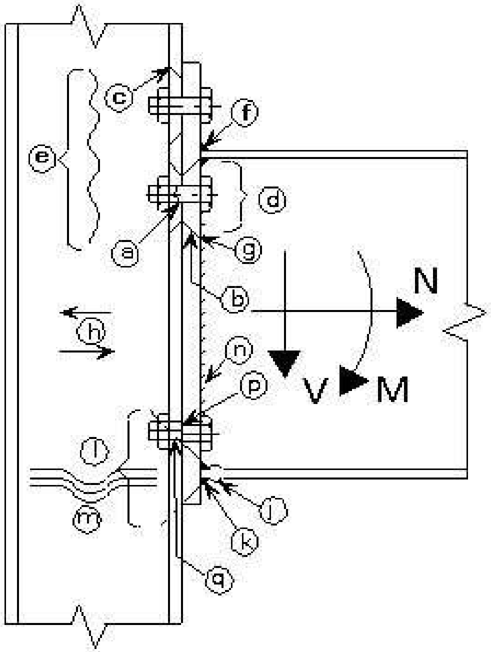


FIG. 14 TYPICAL MOMENT CONNECTIONS



Zone	Ref	Checklist item
Tension	a	Bolt tension
	b	End plate bending
	c	Column flange bending
	d	Beam web tension
	e	Column web tension
	f	Flange to end plate weld
	g	Web to end plate weld
Horizontal shear	h	Column web shear
Compression	j	Beam flange compression
	k	Beam flange weld
	l	Column web bearing
	m	Column web buckling
Vertical shear	n	Web to end plate weld
	p	Bolt shear
	q	Bolt bearing

FIG. 15 CRITICAL COMPONENETS IN MOMENT CONNECTIONS

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CODAL PROVISIONS

SECTION 10 CONNECTIONS - Contents

1. General
2. Fasteners spacing and edge distance
3. Bearing Type Bolts
4. Friction Grip Type Bolts
5. Welds and Welding
6. Design of Connections
7. Minimum Design Action on Connection
8. Intersections (Joints)
9. Choice of fasteners
10. Connection Components
11. Analysis of a Bolt/Weld Group
12. Lug Angles

To enable the designer to complete the design without the need to refer several other codes for simple values

- strengths of bearing and friction grip bolts
- strengths of welds for various fusion angles
- guidelines for design of splices, connections etc
- Analysis of bolt/weld groups kept simple
- guidelines for design of semi-rigid connections

10.2 Fasteners spacing and edge distance

1. *Minimum Spacing* - **2.5** times the nominal diameter
2. *Maximum Spacing* - shall not exceed **32*t* or 300 mm**, whichever is less, where *t* is thickness of the thinner plate

10.2.2.2 pitch shall not exceed **16*t* or 200 mm**, in tension members and **12*t* or 200 mm**, whichever is less, in compression members

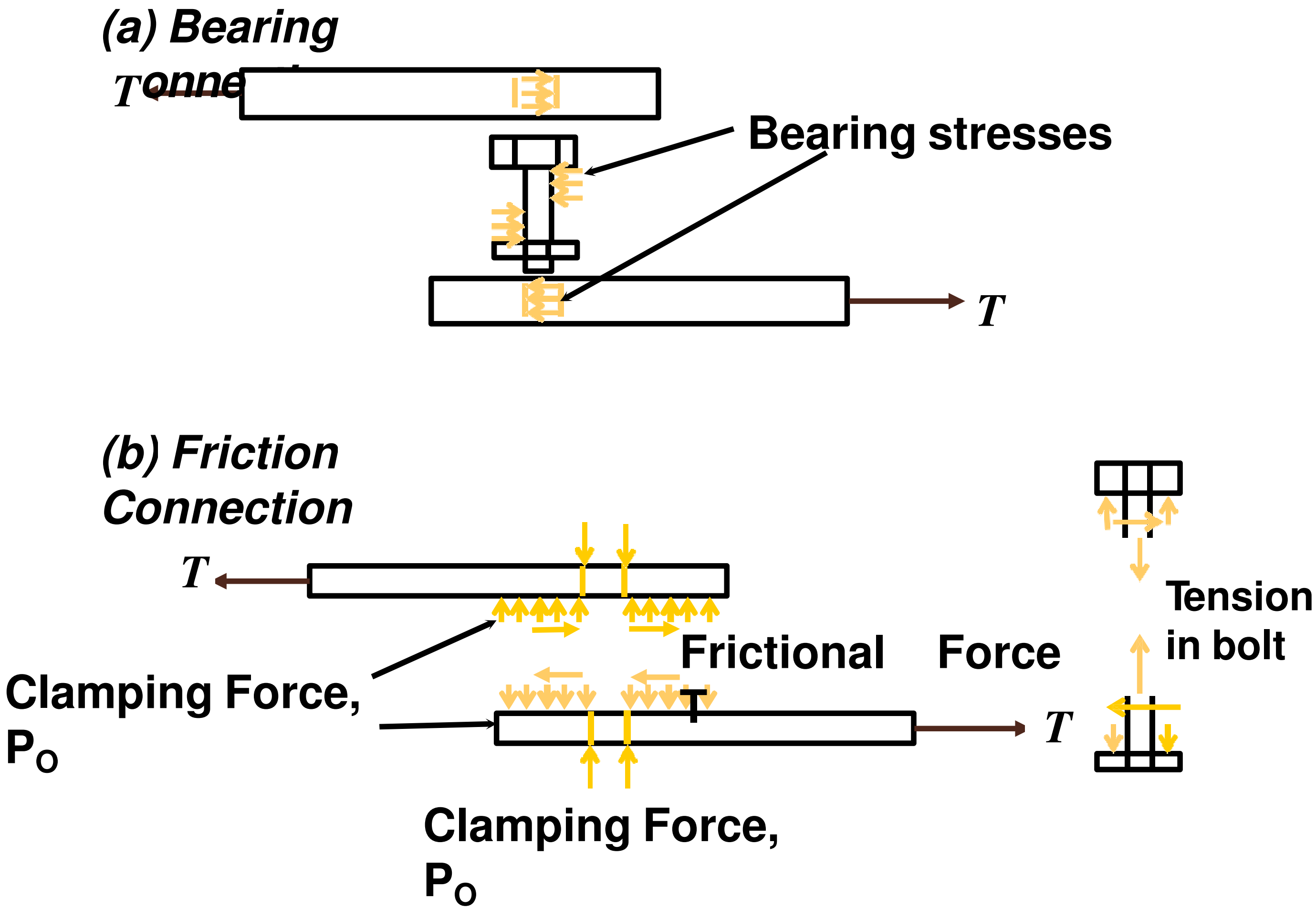
3. E*dge and End Distances* minimum edge shall be not less than that given in Table 10.1. maximum edge distance should not exceed **12 $t\varepsilon$**, where $\varepsilon = (250/f_y)^{1/2}$

4. *Tacking Fasteners* spacing in line not exceeding **32t or 300 mm** If exposed to the weather, **16 t or 200** mm

   max. spacing in tension members **1000 mm**

   max. spacing in compression members **600 mm**

FORCE TRANSFER MECHANISM

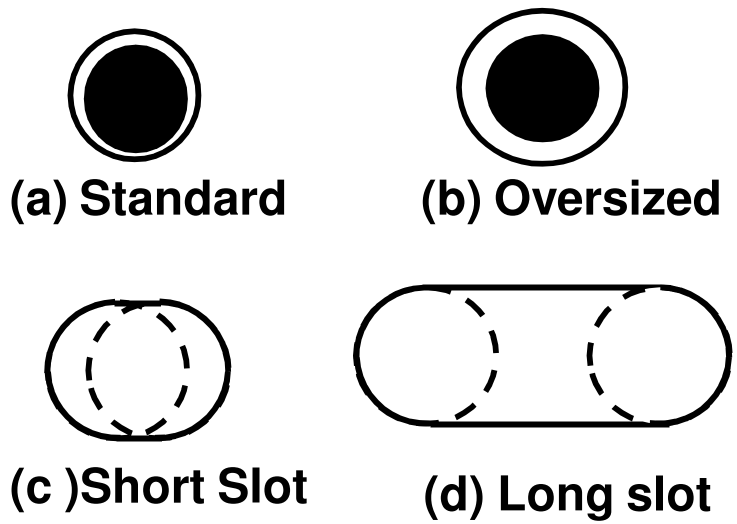


Bolt Shear Transfer – Free Body Diagram

Bolts and Bolting

Bolt Grade: **Grade 4.6 :- f_u = 40 kgf/mm² and f_y = 0.6*40 = 24 kgf/mm²**

Bolt Types: **Black, Turned & Fitted, High Strength Friction Grip**



Hole types for HSFG bolts

Table 19 Clearances for Fastener Holes

(*Clause* 10.2.1)

Sl No.	Nominal Size of Fastener, *d* mm	Size of the Hole = Nominal Diameter of the Fastener + Clearances mm			
		Standard Clearance in Diameter and Width of Slot	Over Size Clearance in Diameter	Clearance in the Length of the Slot	
				Short Slot	Long Slot
(1)	(2)	(3)	(4)	(5)	(6)
i)	12 – 14	1.0	3.0	4.0	2.5 *d*
ii)	16 – 22	2.0	4.0	6.0	2.5 *d*
iii)	24	2.0	6.0	8.0	2.5 *d*
iv)	Larger than 24	3.0	8.0	10.0	2.5 *d*

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10.2.3 *Maximum Spacing*

10.2.3.1 The distance between the centres of any two adjacent fasteners shall not exceed $32t$ or 300 mm, whichever is less, where t is the thickness of the thinner plate.

10.3 Bearing Type Bolts

$$V_{sb} = \frac{f_u}{\sqrt{3}} \left(n_n A_{nb} + n_s A_{sb} \right) / \gamma_{mb}$$

10.3.1.1 Reduction factor in shear for Long Joints

$$\beta_{lj} = 1.075 - (l_j / 200d)$$

$$\text{but} \quad 0.75 \le \beta_{lj} \le 1.0$$

10.3.1.2 Reduction factor in shear for Large Grip Lengths

$$\beta_{lg} = 8\,d / (3\,d + l_g)$$

10.3.2.3 Reduction factor for Packing Plates

$$\beta_{pk} = (1 - 0.0125\,t_{pk})$$

10.3 Bearing Type Bolts

3. Bearing Capacity of bolt on any ply

$$V_{sb} = (2.5\ d\ t\ f_u)/\ \gamma_{mb}$$

4. Tension Capacity

$$T_b = (0.90\ f_{ub}\ A_n)/\ \gamma_{mb} \quad < (f_{yb}\ A_{sb}\ (\gamma_{m1}/\gamma_{m0}))/\ \gamma_{mb}$$

10.3.5 Bolt subjected to combined shear and tension

$$\left(\frac{V}{V_{sd}}\right)^2 + \left(\frac{T_e}{T_{nd}}\right)^2 \leq 1.0$$

10.4 Friction Grip Type Bolting

10.4.3 Slip resistance

$$V_{sf} = (\mu_f\, n_e\, K_h\, F_o)/\, \gamma_{mf}$$

Where,

μ_f = coefficient of friction (slip factor) as in Table 10.2 ($\mu_f \leq 0.55$)

n_e = number of effective interfaces offering frictional resistance to slip

K_h = 1.0 for fasteners in clearance holes

= 0.85 for fasteners in oversized and short slotted holes

= 0.7 for fasteners in long slotted holes loaded parallel to the slot.

γ_{mf} = 1.10 (if slip resistance is designed at service load)

γ_{mf} = 1.25 (if slip resistance is designed at ultimate load)

F_o = minimum bolt tension (proof load) at installation ($0.8\, A_{sb}\, f_o$)

A_{sb} = shank area of the bolt

f_o = proof stress (= $0.70\ f_{ub}$)

Note: V_{ns} may be evaluated at a service load or ultimate load using appropriate partial safety factors, depending upon whether slip resistance is required at service load or ultimate load.

TABLE 10.2 TYPICAL AVERAGE VALUES FOR COEFFICIENT OF FRICTION (μ_f)

Treatment of surface	*Coefficient of friction (μ_f)*
Clean mill scale	0.33
Sand blasted surface	0.48
Red lead painted surface	0.1

10.4 Friction Grip Type Bolting

10.4.2 Bearing capacity

$$V_{bf} = (2.2\ d\ t\ f_{up}) / \gamma_{mf} \le (3\ d\ t\ f_{yp}) / \gamma_{mf}$$

10.4.3 Tension capacity

$$T_f = (0.9\ f_u\ A) / \gamma_{mf}$$

10.4.4 Combined Shear and Tension

$$\left(\frac{V}{V_{sdf}}\right)^2 + \left(\frac{T_e}{T_{ndf}}\right)^2 \le 1.0$$

Reduction factor in shear for Long Joints will apply here

10.4 Friction Grip Type Bolting

10.4.5 Prying Force

$$Q = \frac{l_v}{2\, l_e}\left[T_e - \frac{\beta \gamma f_o b_e t^4}{27\, l_e l_v^2}\right]$$

$$l_e = 1.1\, t \sqrt{\frac{\beta f_o}{f_y}}$$

β = 2 for non-pretensioned and 1 for pretensioned

γ = 1.5 for LSM

b_e = effective width of flange per pair of bolts

(Conti….)

10.5 Welds and Welding

1. End returns- not less than twice the size of the weld
2. Lap joint - not less than four times the thickness of the thinner part
3. Size of weld
4. Effective throat thickness - shall generally not exceed $0.7t$, K times the fillet size
5. Effective length or Area of weld
6. Intermittent welds - effective length of not less than four times the weld size, with a minimum of 40 mm,
7. weld types and quality - Confirm to IS:814
8. Design stresses in welds $f_{wd} = f_u/(\sqrt{3})\,\gamma_{mw}$

(Conti….)

10.5.8 Fillet weld applied to the edge of a plate or section

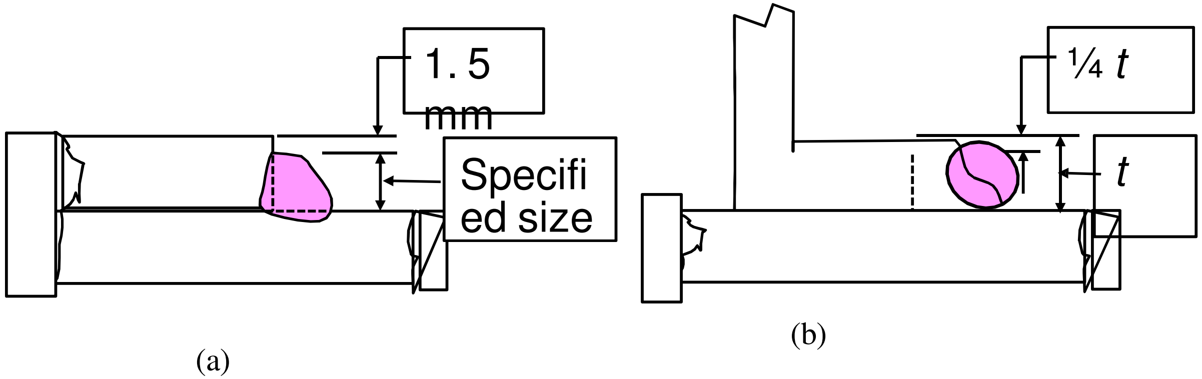
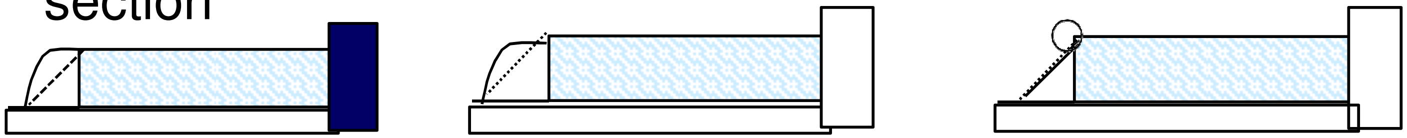


Fig. 10.1 fillet welds on square edge of plate or round toe of rolled section



a) desirable

b) acceptable because of full throat thickness

c) not acceptable because of reduced throat thickness

Fig10.2 Full size fillet weld applied to the edge of a plate or section

10.5.9 Stresses due to Individual forces

$$f_a \text{ or } q = \frac{P}{t_t \, l_w}$$

10.5.10 Combination of stresses

10.5.10.1 Fillet welds

$$f_e = \sqrt{f_a^2 + 3q^2} \leq \frac{f_u}{\sqrt{3}\,\gamma_{mw}}$$

Combined bearing, bending and shear

$$f_e = \sqrt{f_b^2 + f_{br}^2 + f_b f_{br} + 3q^2}$$

(Conti….)

10.6 Design of Connections

- Connections and adjacent regions of the members shall be designed such that :

a) the design action effects distributed to various elements shall be in equilibrium with the design action effects on the connection,

b) the required deformations in the elements of the connections are within their deformations capacities,

c) all elements in the connections and the adjacent areas of members shall be capable of resisting the design action effects acting on them,

d) the connection elements shall remain stable under the design action effects and deformations

10.7 Minimum Design Action on Connection

Connections carrying design action effects, shall be designed to transmit the greater of.

a) The design action in the member; and

b) The minimum design action effects expressed either as the value or the factor times the member design capacity for the minimum size of member required by the strength limit state, specified as follows:

i) Connections in Rigid Construction – a bending moment of at least 0.5 times the member design moment capacity

ii) Connections to Beam in Simple Construction – a shear force of at least 0.15 times the member design shear capacity or 40 kN. Whichever is lesser.

iii) Connections at the ends of Tensile or Compression Member – a force of at least 0.3 times the member design capacity

iv) Splices in Members Subjected to Axial Tension – a force of at least 0.3 times the member design capacity in tension.

v) Splices in Members Subjected to Axial Compression – for ends prepared for full contact – adequate fasteners to keep line and transmit $0.15P_d$

for ends not prepared for full contact – adequate fasteners to keep line and transmit $0.3P_d$ and a moment of Pd L/1000 where L= dist. bet. lat supports

vi) Splices in Flexural Members – a bending moment of 0.3 times the member design capacity in bending unless designed to transmit shear only

vii) Splices in Members Subject to Combined Actions – a splice in a member subject to a combination of design axial tension or design axial compression and design bending moment shall satisfy requirements in (iv), (v) and (vi) above

Other details

8. Intersections

At a joint, the member centroidal axes shall meet at a point, otherwise the members shall be designed for the bending moment arising due to eccentricity

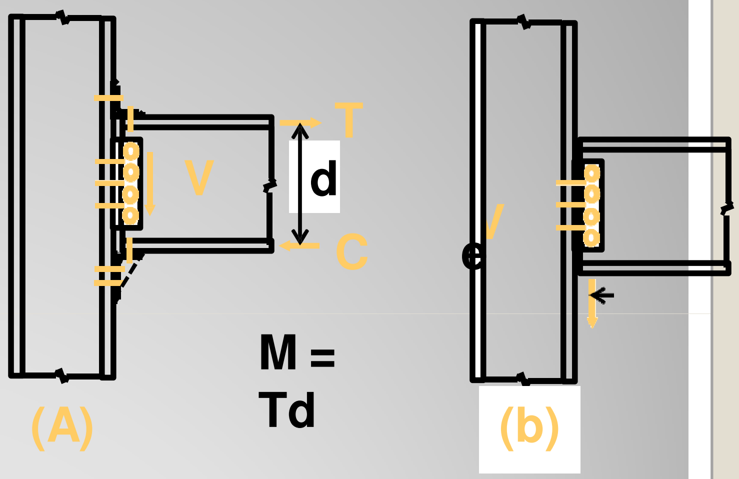
9. **Choice of fasteners** – Use HSFG, weld or fitted bolts to avoid slip in serviceability. When ordinary bolts are subjected to impact or vibration use locking devices

10. **Connection Components** – (Cleats, gusset plates, brackets and the like) shall have their capacities assessed using the provisions of Sections 5,6,7,8 and 9 as applicable.

GENERAL ISSUES IN CONNECTION DESIGN

Assumptions in traditional analysis

- Connection elements are assumed to be rigid compared to the connectors
- Connector behavior is assumed to be linearly elastic
- Distribution of forces arrived at by assuming idealized load paths
- Provide stiffness according to the assumed behavior
- ensure adequate ductility and Rotation capacity
- provide adequate margin of safety



Standard Connections (a) moment connection (b) simple connection

10.11 Analysis of a Bolt/Weld Group

10.11.1 Bolt/Weld Group Subject to In-plane Loading

The design force in a bolt/weld shall be determined by

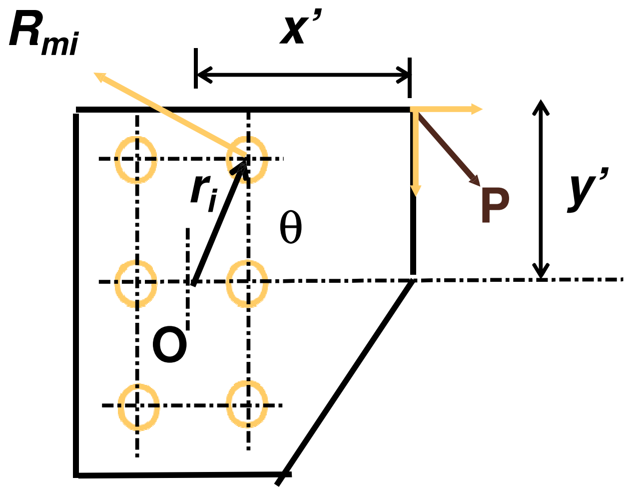
a) considering the connection plates to be rigid and to rotate relative to each other about a point known as the instantaneous centre of rotation ICR of the group.

b) In the case of a group subject to a pure couple only, the ICR coincides with the group centroid. In the case of in-plane shear force applied at the group centroid, the ICR is at infinity and the design force is uniformly distributed throughout the group. In all other cases, either the results of independent analyses for a pure couple alone and for an in-plane shear force applied at the group centroid shall be superposed, or a recognized method of analysis shall be used.

c) The design force in a bolt or design force per unit length at any point in the group shall be assumed to act at right angles to the radius from that point to the instantaneous centre, and shall be taken as proportional to that radius.

COMBINED SHEAR AND MOMENT IN PLANE

- Bolt shear due to P_x and P_y
  $R_{xi} = P_x/n$ and $R_{yi} = P_y/n$
- $M = P_x\, y' + P_y\, x'$
- $R_{mi} = k\, r_i$
  $M_i = k\, r_i^2$
  $MR = \Sigma\, k\, r_i^2 = k\, \Sigma\, r_i^2$
- Bolt shear due to M
  $R_{mi} = M\, r_i / \Sigma\, r_i^2$



Bolt group eccentrically loaded in shear

Combined shear

$$R_i = \sqrt{\left[(R_{xi} + R_{mi}\cos\theta_i)^2 + (R_{yi} + R_{mi}\sin\theta_i)^2\right]}$$

$$R_i = \sqrt{\left\{\left[\frac{P_x}{n} + \frac{My_i}{\sum(x_i^2 + y_i^2)}\right]^2 + \left[\frac{P_y}{n} + \frac{Mx_i}{\sum(x_i^2 + y_i^2)}\right]^2\right\}}$$

10.11 Analysis of a Bolt/Weld Group

a) The design force resulting from shear or axial force shall be considered to be equally shared by all bolts or over the length weld

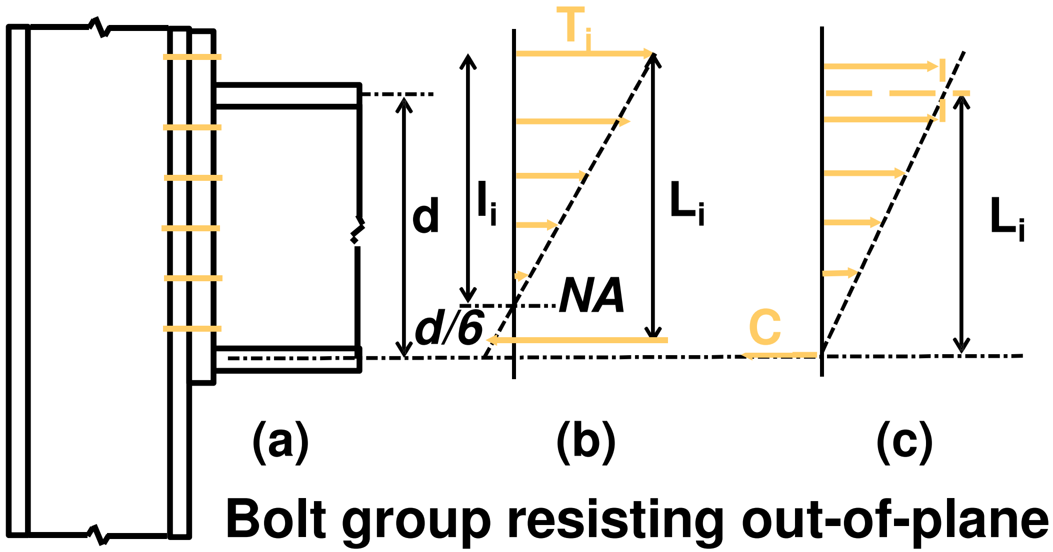
b) The design force resulting from a bending moment shall be considered to vary linearly with the distance from the centroidal axes for the calculation of centroid and second moment:

i) In bearing type of bolt group, plates in the compression side of the NA and only bolts in the tension side may be considered.

ii) In the friction grip bolt group only the bolts shall be considered

iii) The fillet weld group shall be considered in isolation from the connected element; of the weld length.

COMBINED SHEAR AND MOMENT OUT-OF-PLANE



Bolt group resisting out-of-plane moment

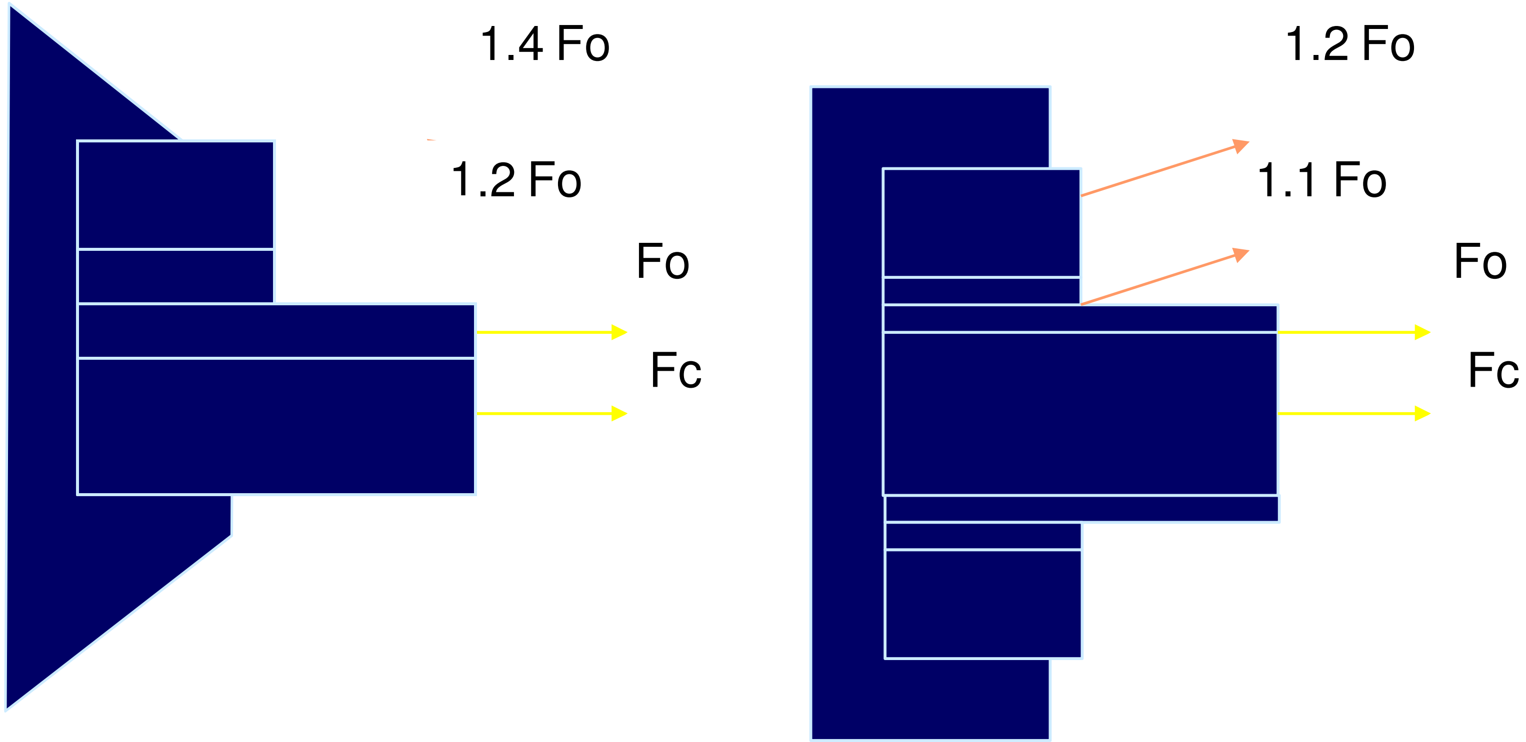
$T_i = kl_i$ where k = constant

$M = \Sigma T_i L_i = k \Sigma l_i L_i$

$T_i = Ml_i / \Sigma l_i L_i$

Shear assumed to be shared equally and bolts checked for combined tension+(prying)+shear

10.12 Lug Angles



G.3 Column Splice

- Where the ends of compression members are machined for bearing over the whole area, they shall be spliced to hold the line

- Else splices shall be designed to transmit all the force

- splices shall be proportioned and arranged so that centroidal axis of the splice coincides with member

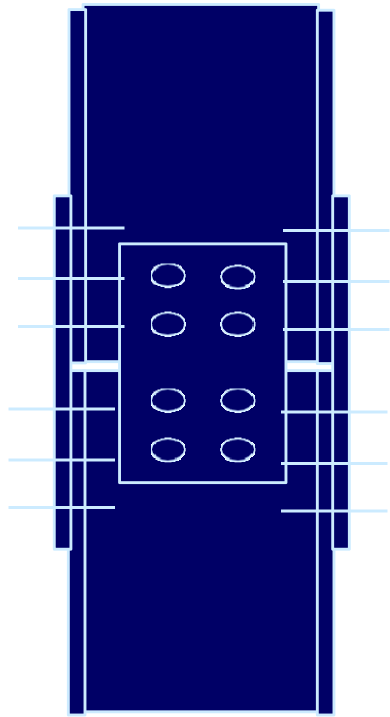
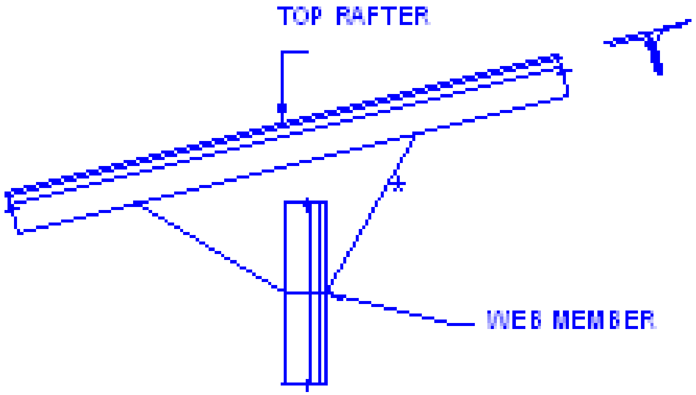


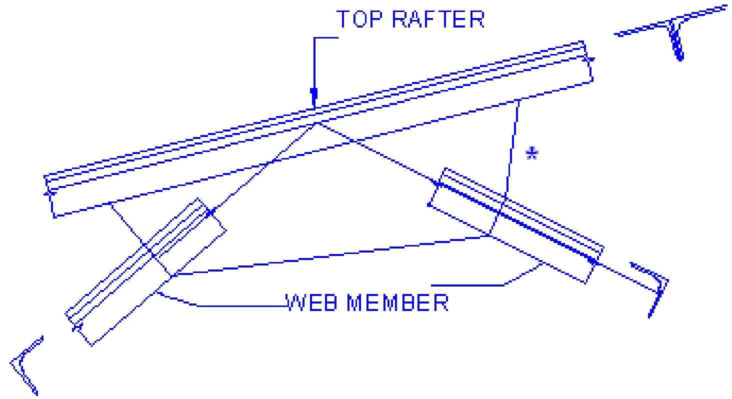
FIG. G.2 COLUMN SPLICE (TYPICAL)

TABLE G.1 CONNECTION CLASSIFICATION LIMITS

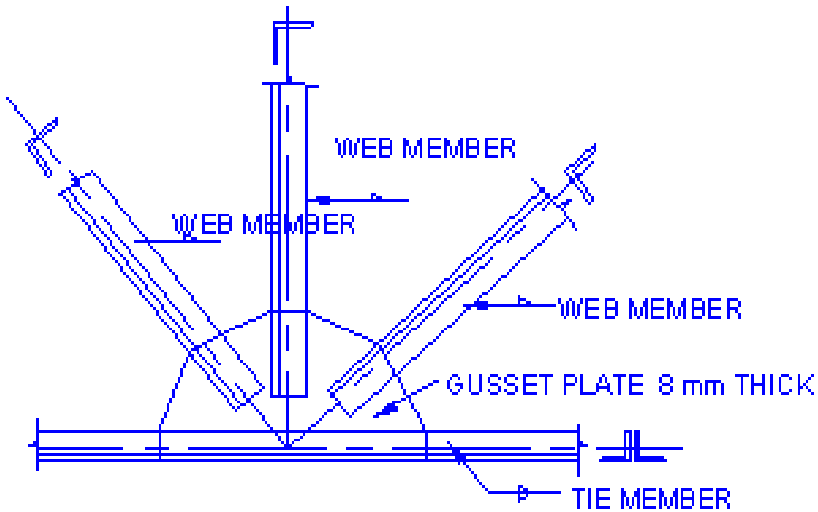
Nature of the connection	**In terms of Strength**	**In terms of Stiffness**
Rigid connection	$m^1 \geq 0.7$	$m^1 \geq 2.5\theta^1$
Semi-Rigid connection	$0.7 > m^1 > 0.2$	$2.5\theta^1 > m^1 > 0.5\theta^1$
Flexible connection	$m^1 \leq 0.2$	$m^1 \leq 0.5\theta^1$



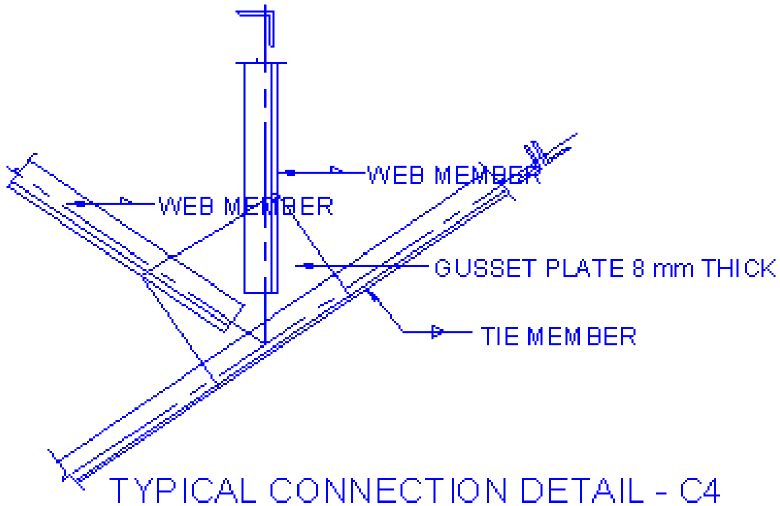
TYPICAL CONNECTION DETAIL - C1



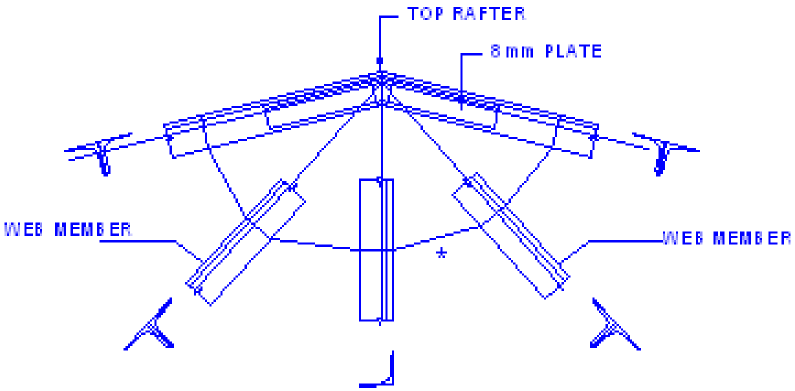
TYPICAL CONNECTION DETAIL - C2



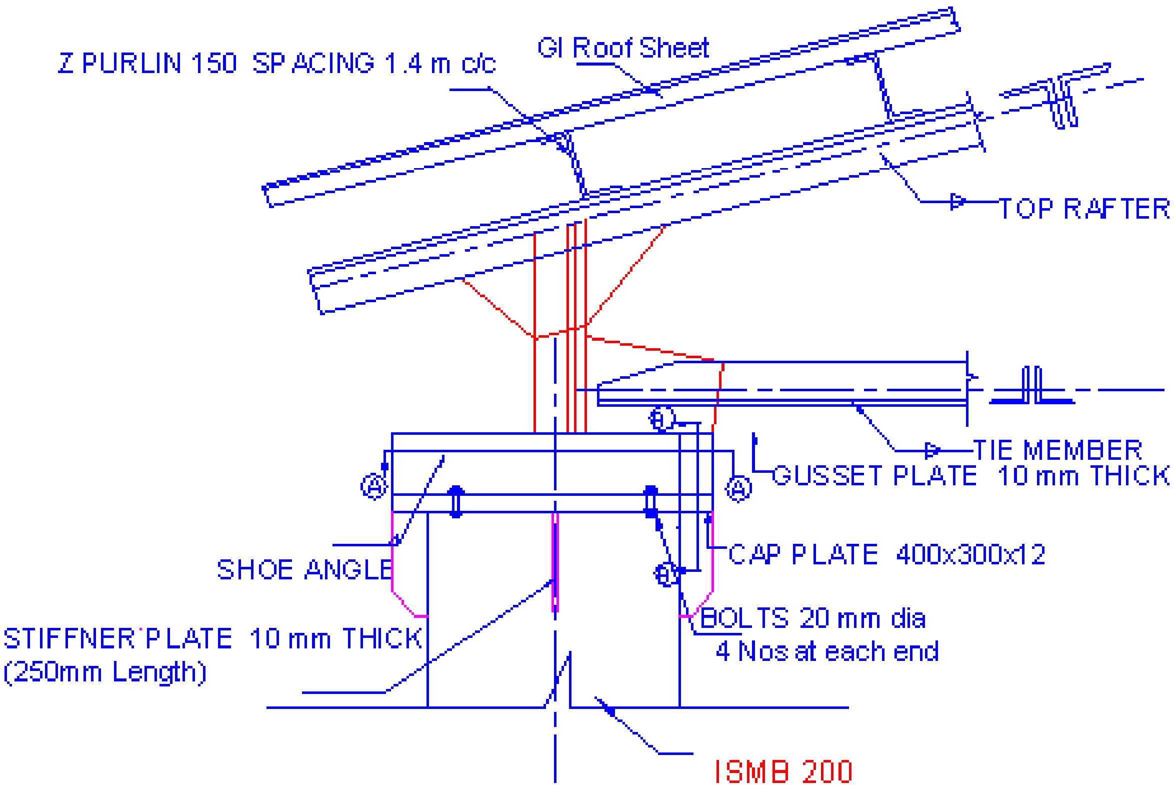
TYPICAL CONNECTION DETAIL - C3



TYPICAL CONNECTION DETAIL - C4



TYPICAL CONNECTION DETAIL - C5



SIDE ELEVATION (ANGLE TRUSS)

THANK YOU