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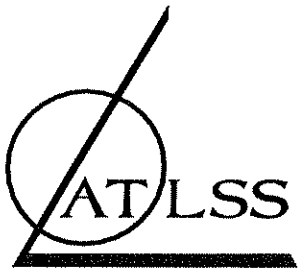
Components of Structural Systems in Steel and Precast Concrete

Corey A. Farschman

E. Sarah Slaughter



ADVANCED TECHNOLOGY FOR
LARGE
STRUCTURAL SYSTEMS

Lehigh University

COMPONENTS OF STRUCTURAL SYSTEMS IN STEEL AND PRECAST CONCRETE

by

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Introduction

This report contains a compilation of existing standard, nonstandard, and proprietary structural forms, structural connectors, load bearing elements, and connections using steel or precast concrete. It focuses on the superstructure of buildings, including the connection of the superstructure to the foundation. Also included is an analytical framework of structural elements and connections that represents all of the feasible combinations of the different types of structural elements. We have also identified some examples of structural systems specifically designed with complementary elements and connections.

This report was developed during the course of research on preassembled and prefabricated systems at the Center for the Advanced Testing of Large Structural Systems (ATLSS) at Lehigh University. The purpose of the research is to develop new structural framing systems that take advantage of the possible benefits of preassembly and prefabrication, such as lower cost, shorter duration, and improved safety. Our objective in developing this report is to provide a basis for the development of new systems by identifying the types of structural forms and connectors that are available, the types of structural elements and connections that are available, the systems that currently exist, and new ways of thinking about the combination of structural elements. We focused on steel and precast concrete forms, since these materials can be used for preassembly and prefabrication of structural systems.

This compilation used several excellent references for steel or precast concrete structural systems, aggregating their material-specific information into a general reference. The references used most extensively were *Design and Typical Details of Connections for Precast and Prestressed Concrete* (PCI, 1988), *Manual of Steel Construction--Load and Resistance Factor Design, First Edition* (AISC, 1986), *Design of Welded Structures* (Blodgett, 1966), and *Fundamentals of Building Construction* (Allen, 1990). Each chapter lists major references used and sources for information and illustrations where applicable.

This report is organized into four chapters. Chapter 1, Structural Forms and Connectors, contains examples of the currently available steel and precast forms (e.g. W shapes, channels, precast slabs), as well as the available connectors that are used to join the forms into structural elements (e.g. bolts, welds, angles). Chapter 2, Structural Elements and Connections, illustrates different ways that the structural forms and connectors can be used as load bearing elements to perform particular functions (e.g. column, beam, wall, floor) and how the different types of load bearing elements can be connected (e.g. beam to column, column to column, wall to beam). Chapter 3, Analytical Framework of Structural Elements and Connections, was developed to explore all of the plausible ways of combining load bearing elements, to establish new ways of thinking about this issue and possibly leading to ideas for new structural systems. Finally, Chapter 4, Examples of Structural Systems, identifies existing structural systems specifically designed with complementary elements and connections.

CHAPTER 1: Structural Forms and Connectors

Description

The purpose of this chapter is to provide a comprehensive reference of standard, nonstandard, and proprietary steel and precast forms that currently exist, as well as the available connectors that may be used to join the forms. This is especially relevant to the design of new systems using prefabrication and preassembly, since it appears that the use of standard structural forms makes the design easier and more likely to be accepted by industry.

"Standard" structural forms and connectors are those which are easily available from steel and precast concrete manufacturers and fabricators. Standard structural forms and connectors are created in mass quantities, as opposed to "nonstandard" structural forms and connectors which require special fabrication activities, and "proprietary" structural forms and connectors which are available only through licensed manufacturers or not commercially available. Virtually all of the forms and connectors identified are standard; those that are proprietary are indicated by italics.

Structural "forms" are shapes of materials with known structural behaviors used alone or together as structural elements. "Connectors" are materials used to join structural forms. Chapter 2 illustrates many ways that these structural forms and connectors are used as load bearing elements.

The major references used in this chapter were *Design and Typical Details of Connections for Precast and Prestressed Concrete* (PCI, 1988) and *Manual of Steel Construction--Load and Resistance Factor Design, First Edition* (AISC, 1986).

Chapter 1 Outline

Structural Forms and Connectors

I. Structural Forms
   A. Steel Forms
      1. W Shapes (Wide-flange sections)
      2. M Shapes
      3. S Shapes (I-beams)
      4. HP Shapes
      5. American Standard Channels (C)
      6. Miscellaneous Channels (MC)
      7. Angles--Equal legs and unequal legs (L)
      8. Structural Tees
         a. Cut from W shape (WT)
         b. Cut from M shape (MT)
         c. Cut from S shape (ST)
      9. Steel Pipe
      10. Structural Tubing
         a. Square
         b. Rectangular
      11. Bars
         a. Square
         b. Rectangular
         c. Round
      12. Plates
      13. Corrugated Steel Sheets
   B. Precast Concrete Forms
      1. Rectangular cross sections
      2. Square cross sections
      3. L-shapes
      4. Inverted tees
      5. AASHTO shapes (Bulb tees)
      6. I-shapes
      7. T-shapes
      8. Solid flat slabs
      9. Hollow core slabs
      10. Double tee slabs
      11. Single tee slabs
      12. Channel slabs
      13. Ribbed (cassette) slabs
      14. Other miscellaneous shapes
II. Structural Connectors
   A. Steel Connectors
      1. Bolts
      2. Welds
      3. Angles

*Not illustrated.

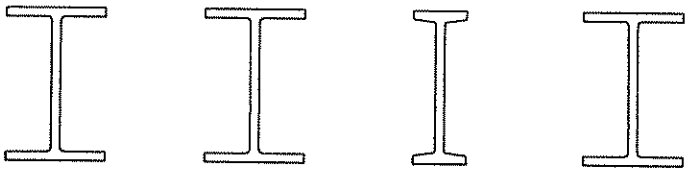
4. Plates (including gusset plates)
5. Structural tees
6. Channels
7. Shear studs
8. Rebar*
9. Brackets*
10. Hangers*
11. Haunches*
12. *ATLSS Connector*

B. Other Materials used as Connectors
1. Grout
2. Cast-in-place concrete

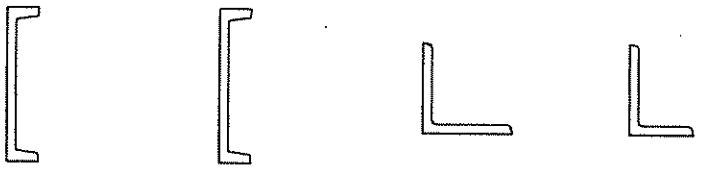
*Not illustrated.

Steel Forms

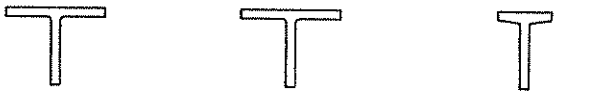
(cross sections)



W Shape (Wide-flange) | M Shape | S Shape (I-beam) | HP Shape

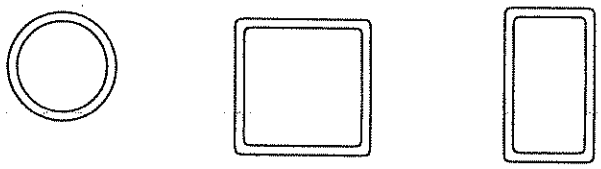


American Standard Channel (C) | Miscellaneous Channel (MC) | Angle (L)-- Equal legs | Angle (L)-- Unequal legs



Cut from W shape (WT) | Cut from M shape (MT) | Cut from S shape (ST)

Structural tees

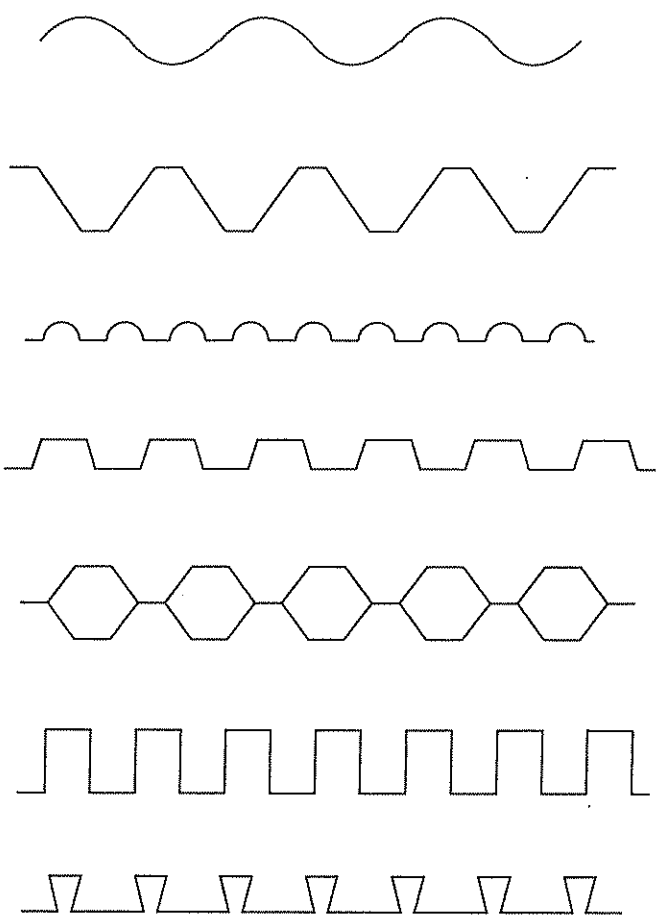


Steel pipe | Square tubing | Rectangular tubing

Square bar | Rectangular bar | Round bar | Plate

Steel Forms (cont)

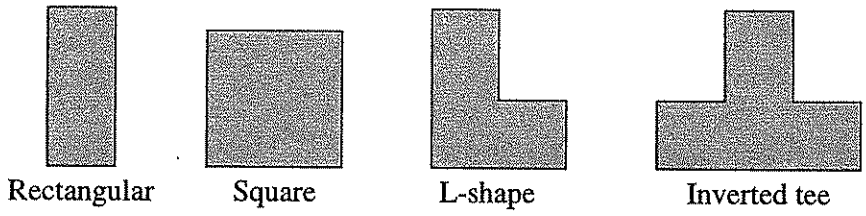
(cross sections)



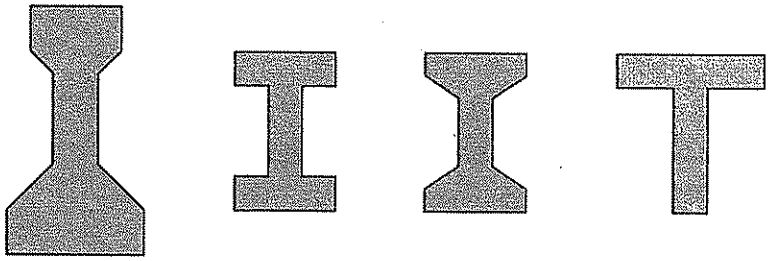
Corrugated Steel Sheets
(Also available with stiffeners
for composite action)

Precast Concrete Forms

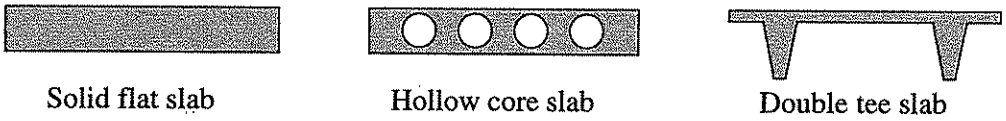
(cross sections)



Rectangular Square L-shape Inverted tee

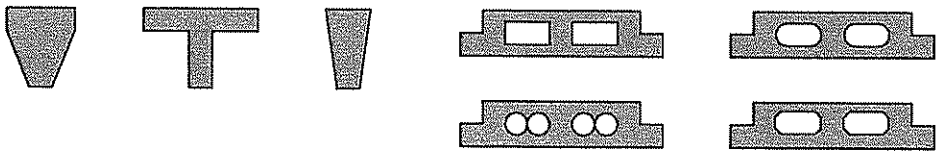


AASHTO shape I-shapes T-shape



Solid flat slab Hollow core slab Double tee slab

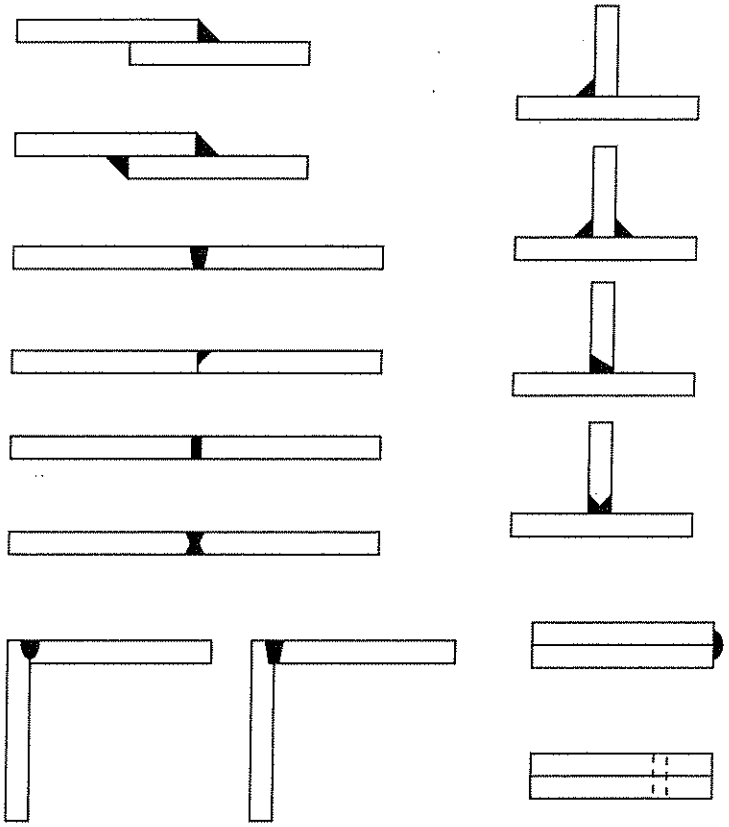
Single tee slab Channel slab Ribbed (cassette) slab



Other miscellaneous shapes

Steel Connectors

Bolts



Welds

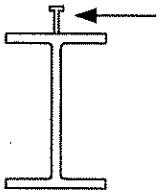
Steel Connectors (cont)

Angles

Plates

Structural tees

Channels



Shear studs

Steel Connectors (cont)

ATLSS Connector

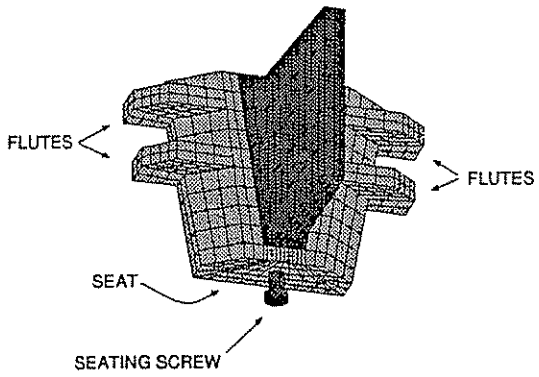


Figure 12. AC with All Features.

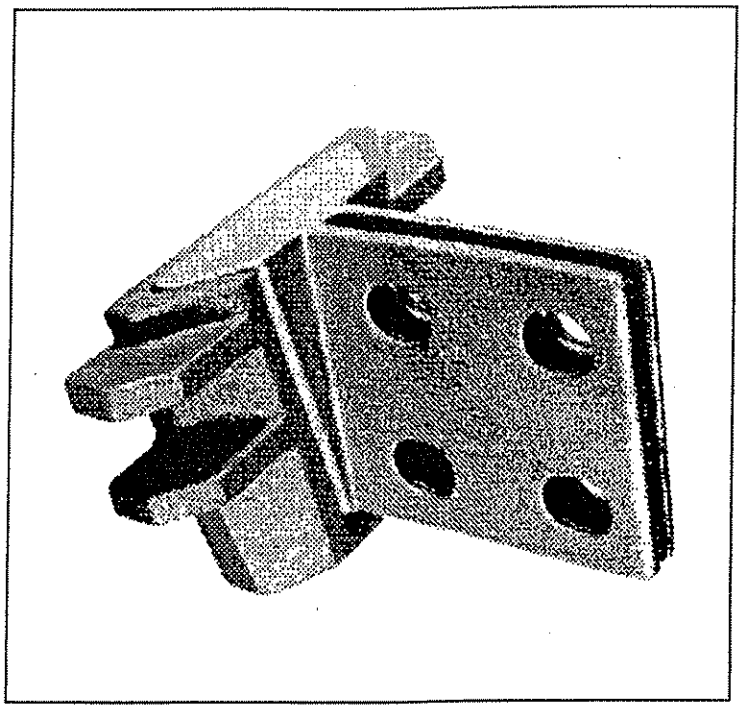
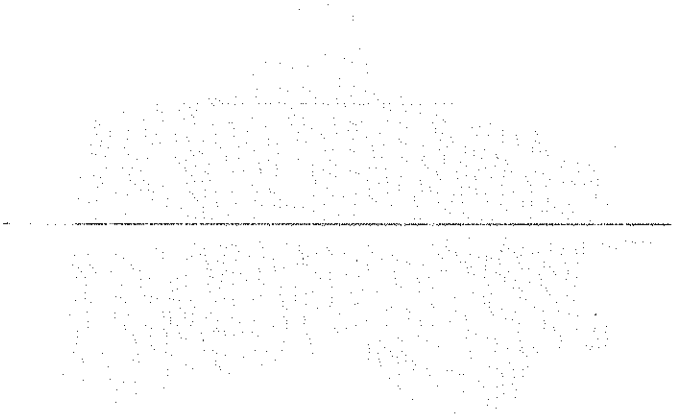


Figure 3. Phase II AC Prototype.

Source: Fleischman et al, 1993



CHAPTER 2: Structural Elements and Connections

Description

This chapter illustrates the different ways that the structural forms and connectors described in the previous chapter can be used as load bearing elements to perform particular functions and how these different types of load bearing elements can be connected.

A "load bearing element" is a structural entity, such as a beam, column, wall slab, or floor slab, that must have the capacity to resist certain applied loads and is used in combination with many other load bearing elements to form a structure. A load bearing element may be composed of a single structural form or a combination of many structural forms joined with structural connectors. A "connection," as opposed to a "connector," joins two load bearing elements by using one or more types of connectors.

There are several different ways to define load bearing elements. The first is the final erected position of the element, which may be horizontal, vertical, or both (three-dimensional). A "horizontal" element, such as a beam or floor slab, is one that lies primarily within the horizontal plane, while a "vertical" element, such as a column or wall slab, lies primarily within the vertical plane. A "three-dimensional" element has both horizontal and vertical components. The second is the dimensionality of the element, which may be single, planar, or three-dimensional. A "single" element, such as a beam or column, is an element that can be approximated as extending in one direction, as opposed to a "planar" element, such as a wall or floor slab, which extends in two directions, and a "three-dimensional" element which extends in three directions. The third way to define load bearing elements is by the continuity of the element, whether it is continuous or discontinuous. A "continuous" element has a uniform, unbroken surface, while the surface of a "discontinuous" element is skeletal and interrupted. The final way to define load bearing elements is by the type of material that the element is made of, which in this context may be steel or precast concrete. Each of these factors is used to classify the different types of elements, the organization of which is described in the next paragraph.

The first part of this chapter, which illustrates the different types of load bearing elements, is organized according to whether the final erected position of the element is vertical, horizontal, or three-dimensional (or "other" in the case of diagonal bracing members). The horizontal and vertical elements are further broken down into whether the element is single or planar. The single elements are listed according to the type of material they are made out of. The planar elements are broken down further into whether the element is discontinuous or continuous. Similar to the single elements, the planar elements are also listed according to the type of material they are made of. The three dimensional elements are not treated in as much detail as the single and planar elements; they are broken down according to whether they are continuous and discontinuous and by the type of material they are made of.

The second part of this chapter gives examples of the different types of connections that are used to join load bearing elements (excluding three-dimensional elements). The organization of this section can be understood most easily with reference to Table 1.

Table 1: Categories of Connections Among Structural Elements by Orientation

		Vertical			
		Single	Planar		
Vertical	Single	1	2	Horizontal	
	Planar	2	3	Single	Planar
Horizontal	Single	4	6	8	9
	Planar	5	7	9	10

The row and column associated with each number in the table refers to the two types of elements that are being connected. In the text, examples of different combinations of these elements are given by the type of connection (e.g. rigid moment resisting) and the materials used. The numbers refer to the subcategories within the connection portion (Part II) of this chapter under which the particular connections are illustrated.

The major references used in this chapter were *Design and Typical Details of Connections for Precast and Prestressed Concrete* (PCI, 1988), *Design of Welded Structures* (Blodgett, 1966), and *Fundamentals of Building Construction* (Allen, 1990).

Chapter 2 Outline

Structural Elements and Connections

I. Load Bearing Elements
  A. Vertical Elements
    1. Single Vertical Elements (Columns)
      a. Steel
        (1) W Shapes (Wide flange sections)
        (2) M Shapes
        (3) S Shapes (I-beams)
        (4) Channels
          (a) C Shapes
          (b) MC Shapes
        (5) Structural tees
          (a) Cut from W Shapes (WT)
          (b) Cut from M Shapes (MT)
          (c) Cut from S Shapes (ST)
        (6) Steel Pipe
        (7) Structural tubing
          (a) Square
          (b) Rectangular
        (8) Built-up sections
        (9) Castellated columns
          (a) W Shape
          (b) Channels
      b. Precast Concrete
        (1) Square columns
        (2) Square columns with corbels
        (3) Rectangular columns
        (4) Rectangular columns with corbels
      c. Composite
        (1) Concrete-filled steel pipes or tubes
        (2) Steel members inside concrete sections
    2. Planar Vertical Elements (wall sections)
      a. Discontinuous
        (1) Steel
          (a) Bents (Vertical preassembled sections)
          (b) Tree columns
          (c) H-sections*
          (d) Vanderyl trusses*
        (2) Precast Concrete
          (a) H-frame
          (b) T-frame
      b. Continuous
        (1) Steel
          (a) Steel plates

*Not illustrated.

(b) Corrugated steel sheets
(c) Bents with corrugated metal siding, etc.*

(2) Precast Concrete
(a) Solid flat wall slabs
(b) Solid flat wall slabs with corbels
(c) Hollow core wall slabs
(d) Hollow core wall slabs with corbels
(e) Double tee wall slabs
(f) Double tees wall slabs with corbels

B. Horizontal Elements

1. Single Horizontal Elements (Beams, etc.)

a. Steel

(1) W Shapes (Wide-flange sections)
(2) M Shapes
(3) S Shapes (I-beams)
(4) HP Shapes
(5) Channels
(a) C Shapes
(b) MC Shapes
(6) Structural tees
(a) Cut from W Shapes (WT)
(b) Cut from M Shapes (MT)
(c) Cut from S Shapes (ST)
(7) Structural tubing
(a) Square
(b) Rectangular
(8) Built-up sections
(a) Plate girders (Built-up wide-flange sections)
(b) Open-web bar joists
(c) *Top hat*
(d) *Vescom* joists*
(e) *Vescom* truss girders*
(f) Other miscellaneous sections
(9) Castellated beams

b. Precast Concrete

(1) Rectangular beams
(2) Square beams
(3) L-shapes beams
(4) Inverted tee beams
(5) AASHTO beams (Bulb tees)
(6) I-shapes
(7) T-shapes
(8) Other miscellaneous shapes

2. Planar Horizontal Elements (floor sections)

a. Discontinuous

(1) Steel
(a) Panels (horizontal preassembled sections)

*Not illustrated.

b. Continuous
(1) Steel
(a) Steel plates
(b) Corrugated steel sheets
(c) Panels with corrugated metal decking, etc.*
(d) Orthotropic decking*
(2) Precast concrete
(a) Solid rectangular floor slabs
(b) Hollow core floor slabs
(c) Double tee floor slabs
(d) Single tee floor slabs
(e) Channel floor slabs
(f) Ribbed (cassette) floor slabs

C. "Three-Dimensional" Elements
1. Discontinuous
a. Steel
(1) *Cubic* frame system
(2) *Falcon Steel* "Hinged section"
(3) Preassembled 3-D sections*
b. Precast concrete
2. Continuous
a. Steel
b. Precast concrete
(1) Box modules*

D. Other Elements
1. Steel diagonal bracing members*

*Not illustrated.

II. Connections

A. Single Vertical Element to Single Vertical Element

Examples:

- •Steel column to foundation--column base
- •Precast column to foundation--column base
- •Steel column to steel column--column splice
- •Precast column to precast column--column splice

B. Planar Vertical Element to Single Vertical Element

Examples:

- •Steel bent to steel columns*
- •Precast wall slab to precast columns--infill walls*
- •Shear walls to columns*
- •Exterior enclosure*
- •Steel bent to single foundation*
- •Precast wall slab to single foundation*

C. Planar Vertical Element to Planar Vertical Element

Examples:

- •Steel bent to steel bent*
- •Precast wall slab to precast wall slab
- •Steel bent to foundation*
- •Precast wall slab to foundation
- •Steel plate to steel bent*
- •Corrugated metal decking to steel bent*

D. Single Horizontal Element to Single Vertical Element

Examples:

- •Steel beam to steel column (rigid, semi-rigid, or simple)
- •Precast beam to precast column (rigid, semi-rigid, or simple)

E. Planar Horizontal Element to Single Vertical Element

Examples:

- •Steel panel to steel columns*
- •Precast floor slab to precast columns*

F. Single Horizontal Element to Planar Vertical Element

Examples:

- •Steel beam to steel bent*
- •Precast beam to precast wall slab

G. Planar Horizontal Element to Planar Vertical Element

Examples:

- •Steel panel to steel bent*
- •Precast floor slab to precast wall slab

H. Single Horizontal Element to Single Horizontal Element

Examples:

- •Steel beam to steel girder (rigid, semi-rigid, or simple)
- •Precast beam to precast girder (rigid, semi-rigid, or simple)
- •Steel beam to steel beam--beam splice (moment or shear)
- •Precast beam to precast beam--beam splice (moment or shear)

I. Planar Horizontal Element to Single Horizontal Element

Examples:

*Not illustrated.

- •Steel panel to steel beam*
- •Precast floor slab to precast beam
- •Steel plate to steel beam*
- •Corrugated metal decking to steel beam*

J. Planar Horizontal Element to Planar Horizontal Element

Examples:

- •Steel panel to steel panel*
- •Precast slab to precast slab
- •Steel plate to steel panel*
- •Corrugated metal decking to steel panel*
- •Steel plate to steel plate*
- •Corrugated metal decking to steel plate*
- •Corrugated metal decking to corrugated metal decking*

K. Other Connections

Examples:

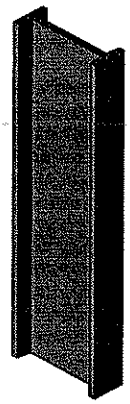
- •Steel truss panel point connection*
- •Bracing member to column*
- •Bracing member to beam*

*Not illustrated.

Single Vertical Elements

Steel

W Shape,
M Shape



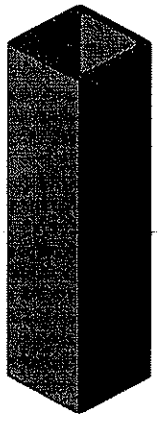
S Shape

Channel
(C, MC Shapes)

Structural tee
(Cut from W,
M Shapes)

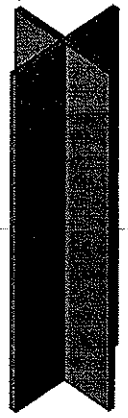
Structural tee
(Cut from
S shape)

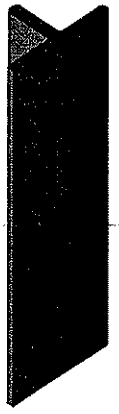
Steel Pipe



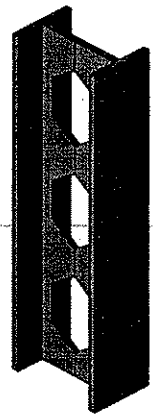
Square
Tubing

Rectangular
Tubing

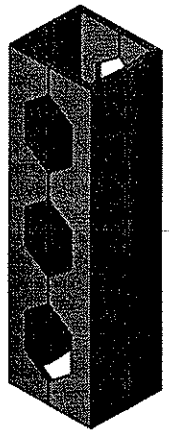




Built-up Sections
(see next page
for more examples)



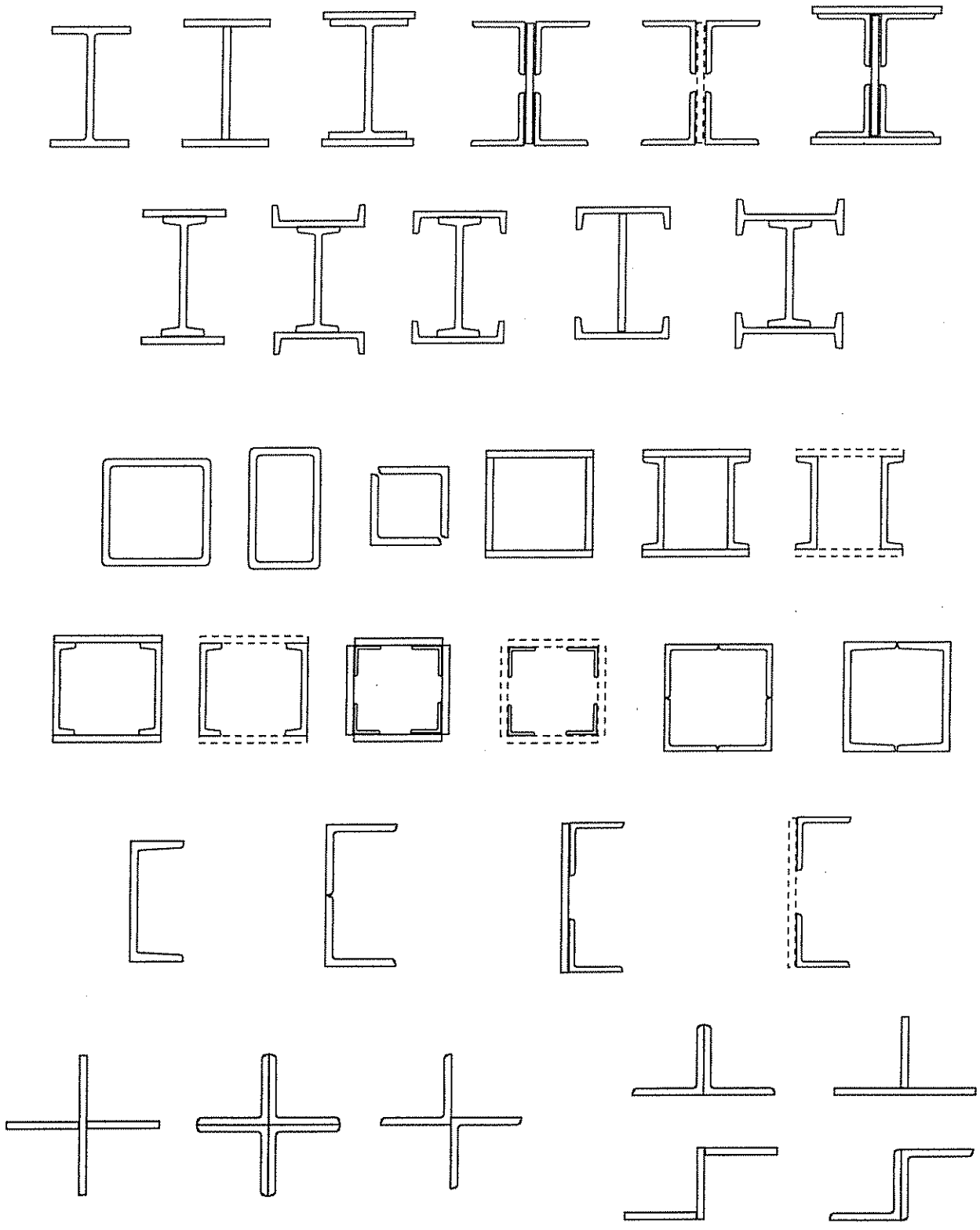
Castellated
W Shape



Castellated
Channels

Single Vertical Elements (cont)

Cross sections of miscellaneous built-up steel elements



Single Vertical Elements (cont)

Steel

Another Example of a Built-up Column

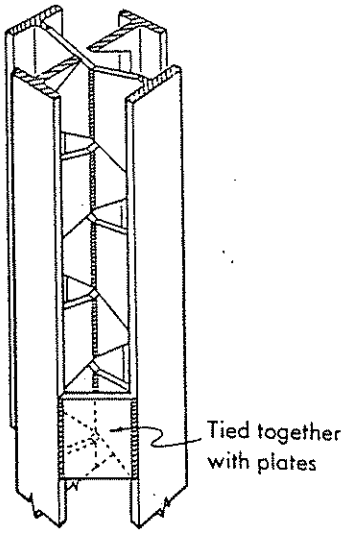


FIG. 5 Two open-web expanded beams can sometimes be nested together to form a column having a high moment of inertia about both its x-x and y-y axes.

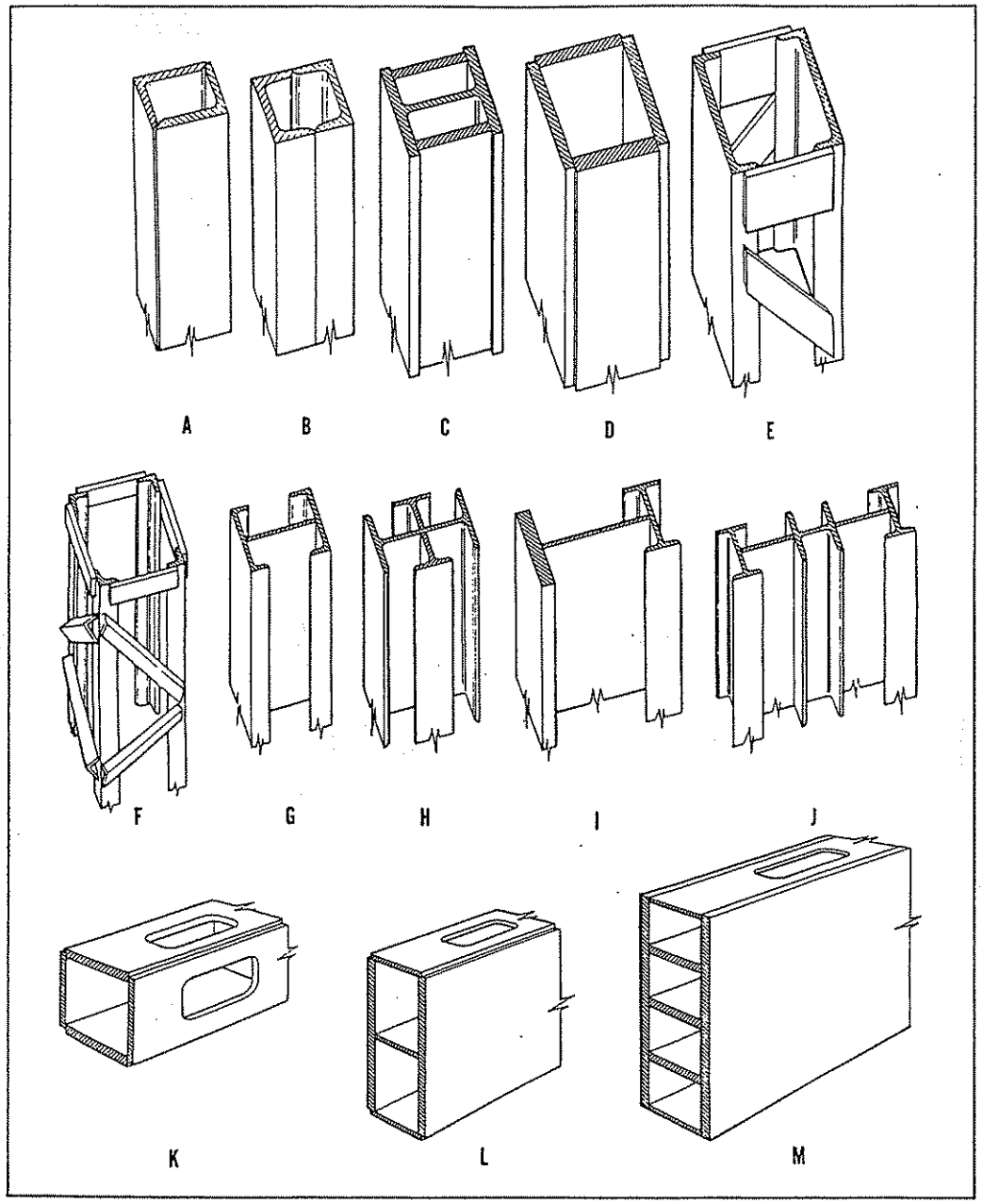
Source: Blodgett, 1966

Single Vertical Elements (cont)

Steel

More Examples of Built-up Columns

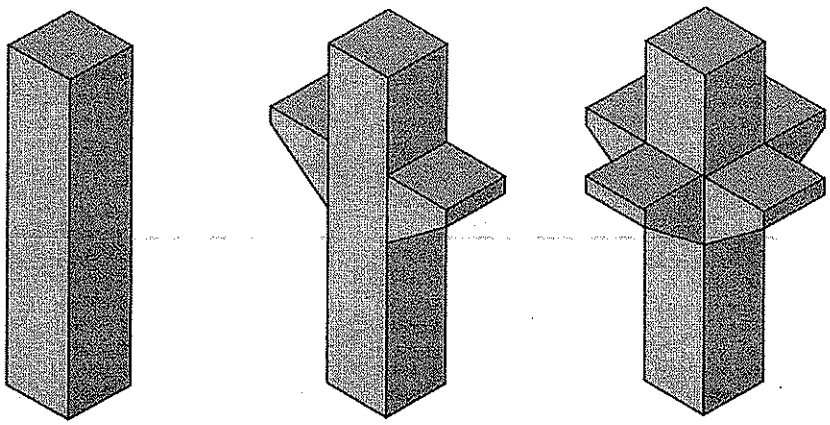
FIGURE 18—Typical Built-Up Compression Members



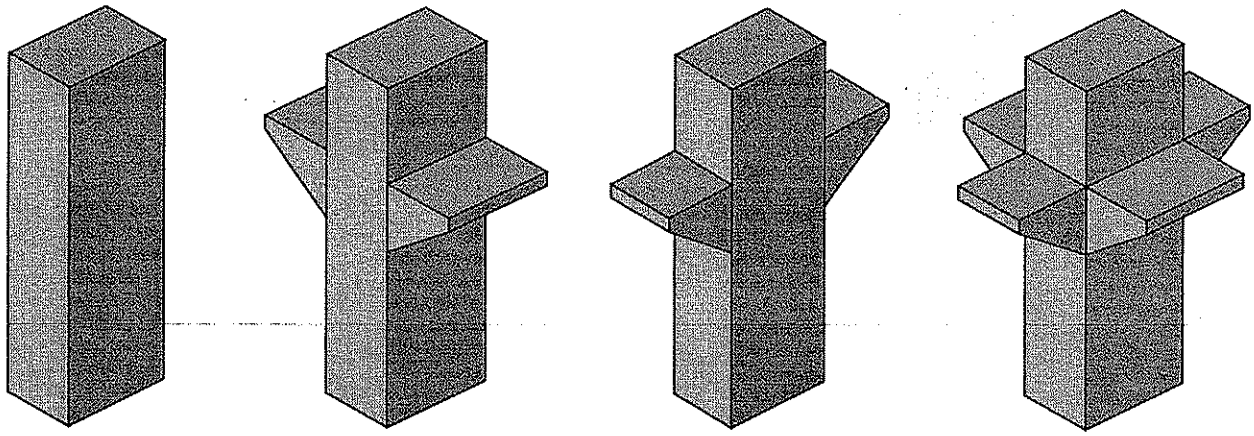
Source: Blodgett, 1966

Single Vertical Elements (cont)

Precast Concrete



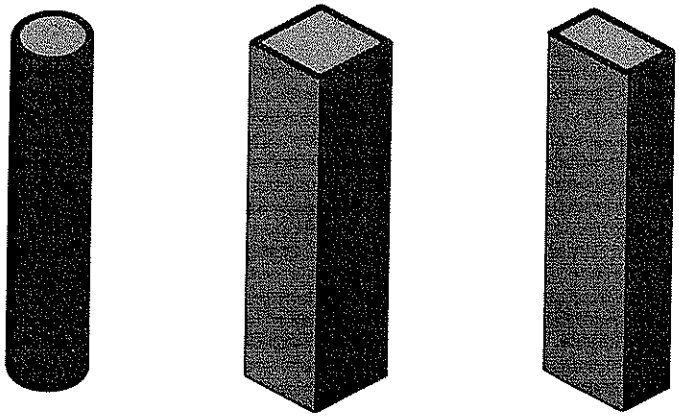
Square columns



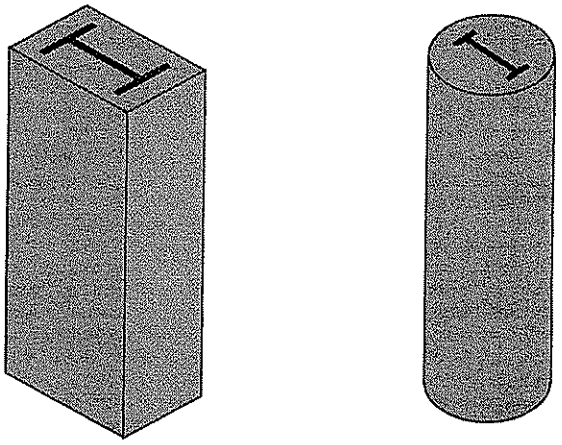
Rectangular columns

Single Vertical Elements (cont)

Composite



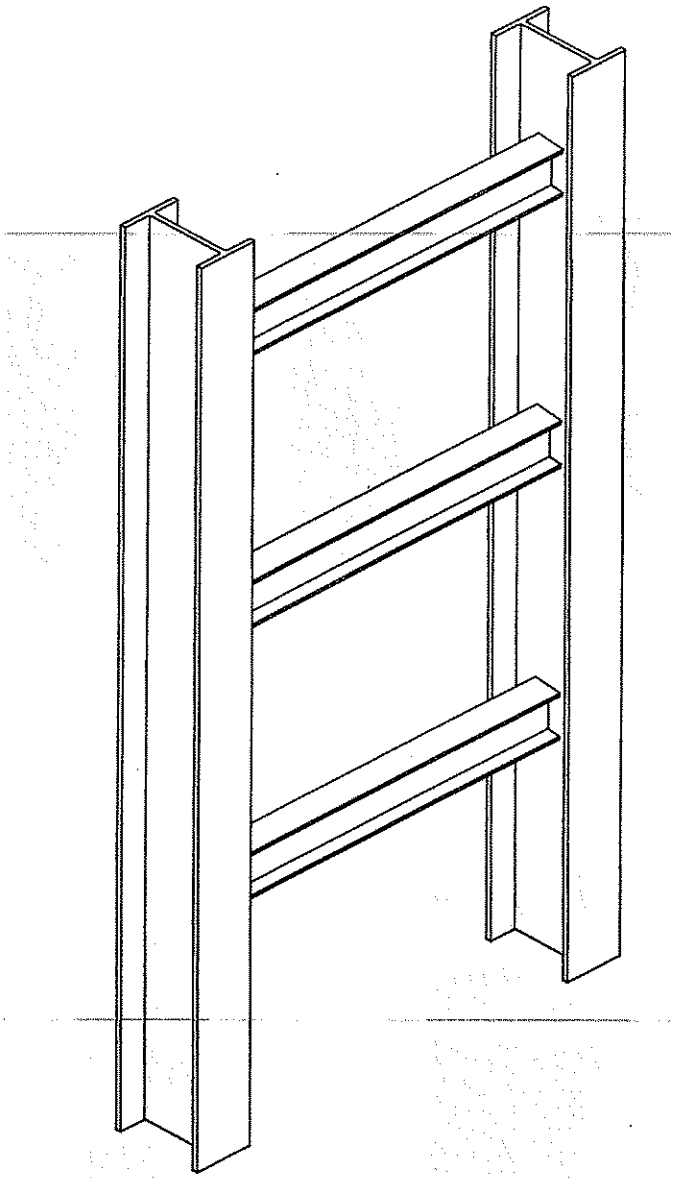
Concrete-filled steel pipes or tubes



Steel members inside concrete sections

Planar Vertical Elements

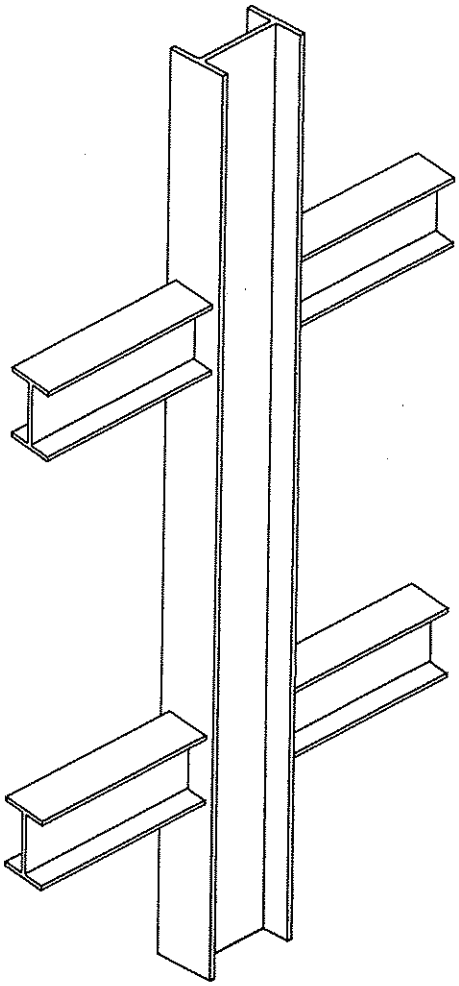
Discontinuous--Steel



Simple Example of a Preassembled Bent

Planar Vertical Elements (cont)

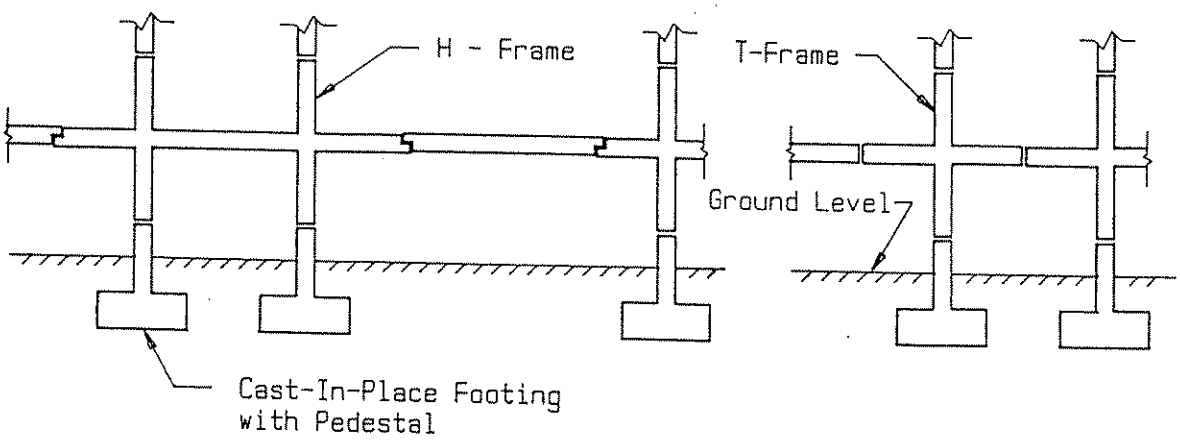
Discontinuous--Steel



Tree Column

Planar Vertical Elements (cont)
Discontinuous--Precast Concrete

H-Frame and T-Frame



(a) H - Frame Configuration

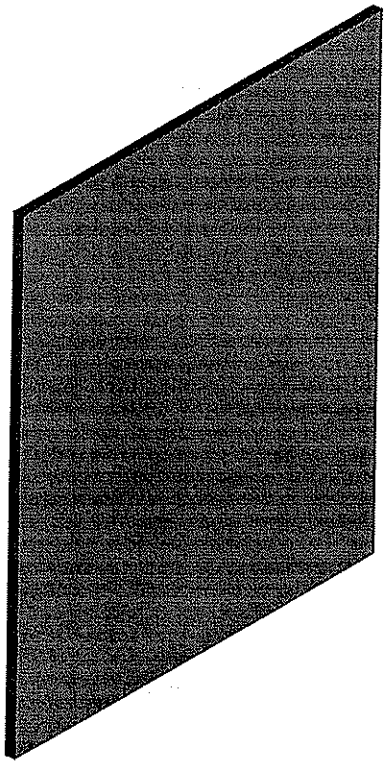
(b) T - Frame Configuration

Fig. 1.8.1 – Frame Configurations to Place Connections Outside of Plastic Regions

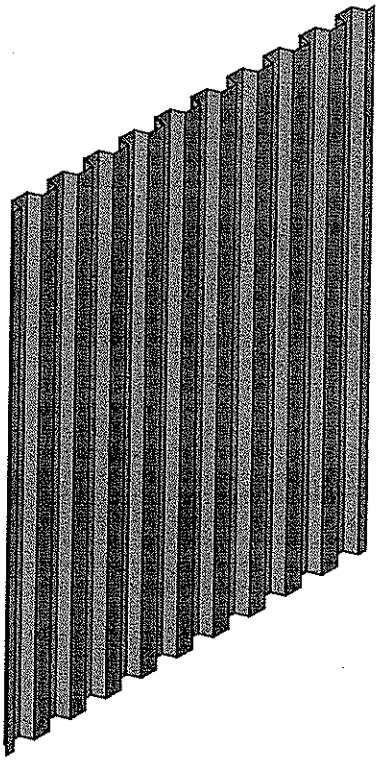
Source: PCI, 1988

Planar Vertical Elements (cont)

Continuous--Steel



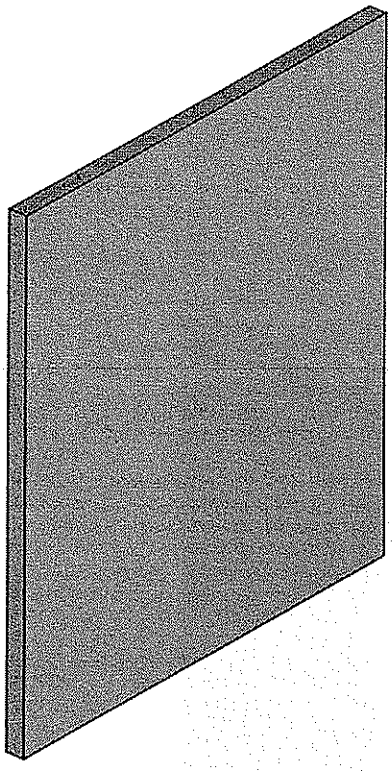
Steel Plates



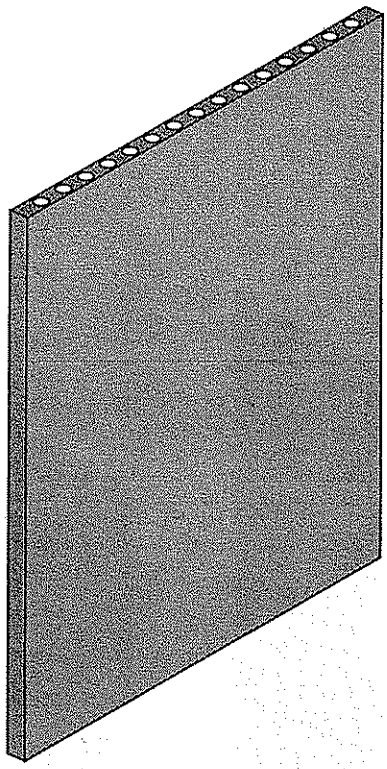
Corrugated Steel Sheets

Planar Vertical Elements (cont)

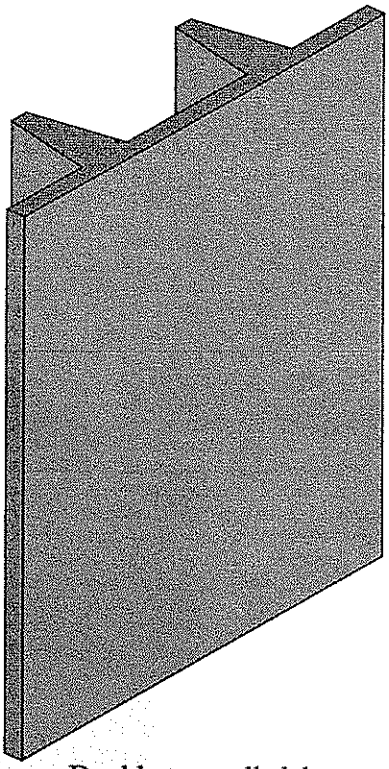
Continuous--Precast



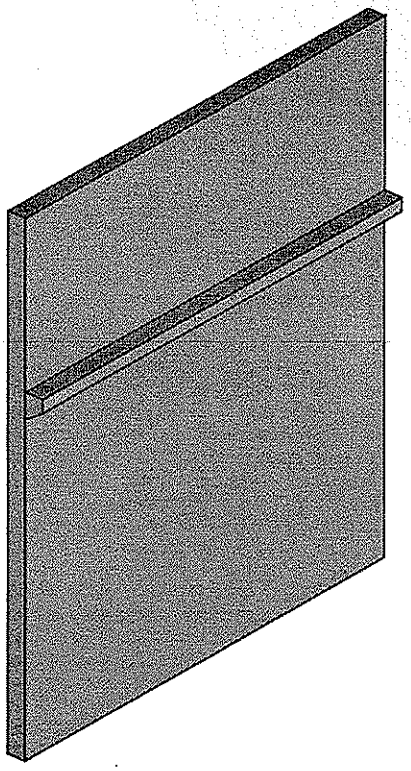
Solid flat wall slab



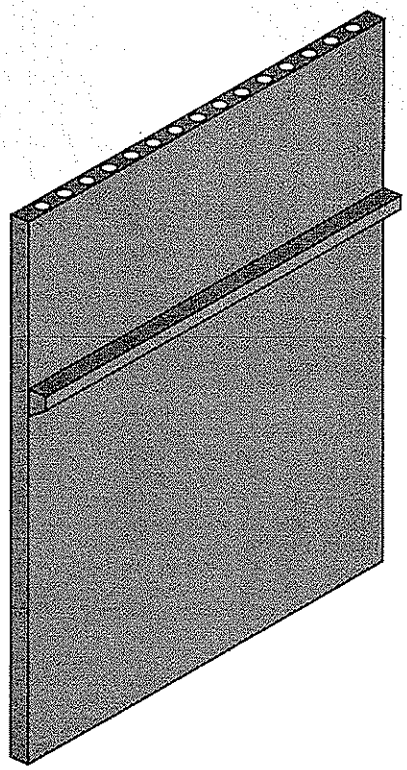
Hollow core wall slab



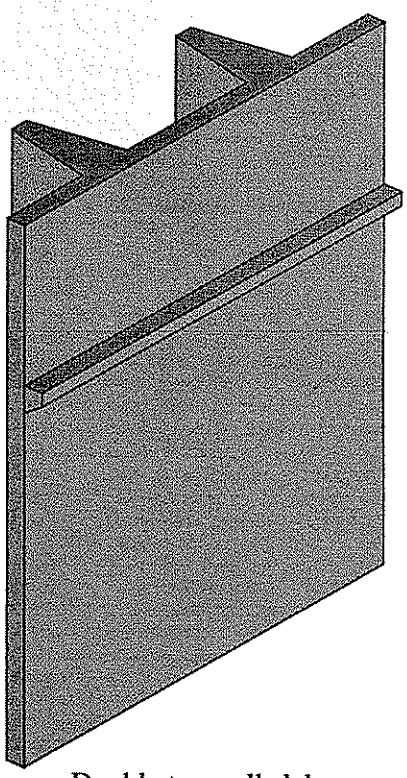
Double tee wall slab



Solid flat wall slab
with corbel



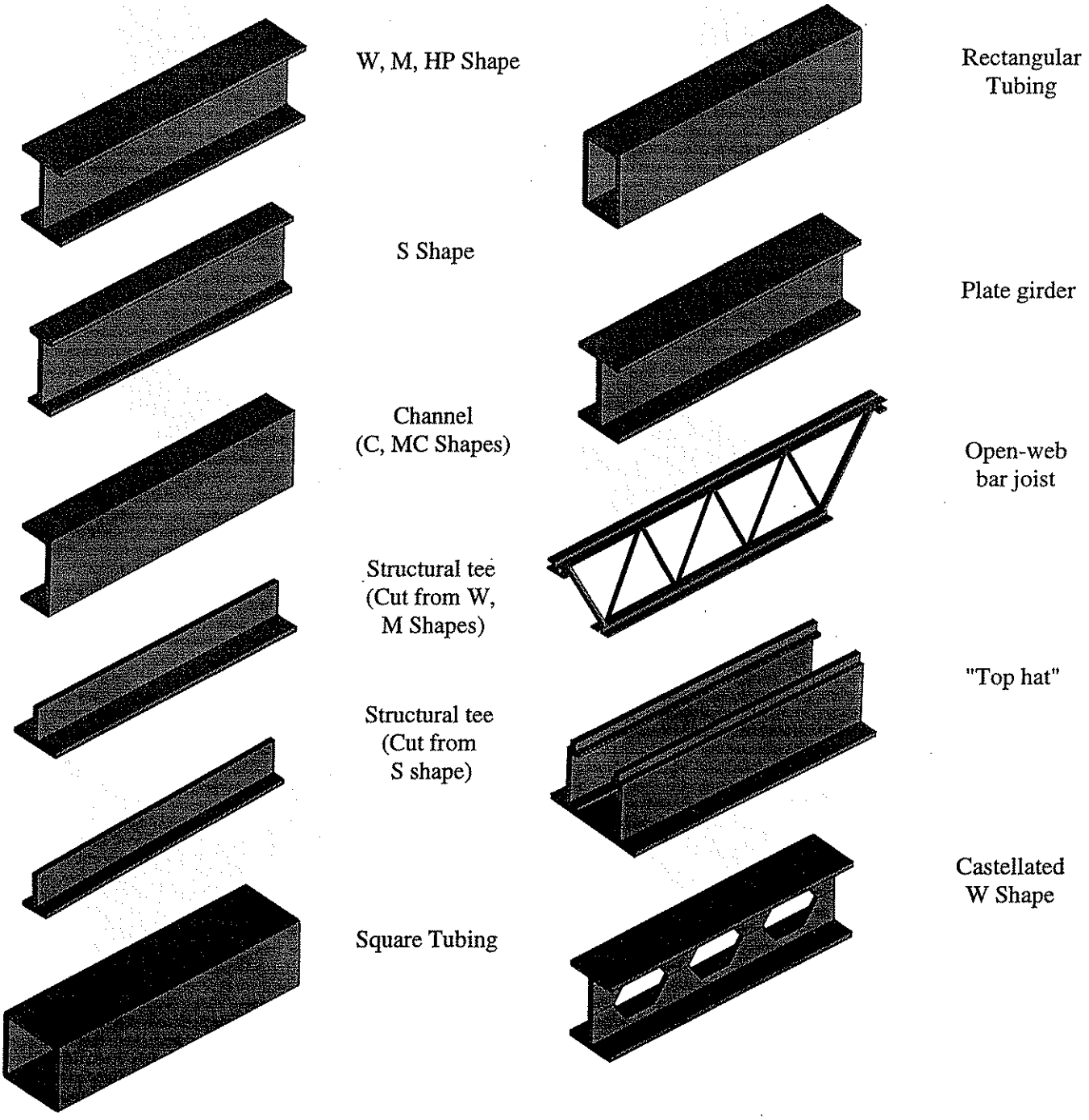
Hollow core wall slab
with corbel



Double tee wall slab
with corbels

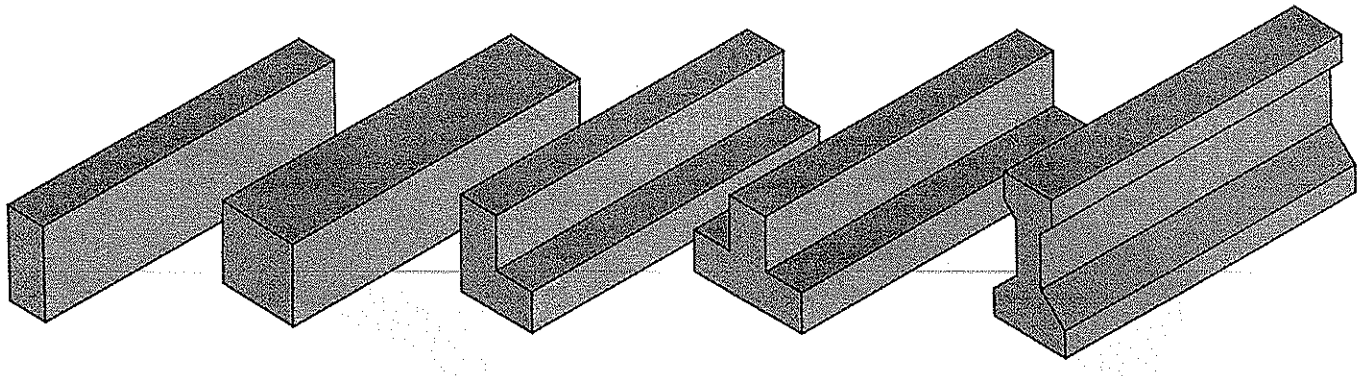
Single Horizontal Elements

Steel

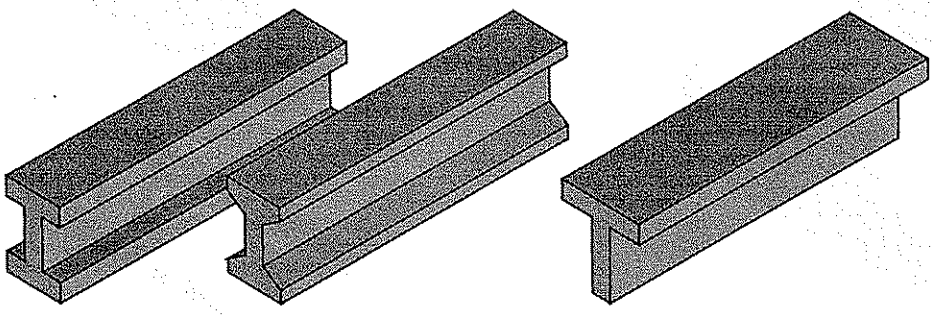


Single Horizontal Elements (cont)

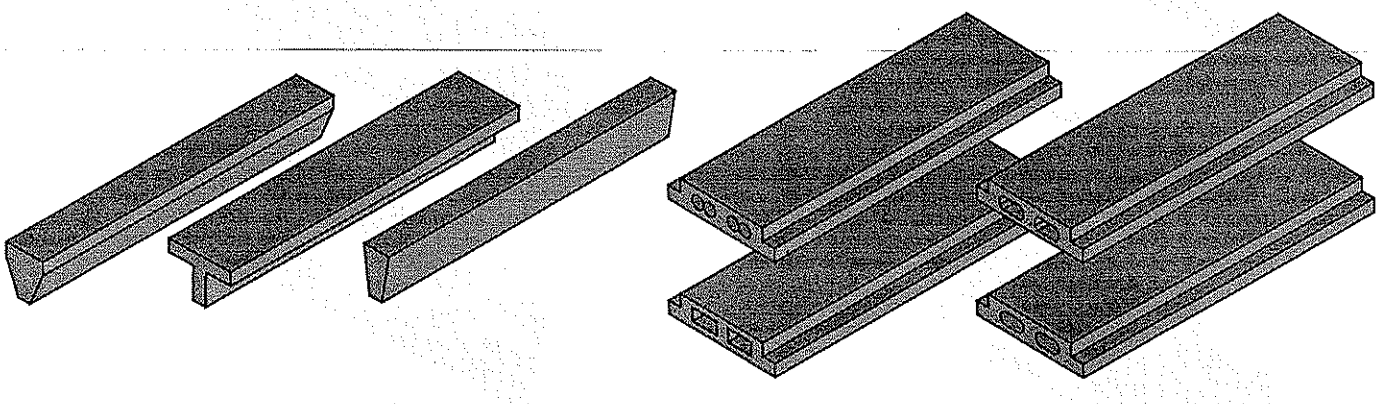
Precast Concrete



Rectangular Square L-shape Inverted tee AASHTO shape



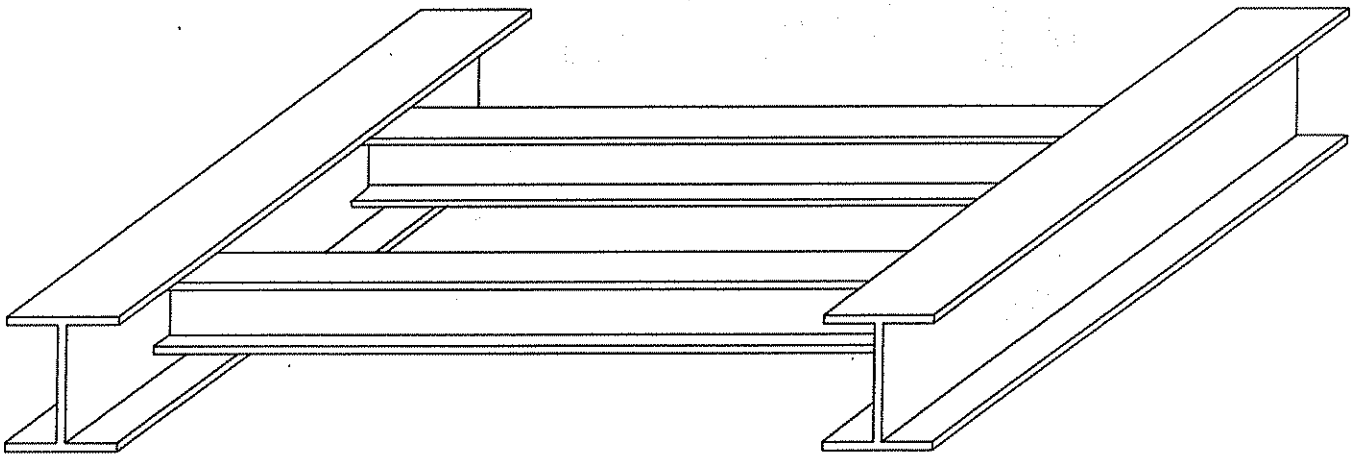
I-shapes T-shape



Other miscellaneous shapes

Planar Horizontal Elements

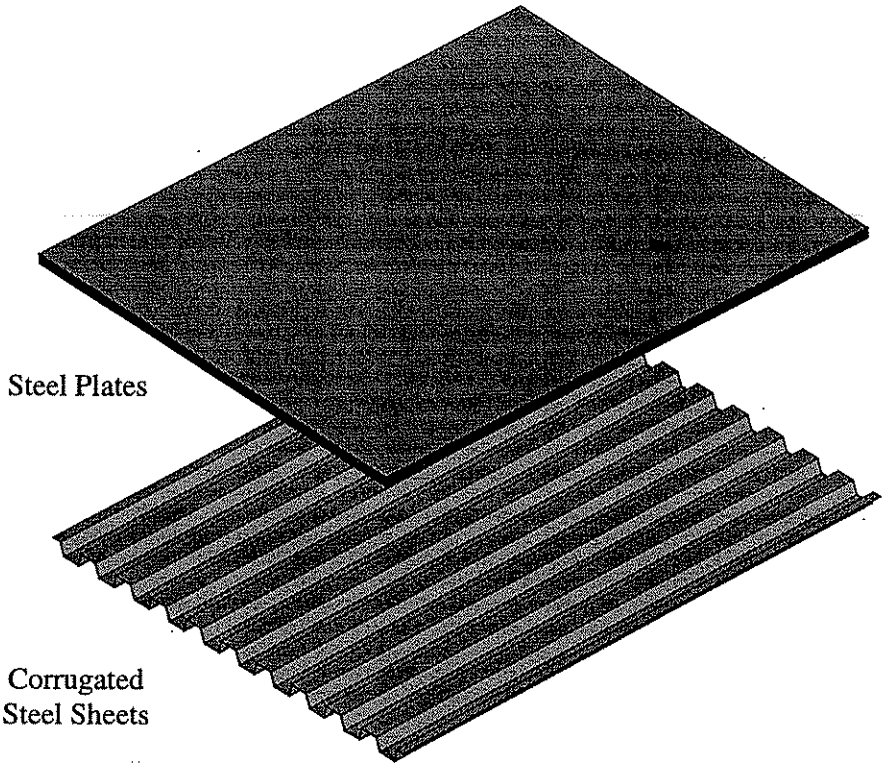
Discontinuous--Steel



Simple Example of a Preassembled Panel

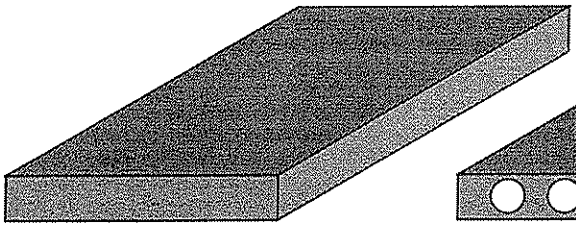
Planar Horizontal Elements (cont)

Continuous--Steel

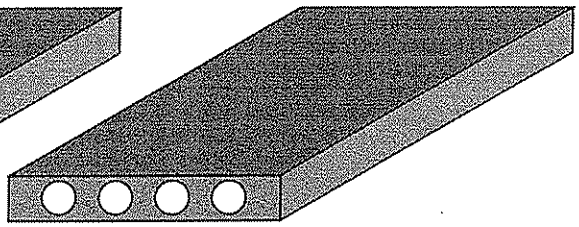


Planar Horizontal Elements (cont)

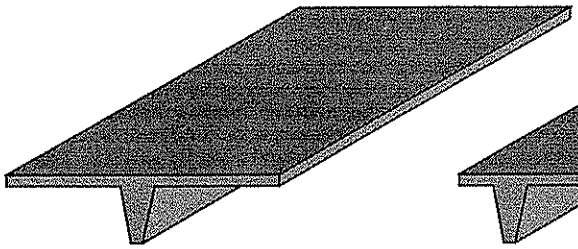
Continuous--Precast Concrete



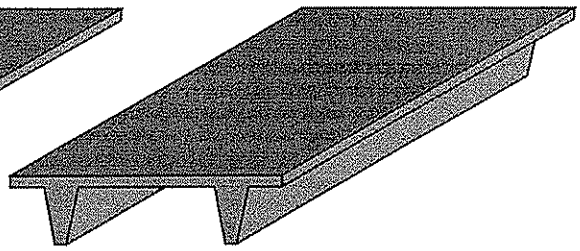
Solid rectangular slab



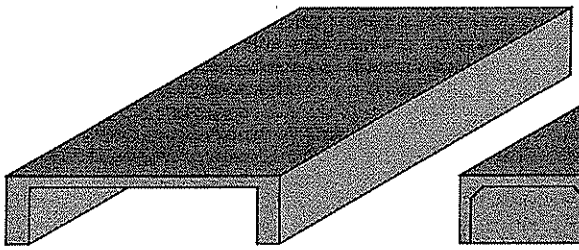
Hollow core slab



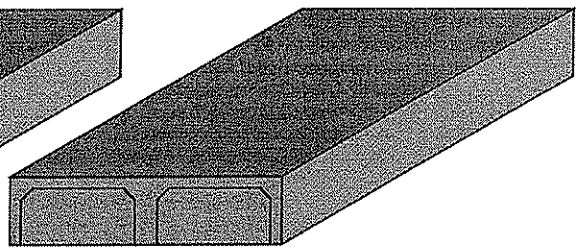
Single tee slab



Double tee slab



Channel slab



Ribbed (cassette) slab

Three-Dimensional Elements
Discontinuous--Steel

Cubic Frame System

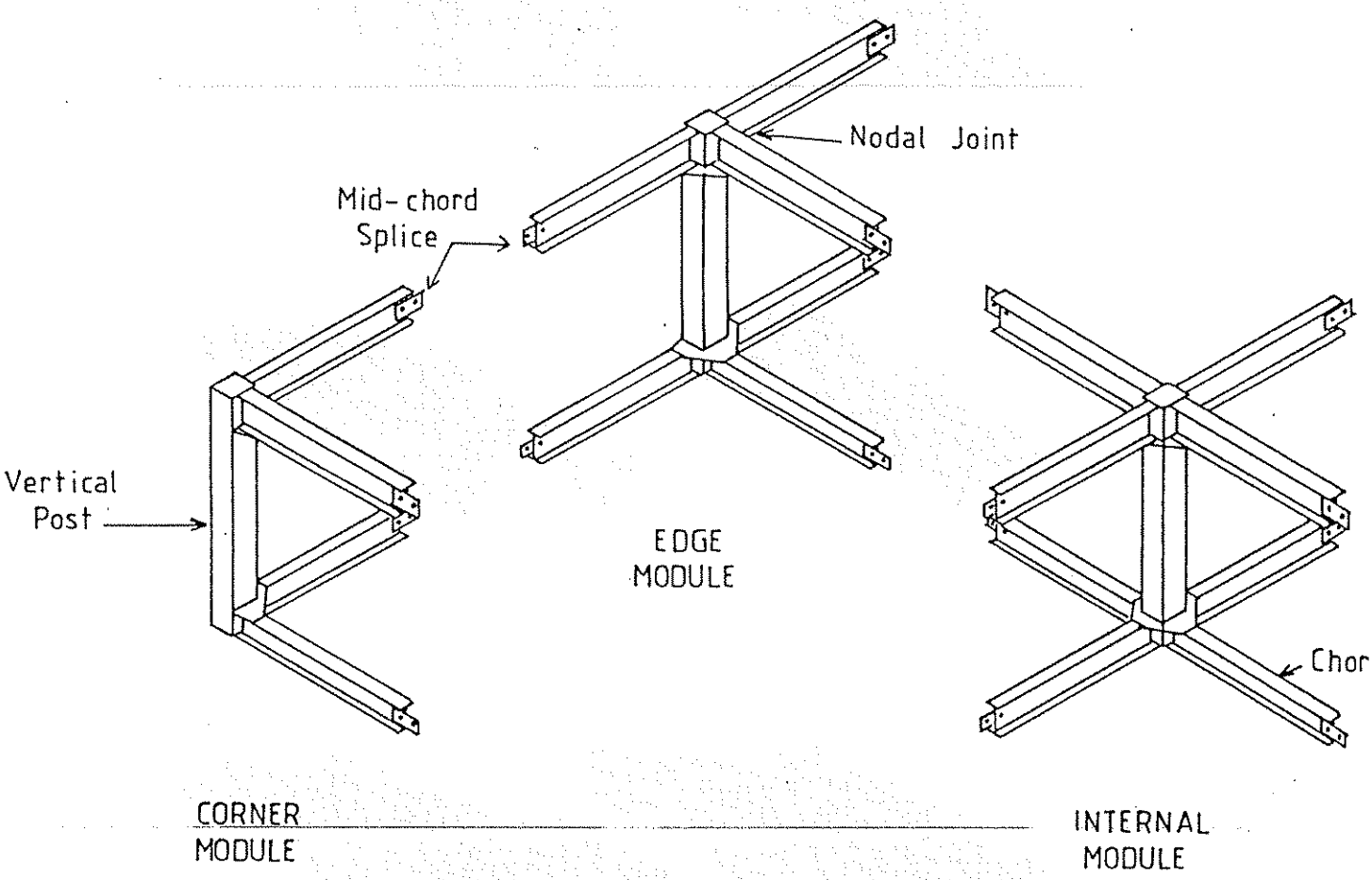
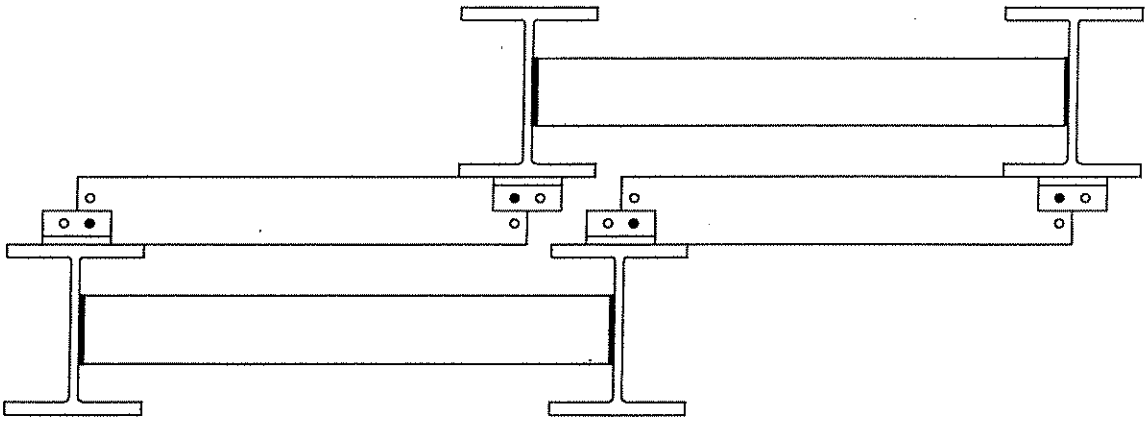


Fig. 1 Module types

Source: Kubic and Worrell (1991)

Three-Dimensional Elements (cont)

Discontinuous--Steel

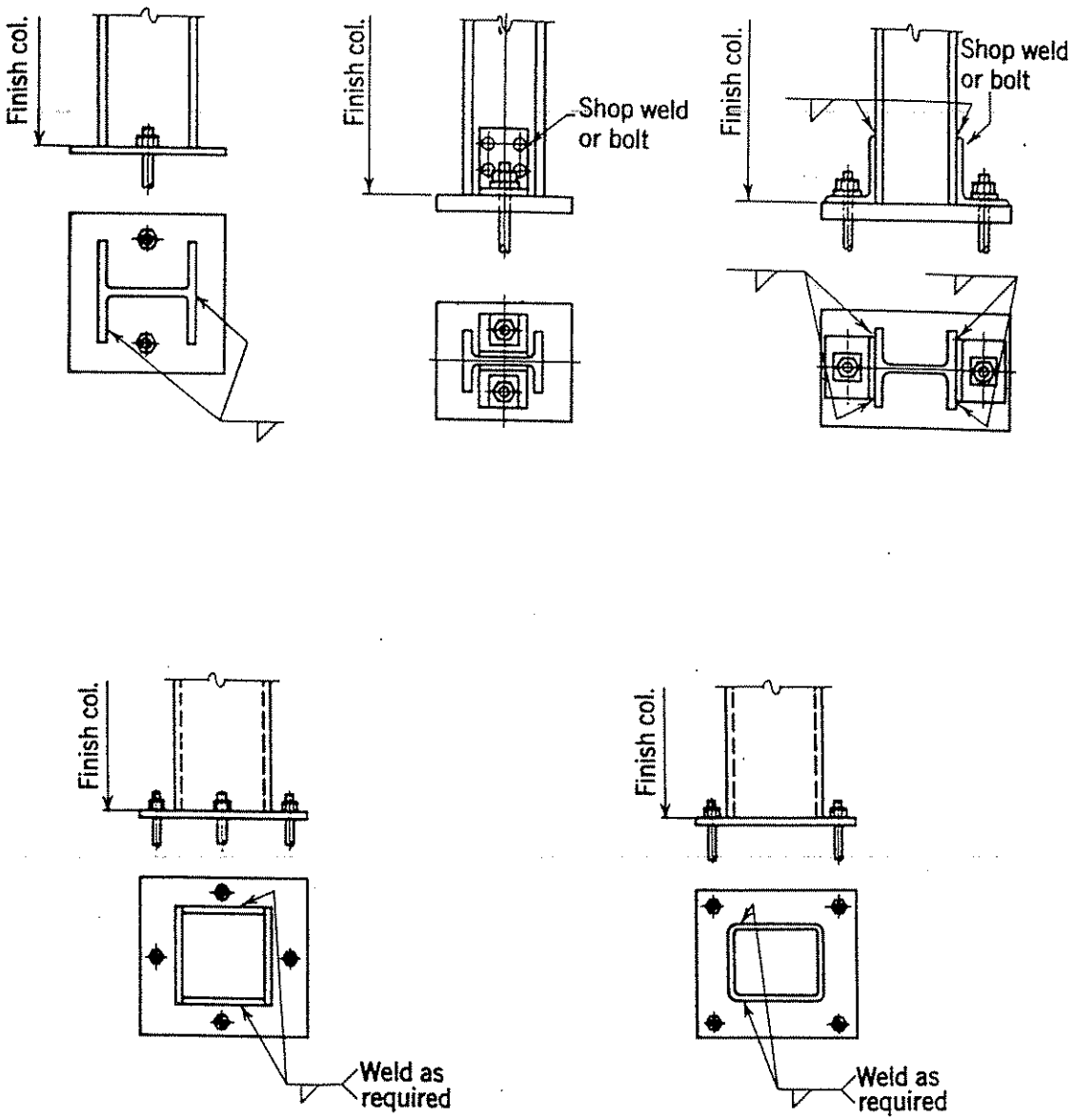


Falcon Steel's "Hinged" Section

CONNECTIONS

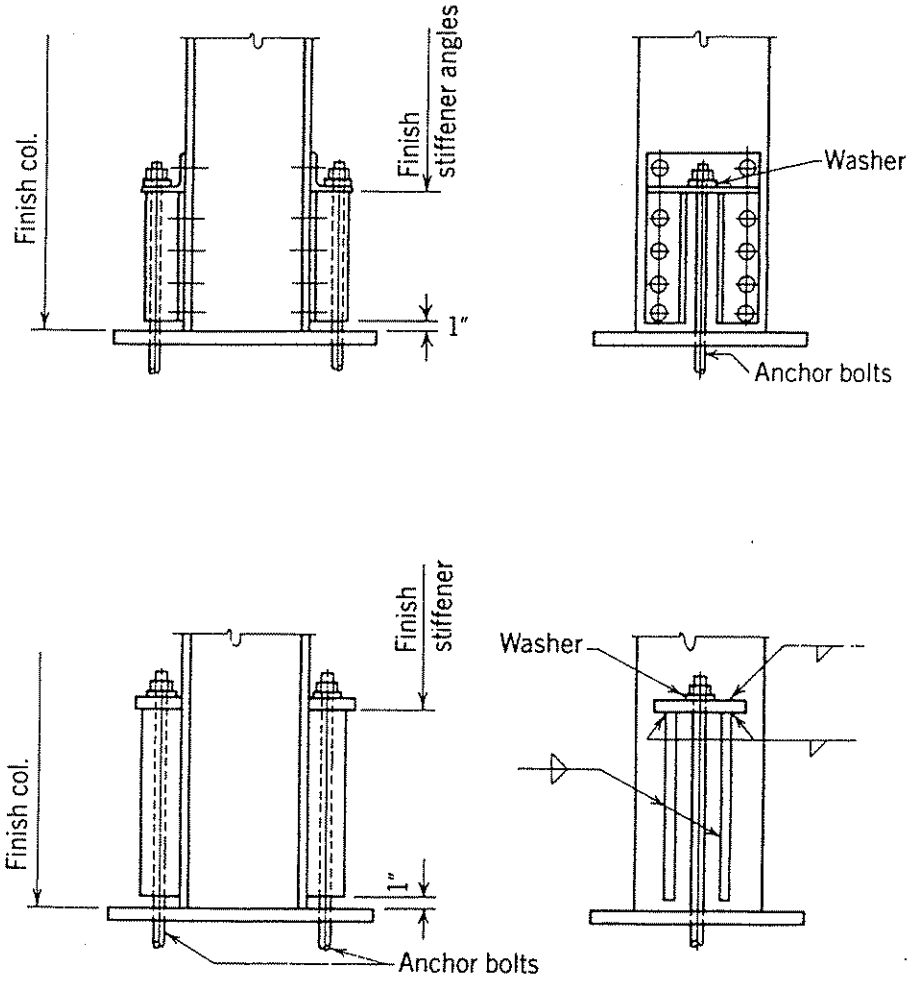
Single Vertical Element to Single Vertical Element

Steel Column to Foundation



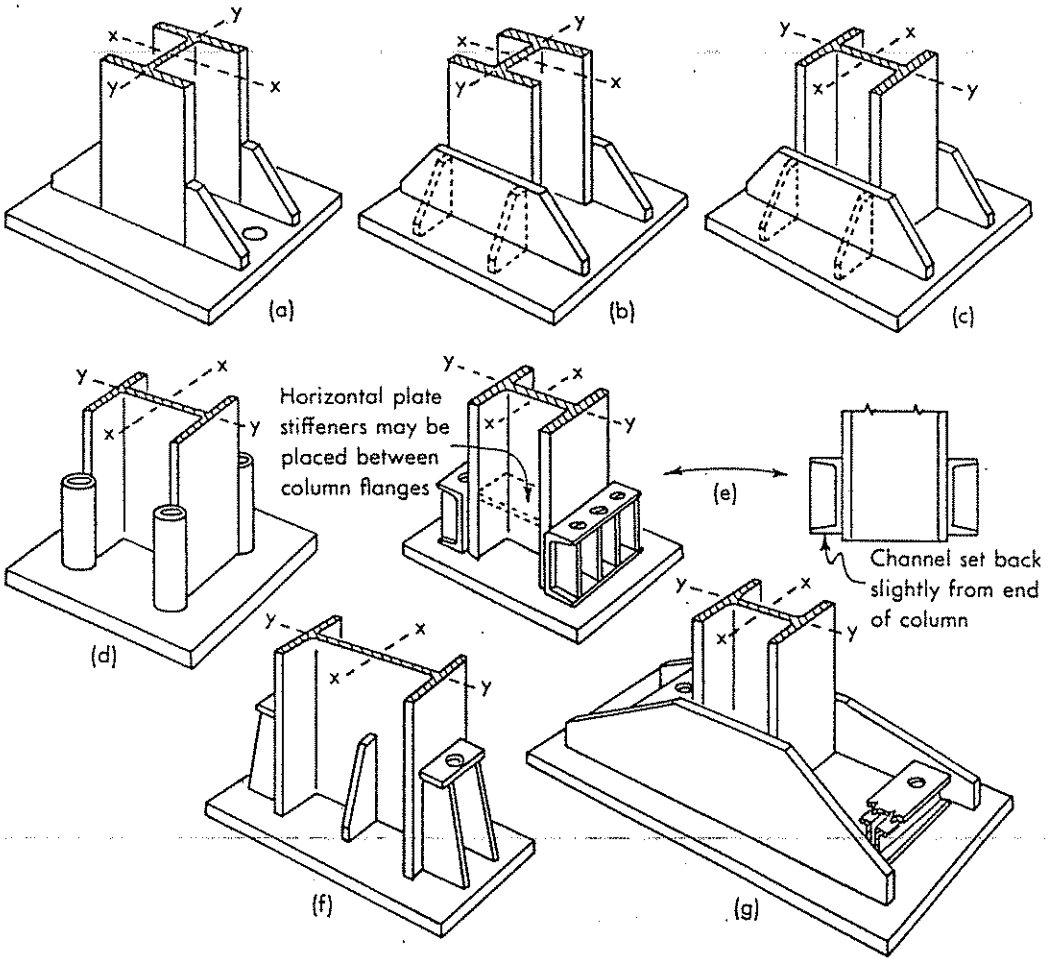
Source: AISC, 1986

Single Vertical Element to Single Vertical Element (cont)
Steel Column to Foundation



Source: AISC, 1986

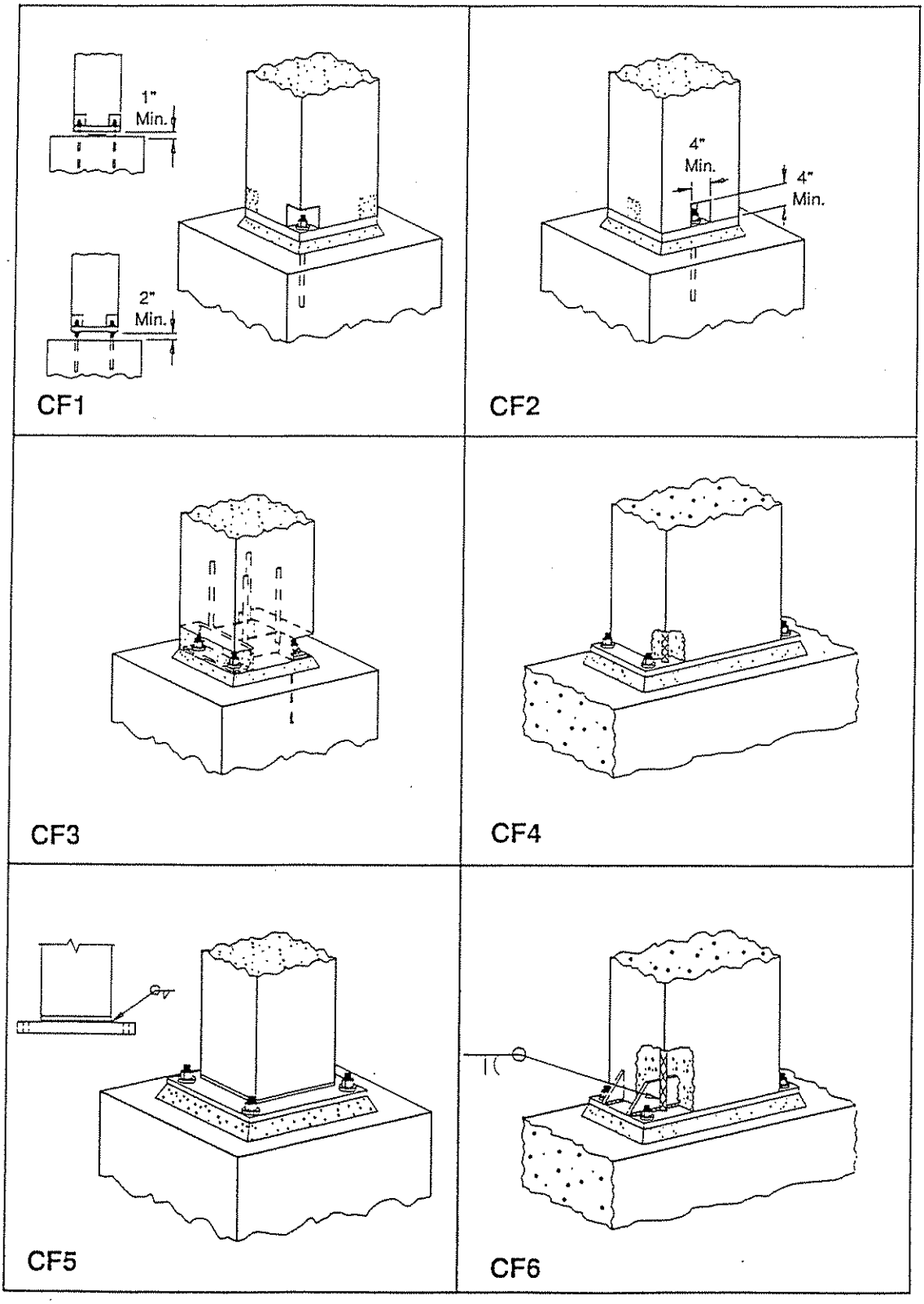
Single Vertical Element to Single Vertical Element (cont)
Steel Column to Foundation



Source: Blodgett, 1966

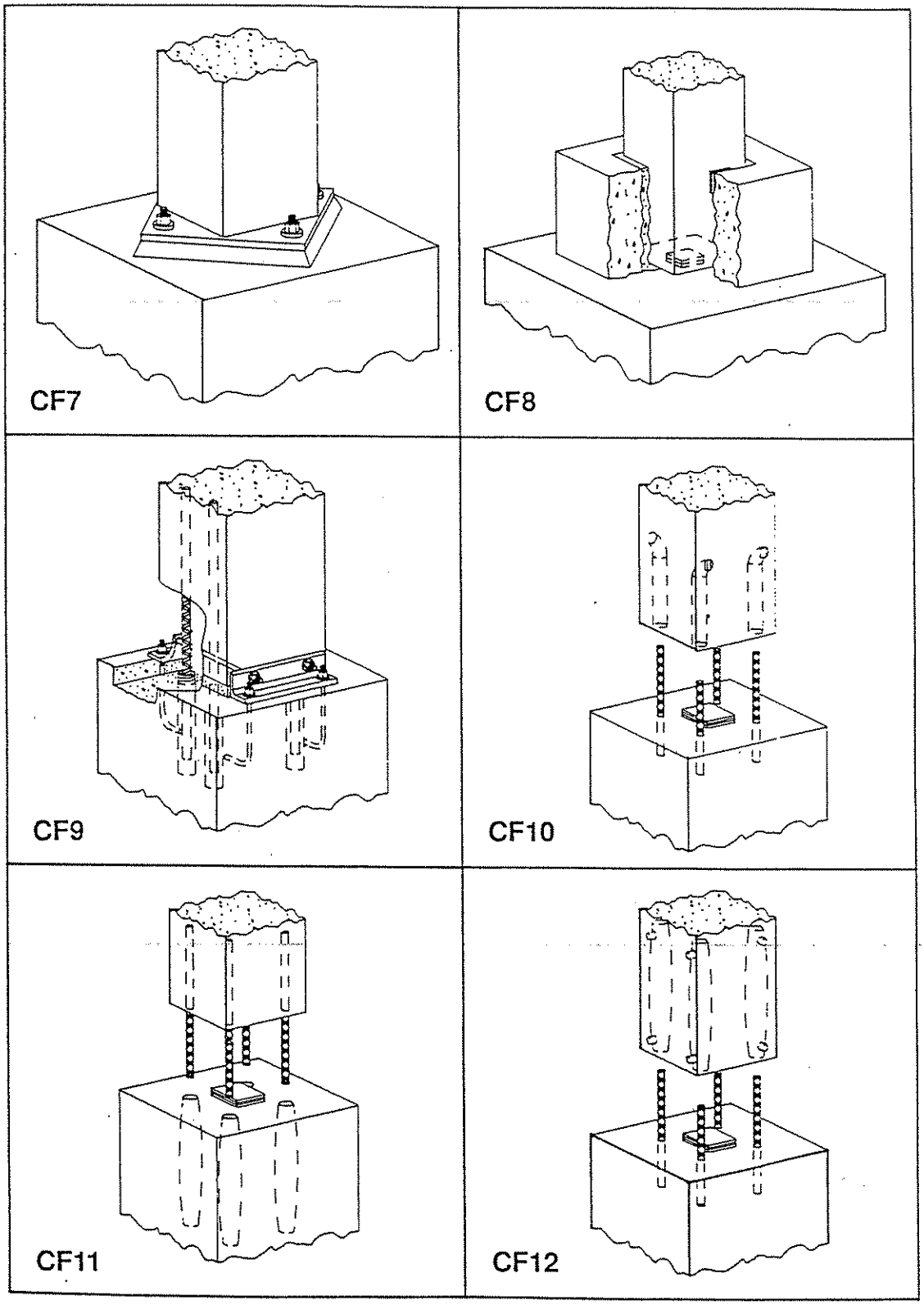
Single Vertical Element to Single Vertical Element (cont)

Precast Concrete Column to Foundation



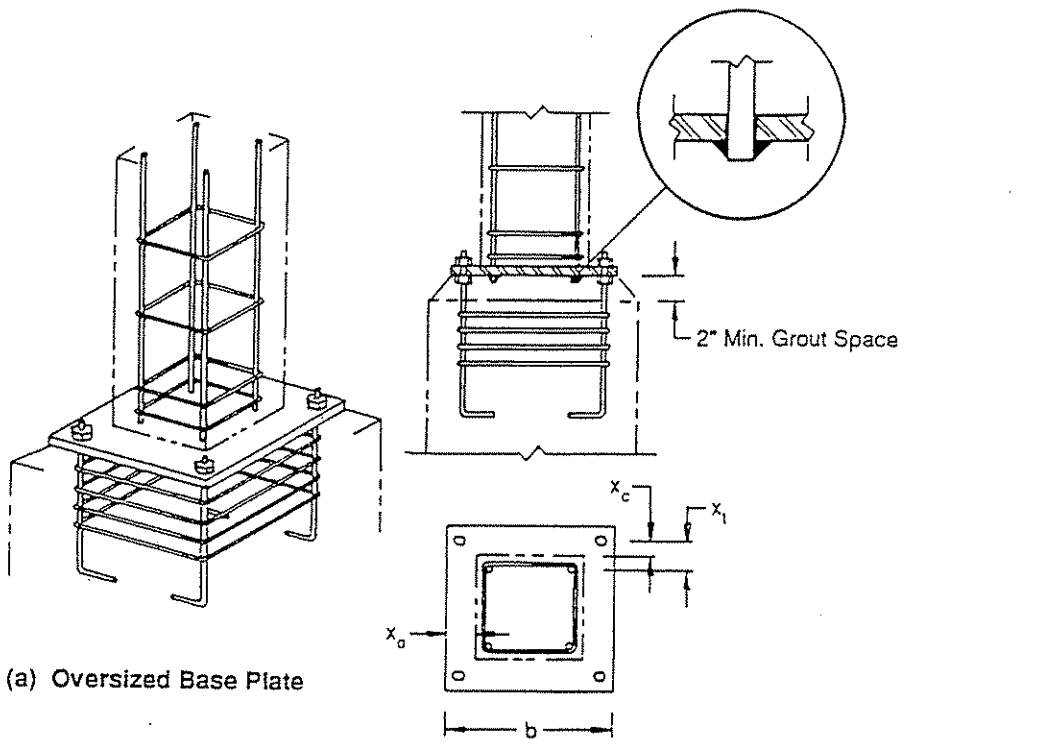
Source: PCI, 1988

Single Vertical Element to Single Vertical Element (cont)
Precast Concrete Column to Foundation

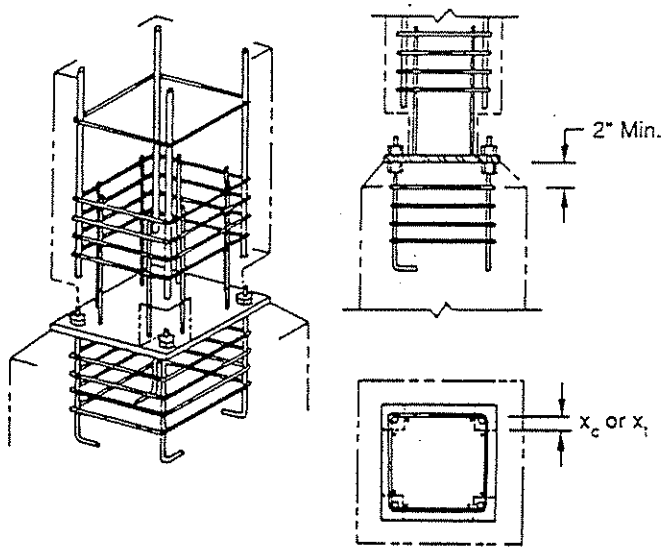


Source: PCI, 1988

Single Vertical Element to Single Vertical Element (cont)
Precast Concrete Column to Foundation



(a) Oversized Base Plate



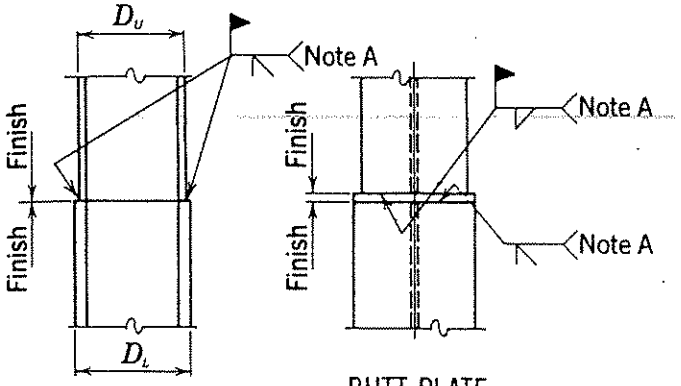
(b) Flush Base Plate

Fig. 4.13.1 – Column Base Connections

Source: PCI, 1988

Single Vertical Element to Single Vertical Element (cont)
Steel Column to Steel Column

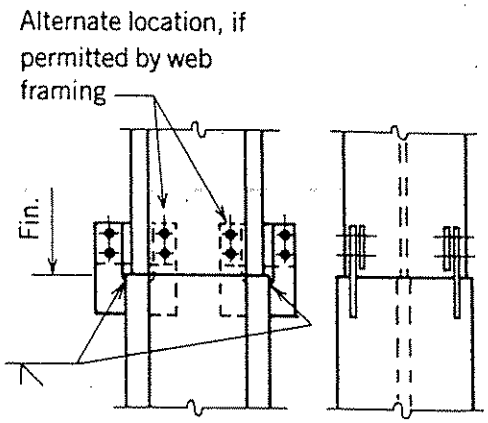
WELDED



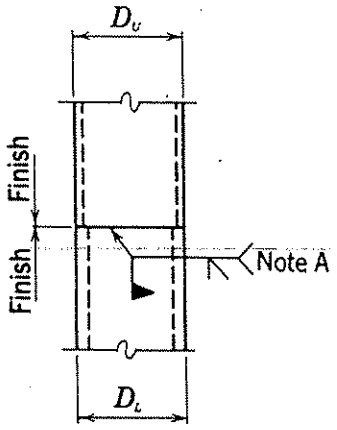
DEPTH OF D_U AND D_L NOMINALLY THE SAME

BUTT PLATE

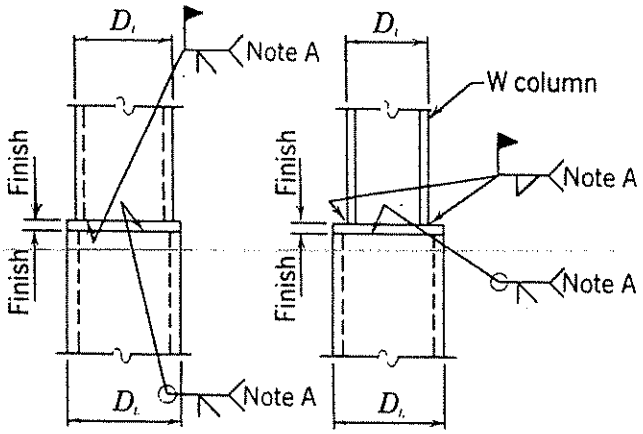
DEPTH D_U NOMINALLY 2 IN. LESS THAN D_L



ERECTION AID AND STABILITY DEVICE



DEPTH OF D_U AND D_L NOMINALLY THE SAME



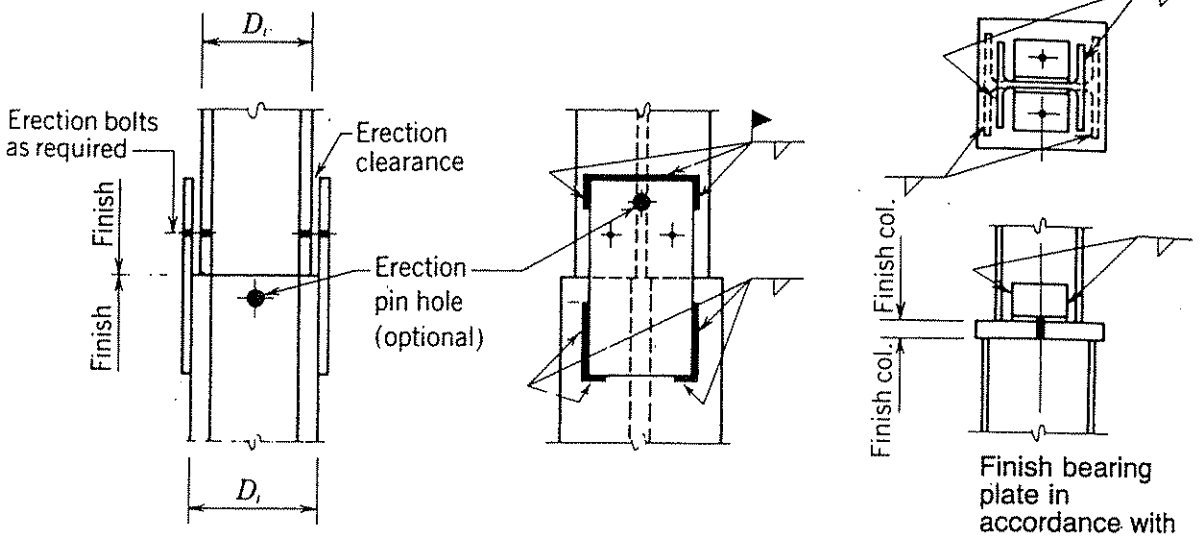
BUTT PLATE

DEPTH D_U NOMINALLY 2 IN. LESS THAN D_L

Source: AISC, 1986

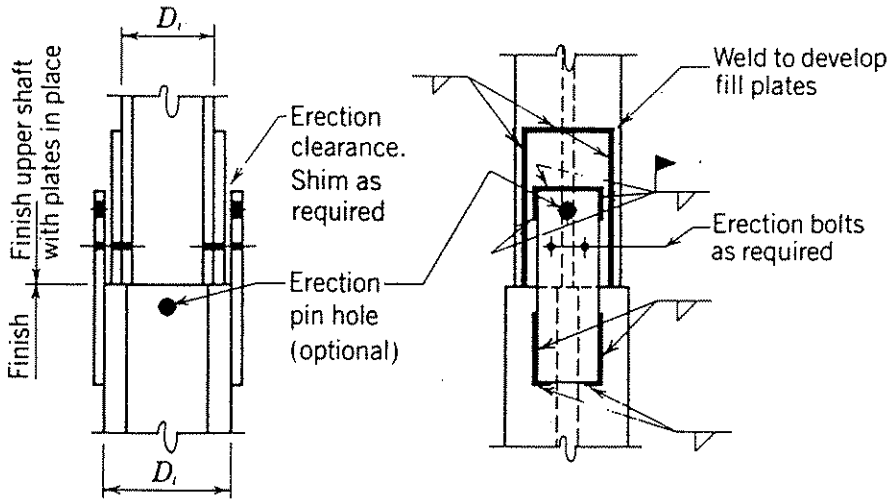
Single Vertical Element to Single Vertical Element (cont)
Steel Column to Steel Column

WELDED



DEPTH OF D_U AND D_L NOMINALLY THE SAME

BUTT PLATE

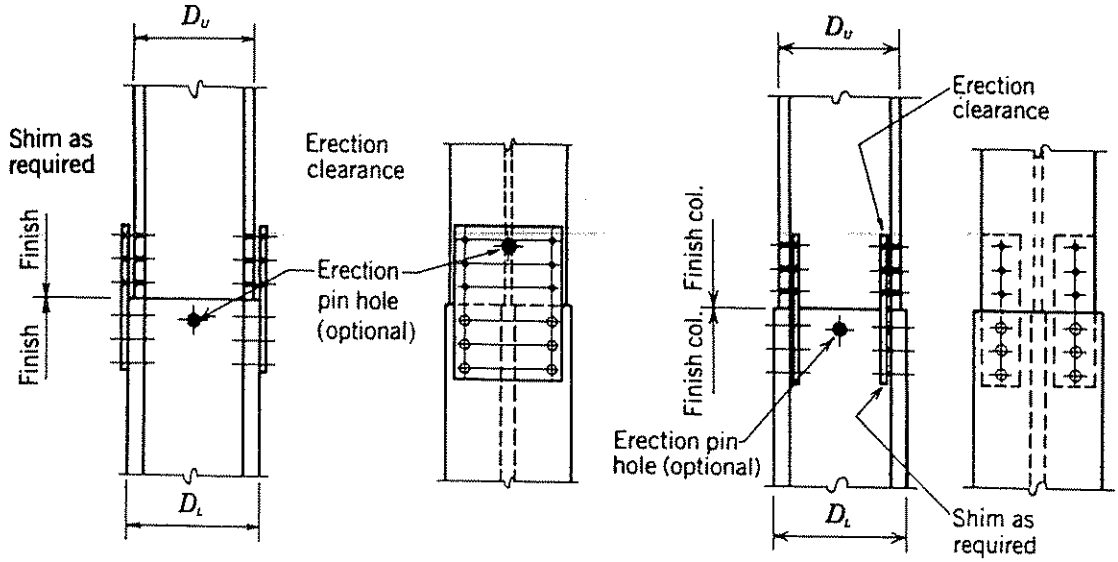


DEPTH D_U NOMINALLY 2 IN. LESS THAN D_L

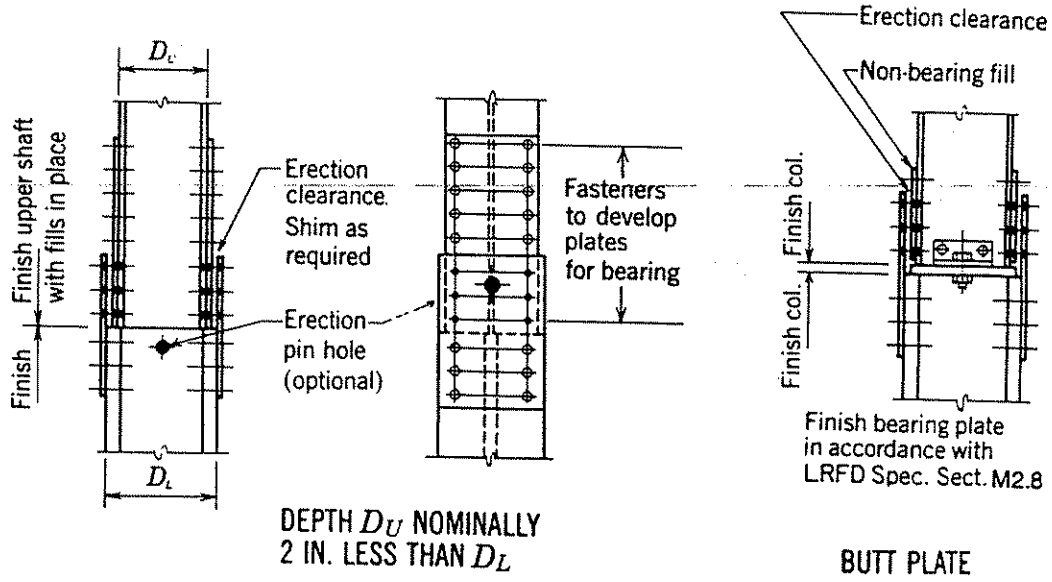
Source: AISC, 1986

Single Vertical Element to Single Vertical Element (cont)
Steel Column to Steel Column

RIVETED AND BOLTED



DEPTH OF D_U AND D_L NOMINALLY THE SAME



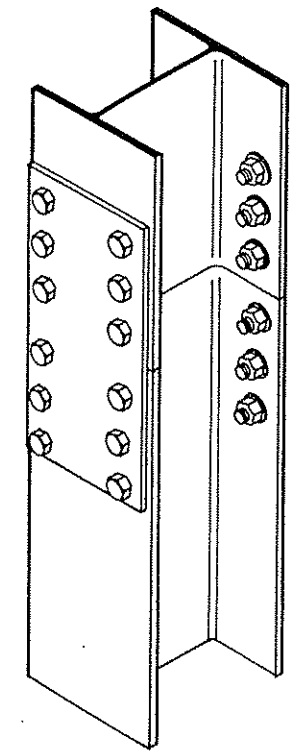
DEPTH D_U NOMINALLY 2 IN. LESS THAN D_L

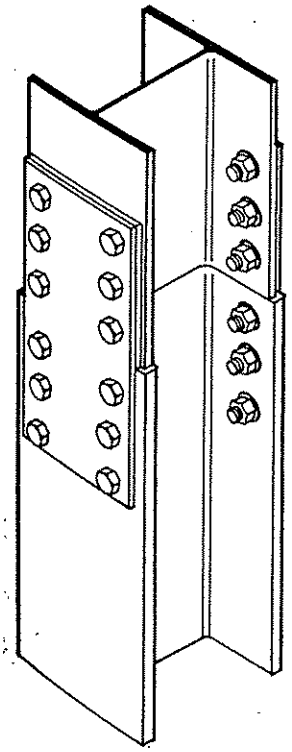
BUTT PLATE

Source: AISC, 1986

Single Vertical Element to Single Vertical Element (cont)

Steel Column to Steel Column





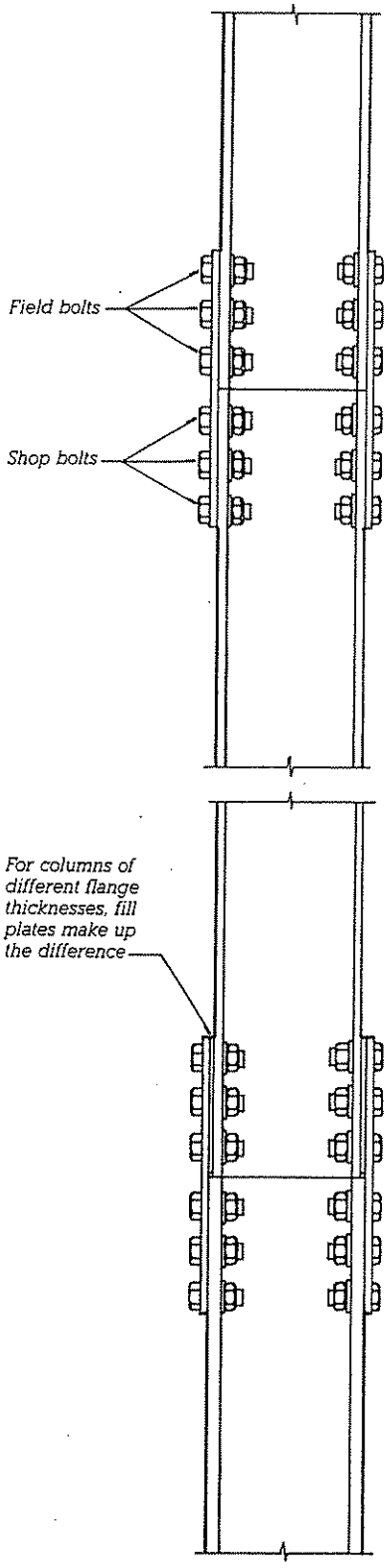


FIGURE 9.35
Bolted column-column connections. Column sizes diminish as the building rises, requiring frequent use of the lower detail.

Source: Allen, 1985

Single Vertical Element to Single Vertical Element (cont)
Steel Column to Steel Column

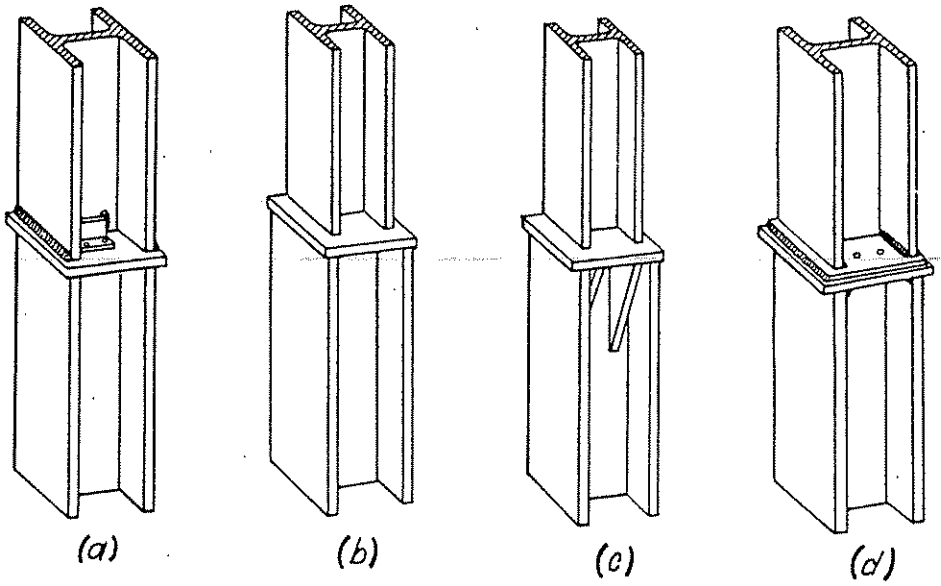


FIG. 1—Typical Column Splices

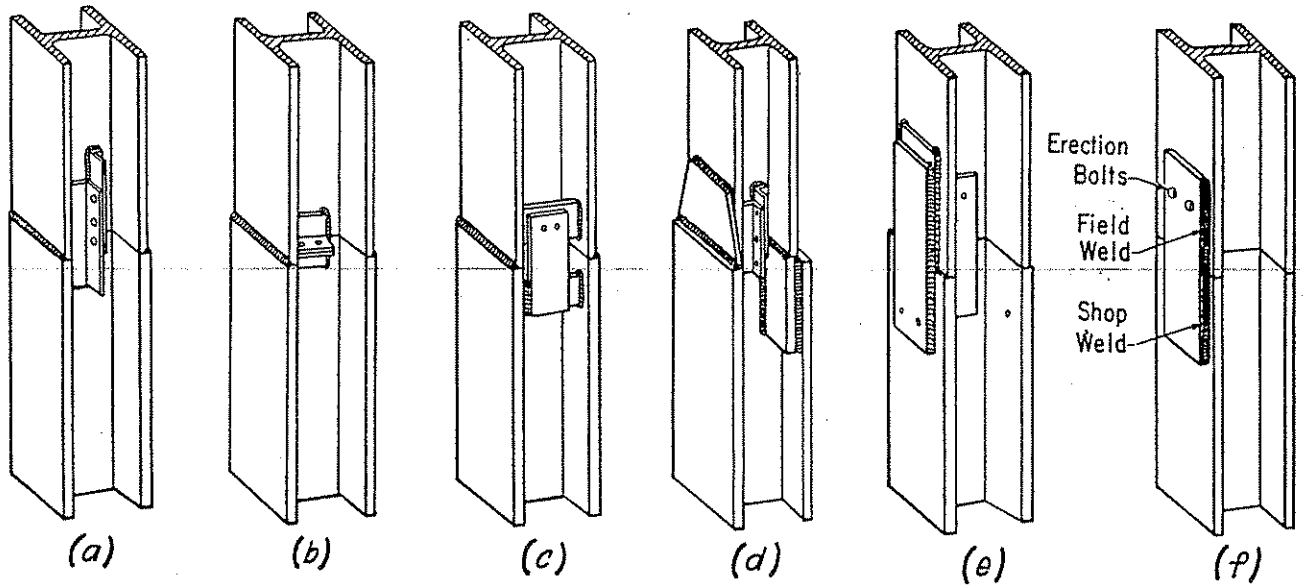


FIG. 2 — Typical Column Splices

Source: Blodgett, 1966

Single Vertical Element to Single Vertical Element (cont)

Steel Column to Steel Column

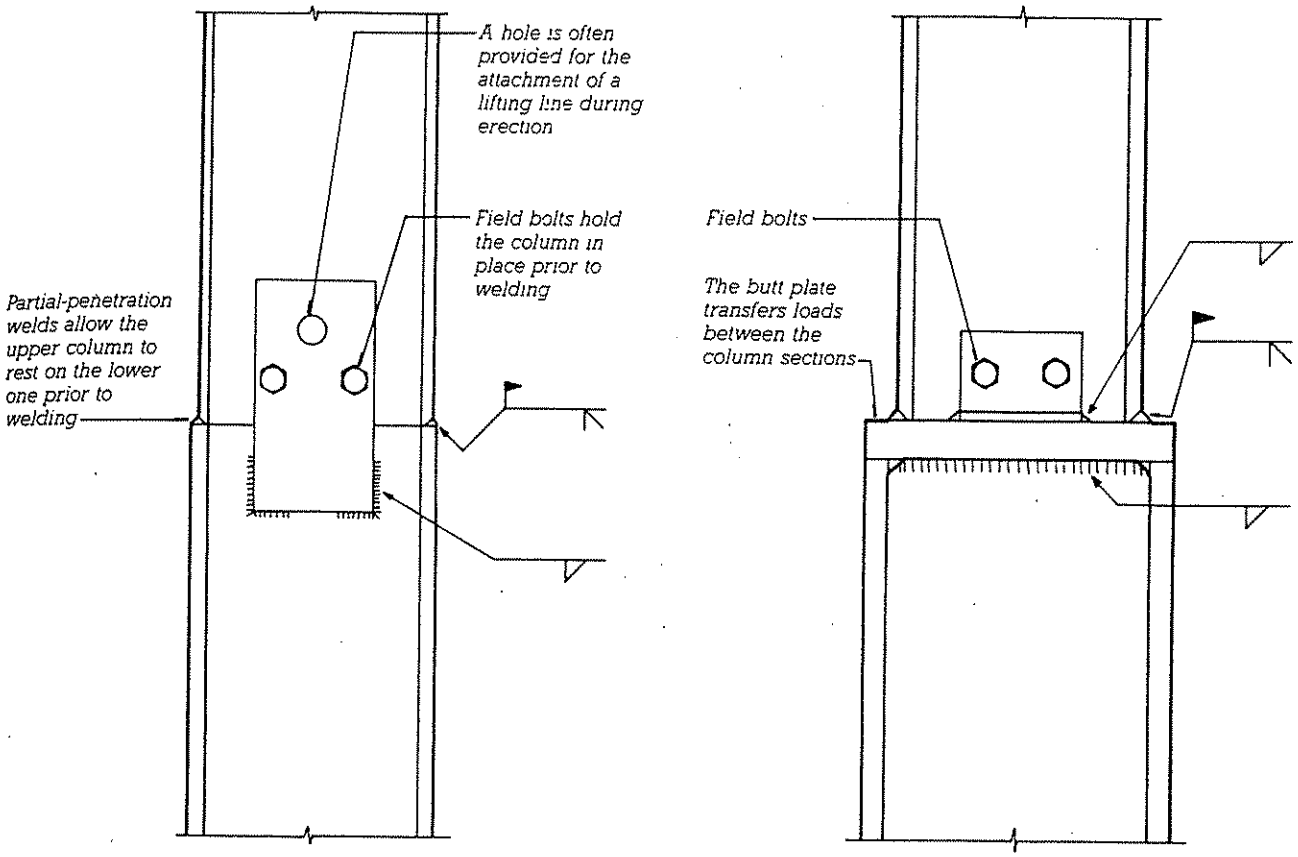
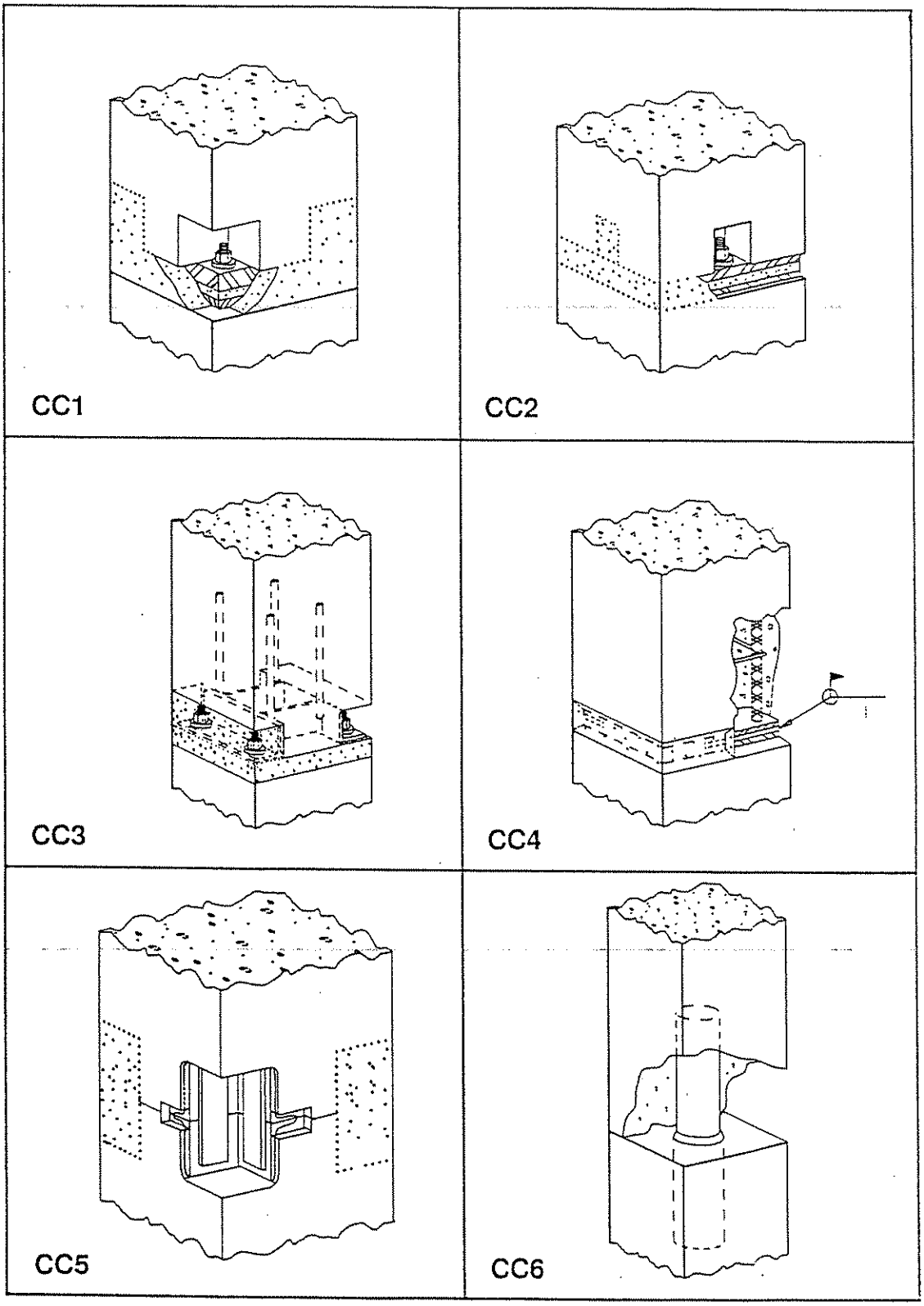


FIGURE 9.39
Welded column-column connections. The butt plate connection is used when a column changes from one nominal size of wide-flange to another.

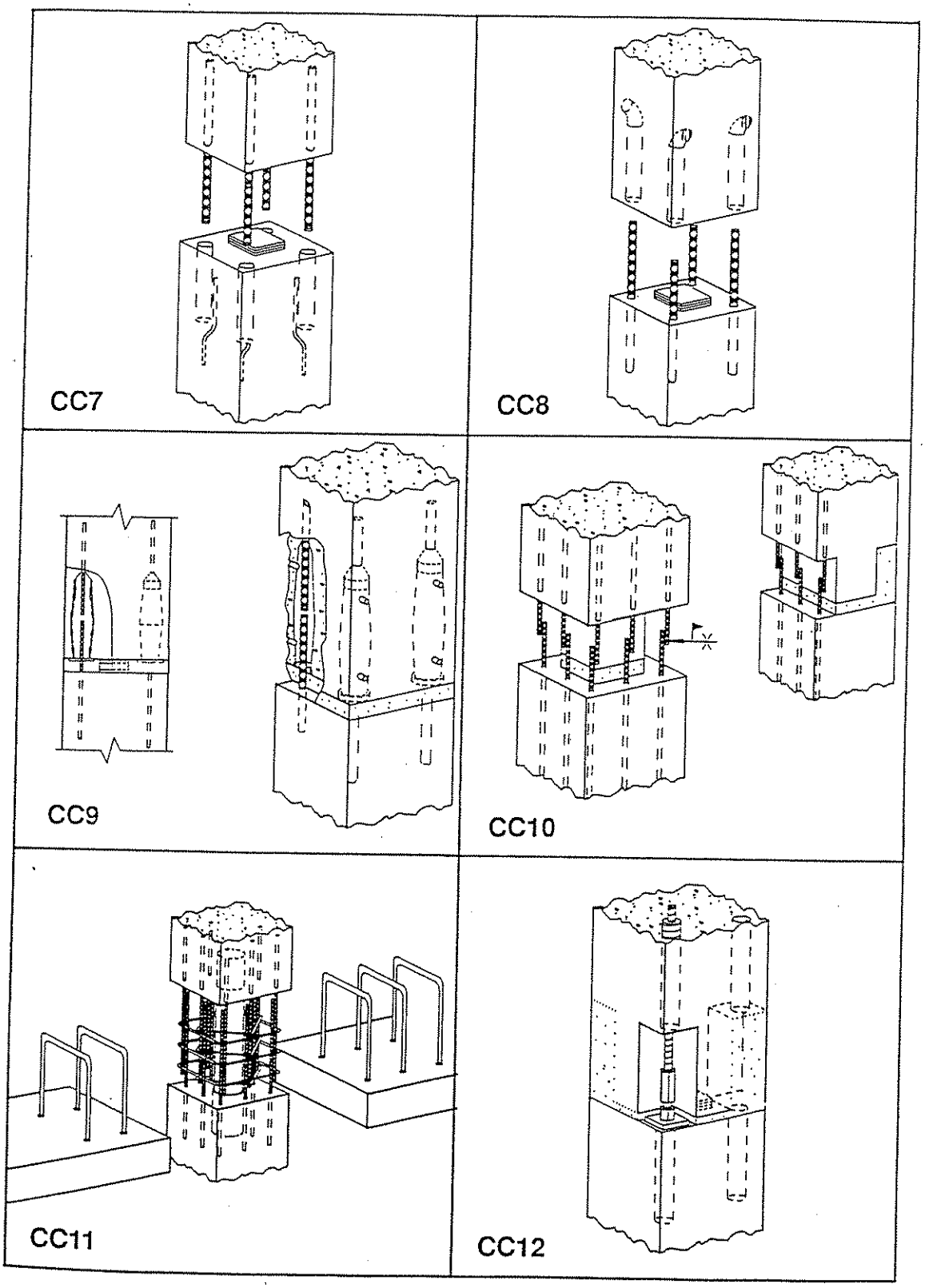
Source: Allen, 1985

Single Vertical Element to Single Vertical Element (cont)
Precast Concrete Column to Precast Concrete Column



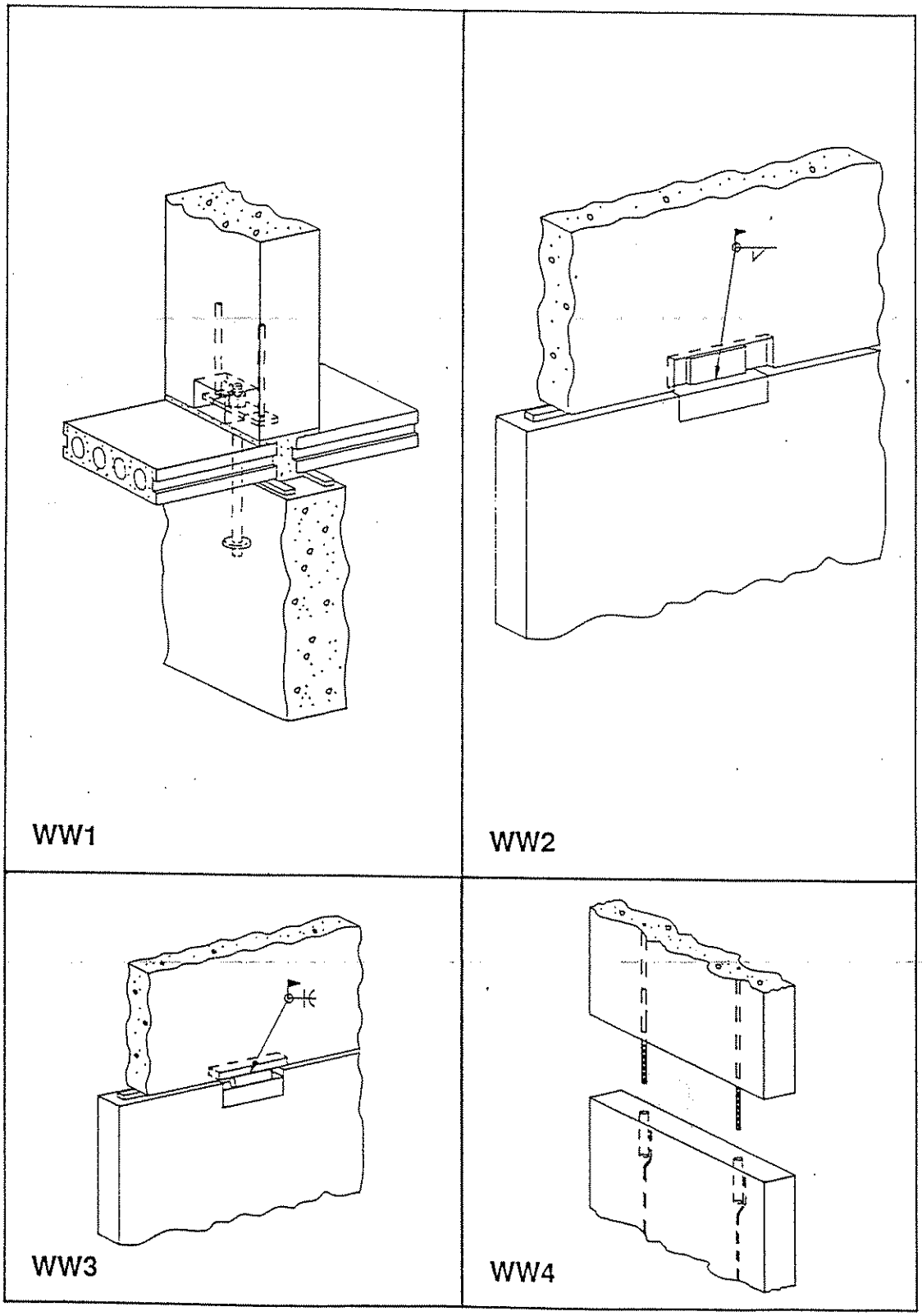
Source: PCI, 1988

Single Vertical Element to Single Vertical Element (cont)
Precast Concrete Column to Precast Concrete Column



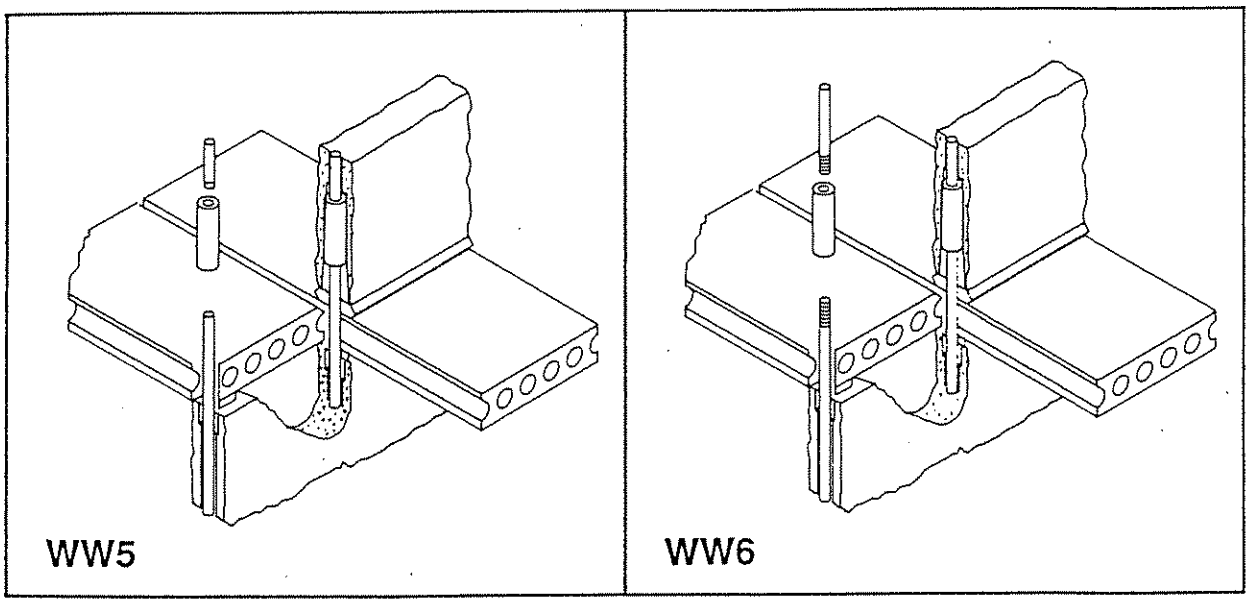
Source: PCI, 1988

Planar Vertical Element to Planar Vertical Element
Precast Concrete Wall Slab to Precast Concrete Wall Slab



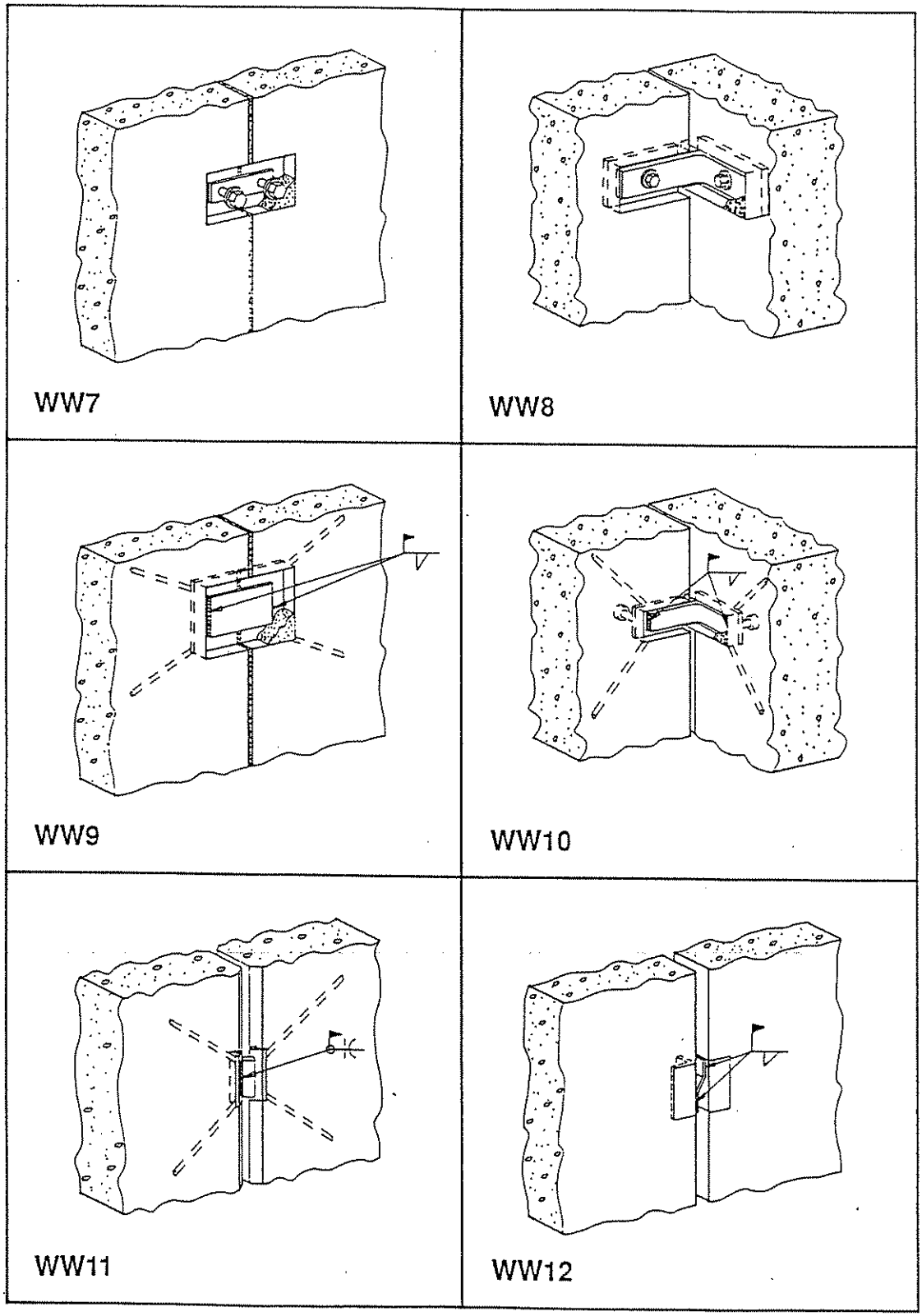
Source: PCI, 1988

Planar Vertical Element to Planar Vertical Element (cont)
Precast Concrete Wall Slab to Precast Concrete Wall Slab



Source: PCI, 1988

Planar Vertical Element to Planar Vertical Element (cont)
Precast Concrete Wall Slab to Precast Concrete Wall Slab



Source: PCI, 1988

Planar Vertical Element to Planar Vertical Element (cont)
Precast Concrete Wall Slab to Precast Concrete Wall Slab

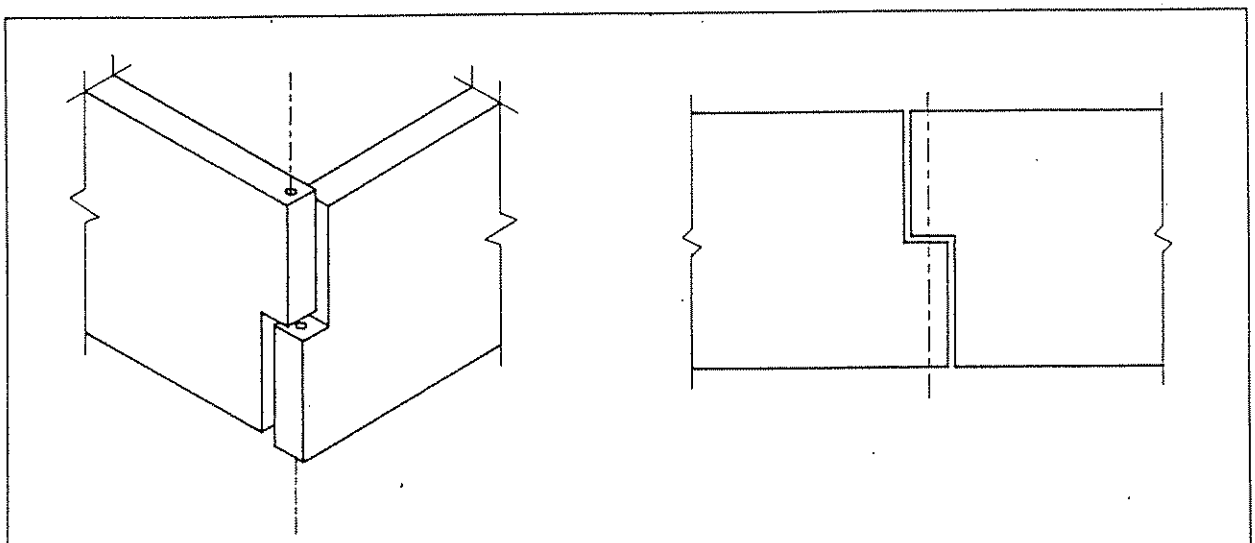


Fig. 1.8.3 – Vertical Joints in Shear Walls

Source: PCI, 1988

Planar Vertical Element to Planar Vertical Element (cont)
Precast Concrete Wall Slab to Precast Concrete Wall Slab

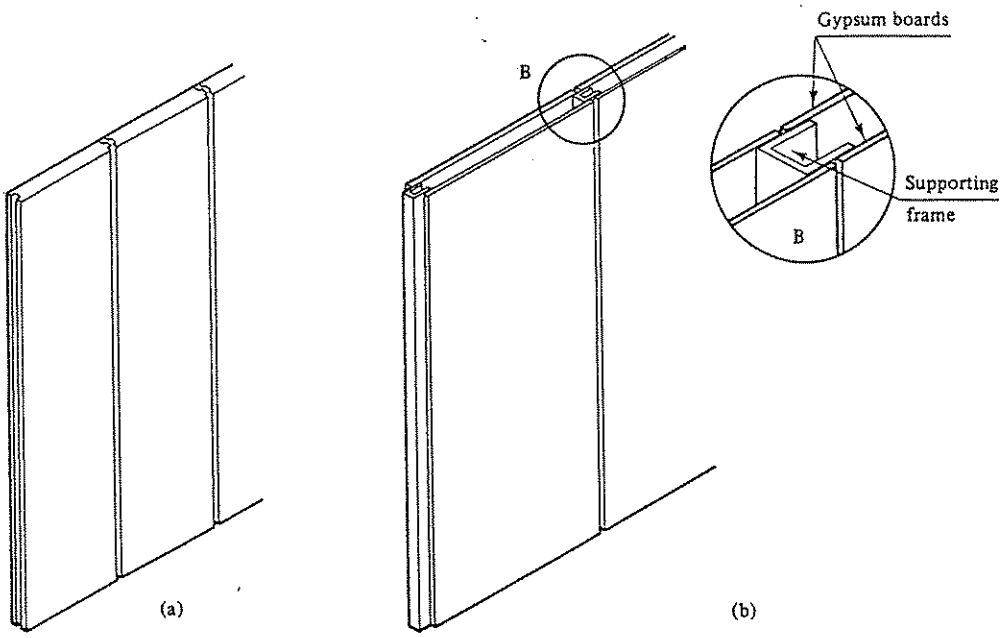
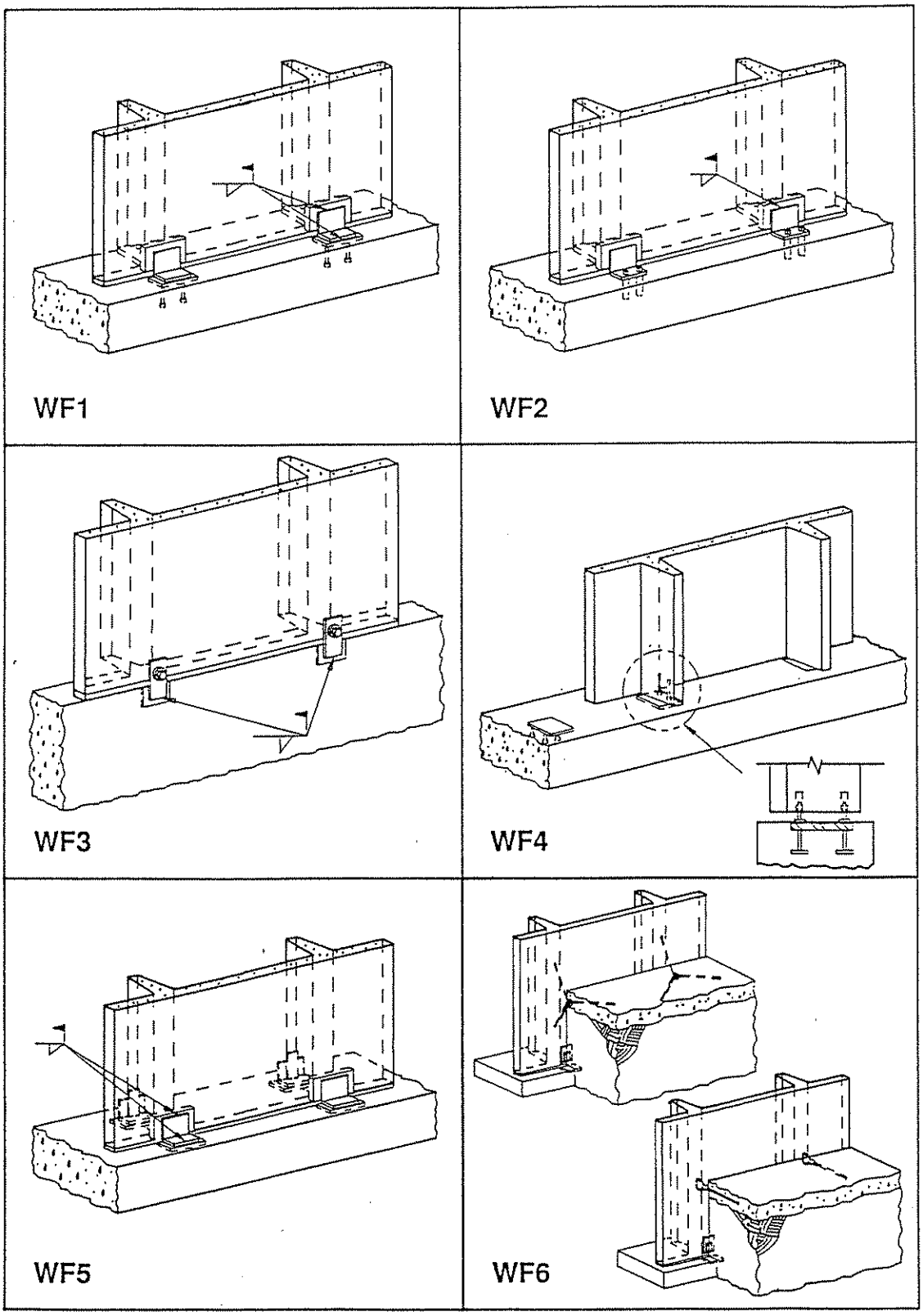


Figure 2.12 Lightweight partitions: (a) cellular concrete and (b) gypsum board.

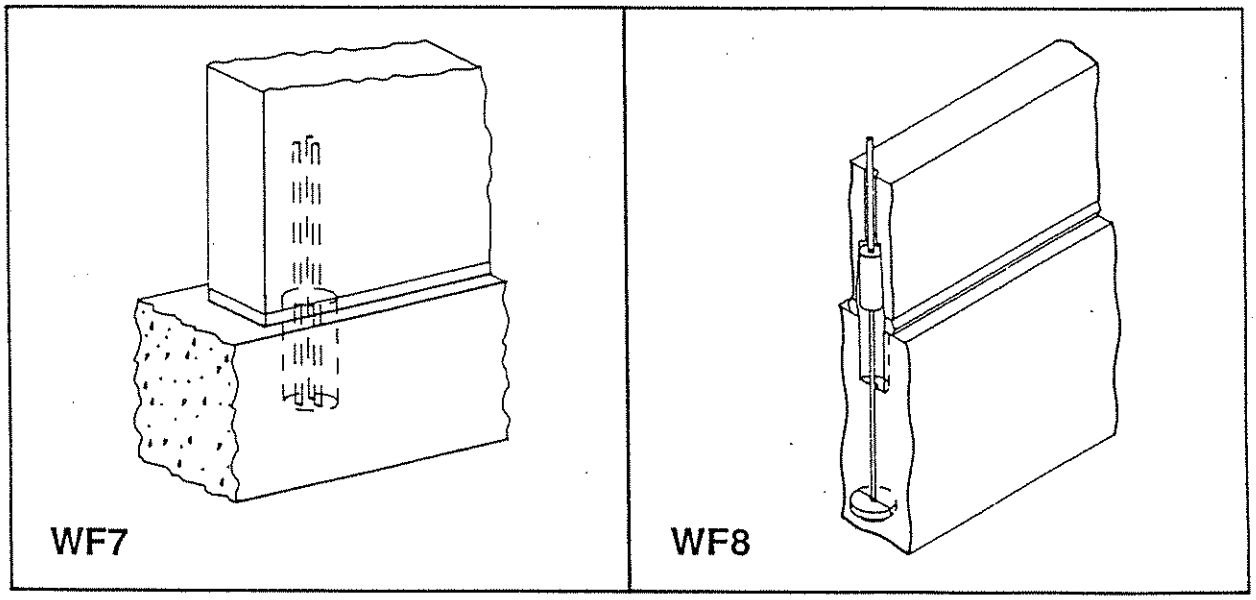
Source: Warszawski, 1990

Planar Vertical Element to Planar Vertical Element (cont)
Precast Concrete Wall Slab to Foundation



Source: PCI, 1988

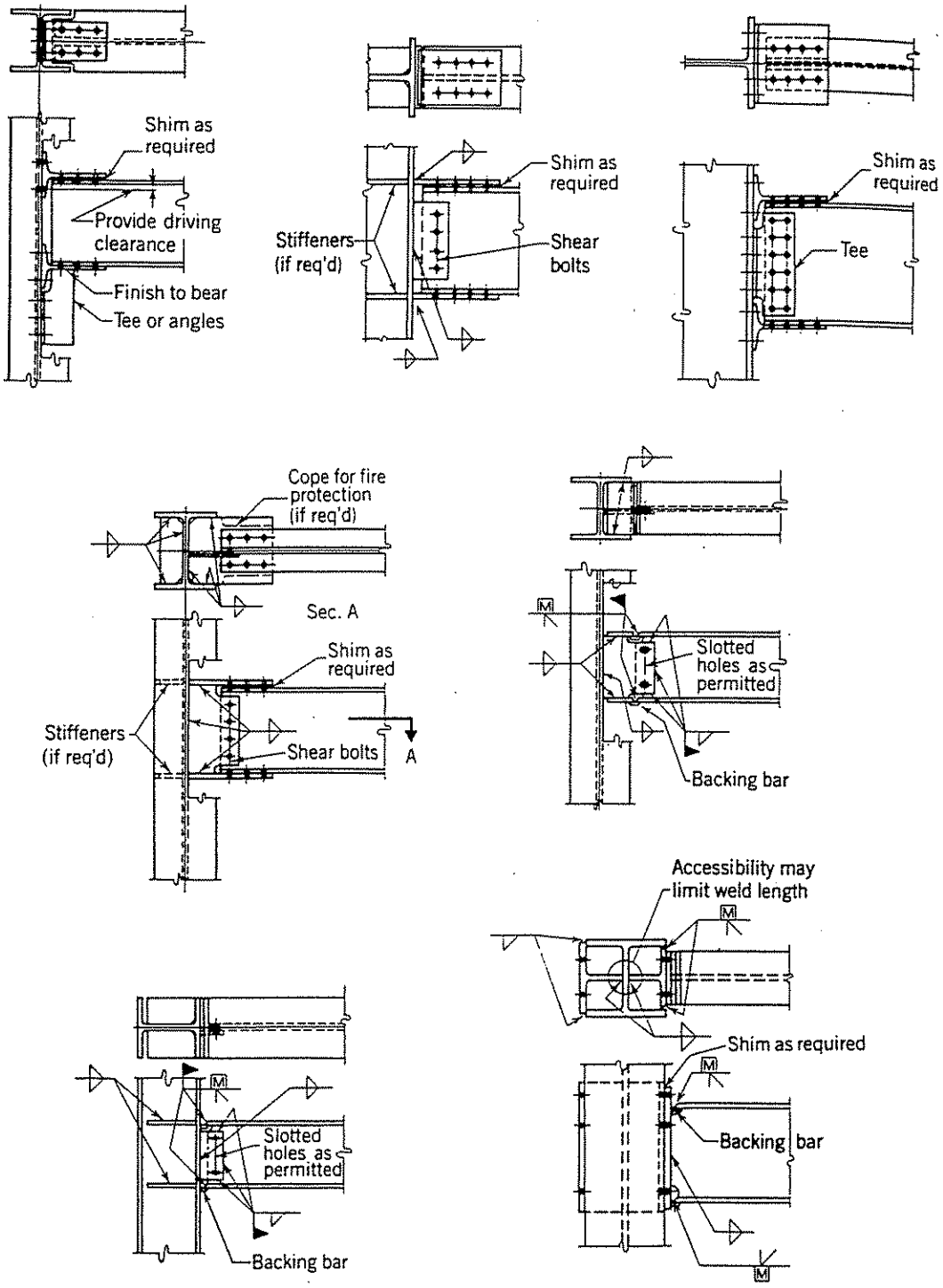
Planar Vertical Element to Planar Vertical Element (cont)
Precast Concrete Wall Slab to Foundation



Source: PCI, 1988

Single Horizontal Element to Single Vertical Element
Steel Beam to Steel Column

MOMENT CONNECTIONS



Source: AISC, 1986

Single Horizontal Element to Single Vertical Element (cont)

Steel Beam to Steel Column

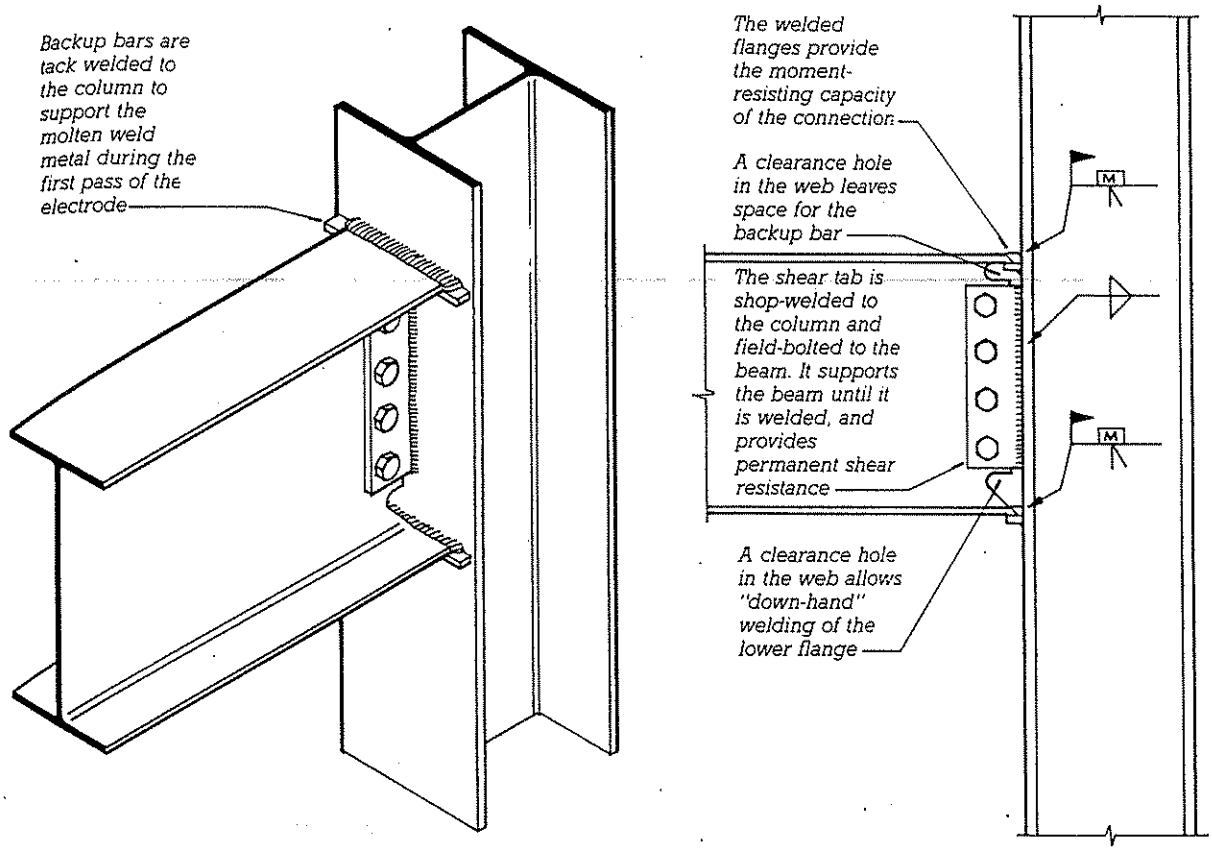


FIGURE 9.28

A welded moment connection (AISC Type 1) for joining a beam to a column. The groove welds develop the full strength of the flanges of the beam, allowing the connection to transmit moments between the beam and the column. If the column flanges are not stiff enough to accept the moments from the beam, stiffener plates similar to those in Figure 9.36 are welded between the column flanges in the plane of each of the beam flanges. The weld symbols are those explained in Figure 9.25. Note that some are field welds, and some are shop welds.

Source: Allen, 1985

Single Horizontal Element to Single Vertical Element (cont)
Steel Beam to Steel Column

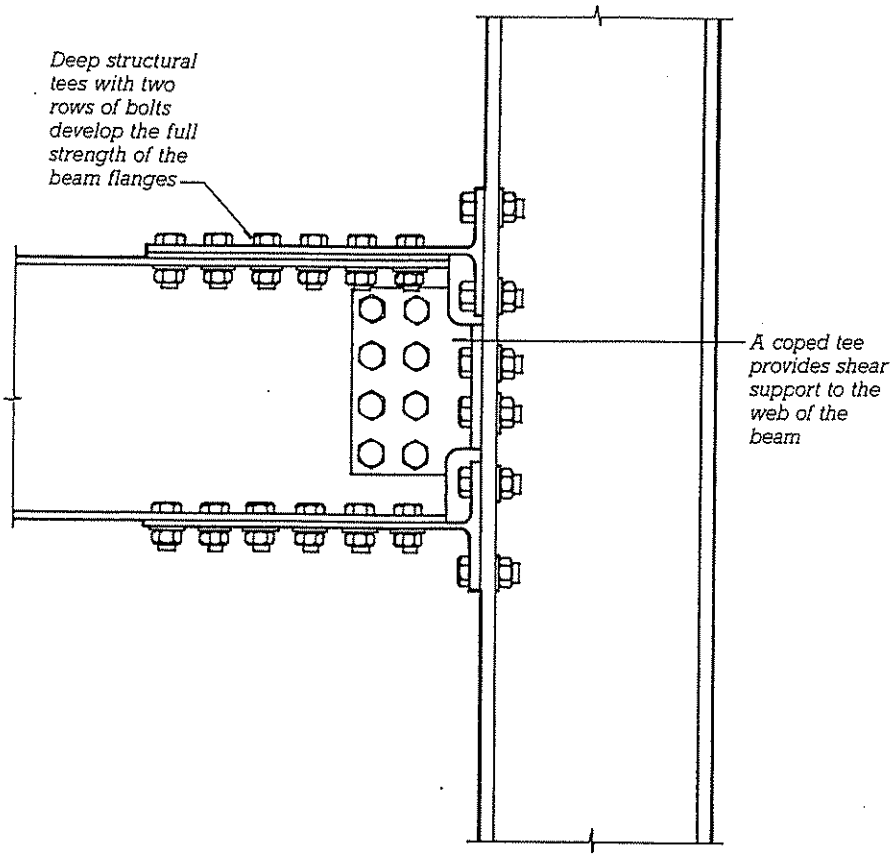


FIGURE 9.33
This detail of an all-bolted AISC Type 1 (moment) connection illustrates the difficulty of developing the full strength of the beam flanges with bolts. This type of connection is so troublesome and expensive to make that it is very seldom used. It involves four different planes of contact, which complicates fitting.

Source: Allen, 1985

Single Horizontal Element to Single Vertical Element (cont)
Steel Beam to Steel Column

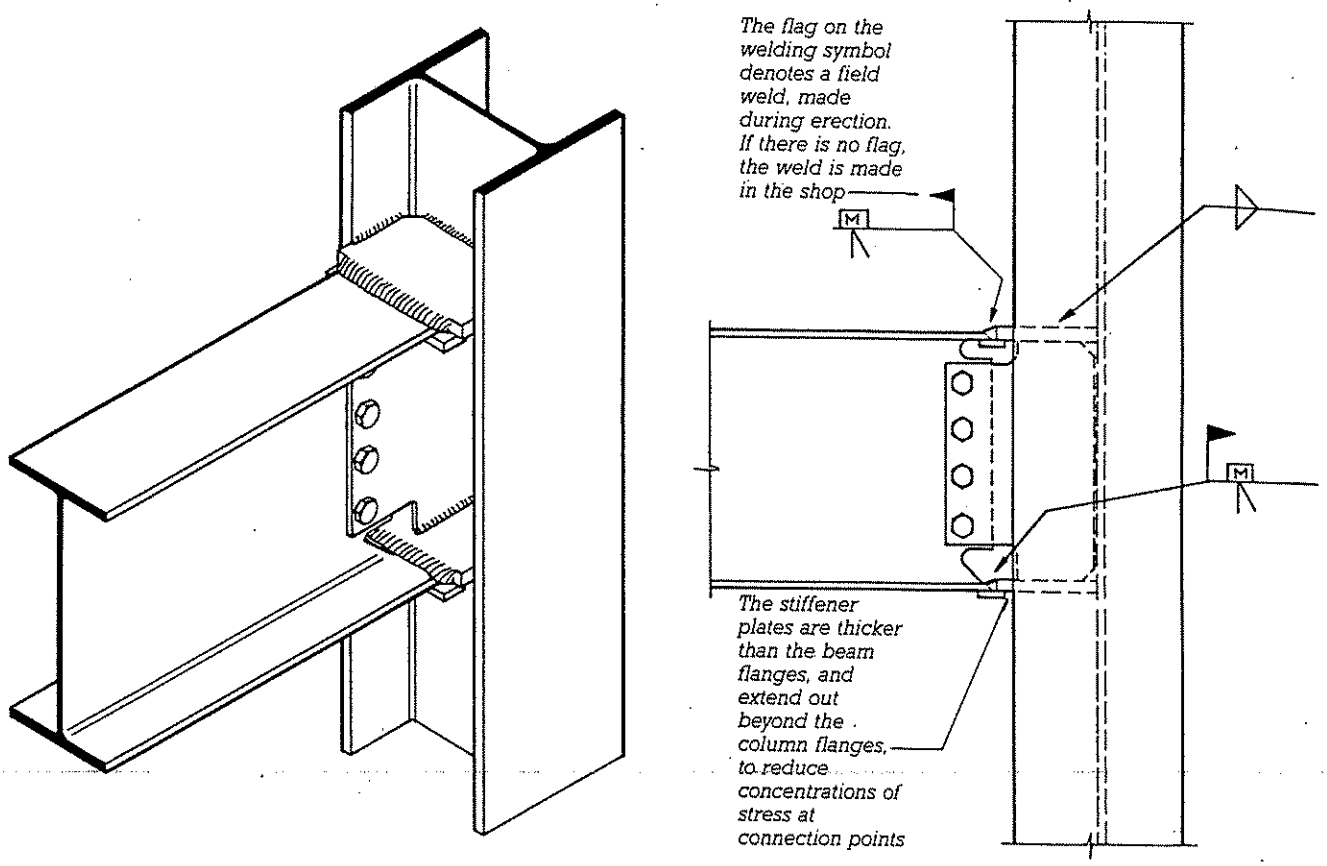


FIGURE 9.36
A welded beam-to-column-web connection (AISC Type 1).

Source: Allen, 1985

Single Horizontal Element to Single Vertical Element (cont)
Steel Beam to Steel Column

14. EXAMPLES OF CONTINUOUS CONNECTIONS

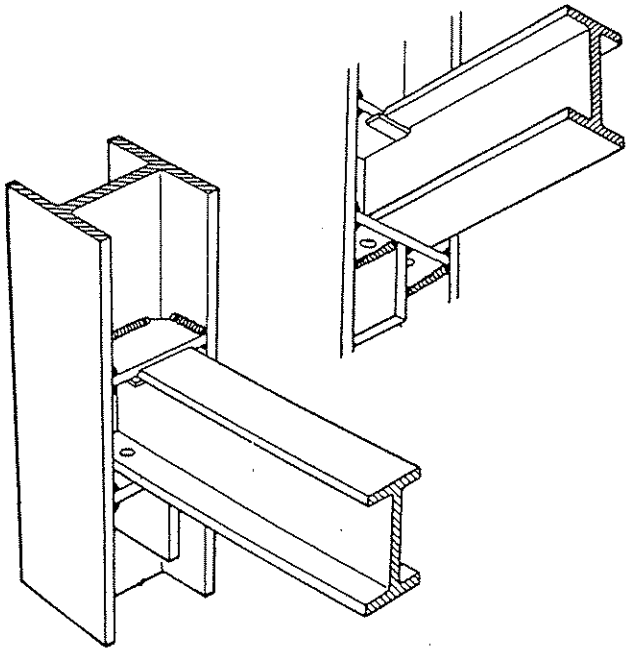


FIGURE 74 (a)

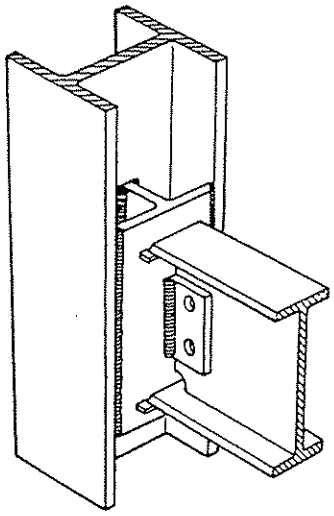


FIGURE 74 (b)

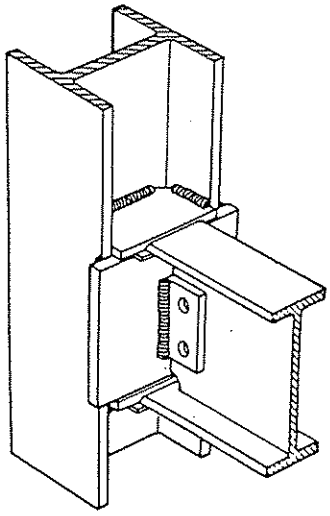


FIGURE 74 (c)

Source: Blodgett, 1966

Single Horizontal Element to Single Vertical Element (cont)
Steel Beam to Steel Column

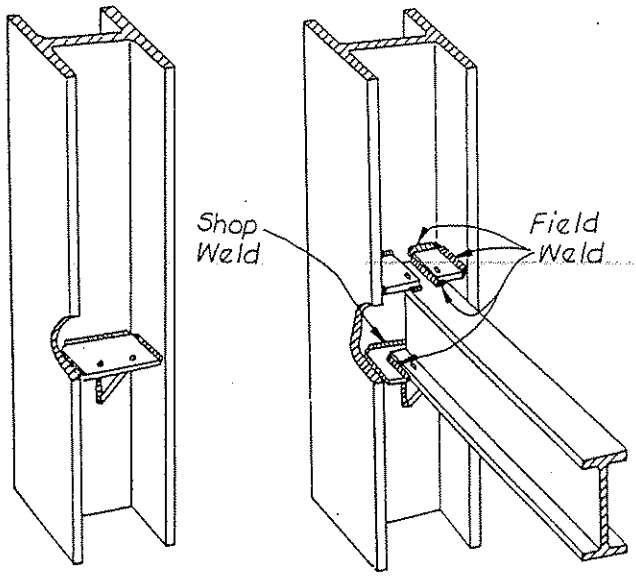


FIGURE 1

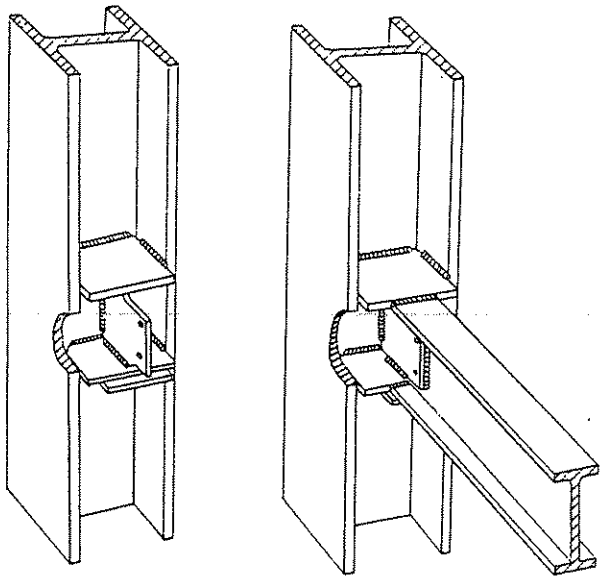


FIGURE 2

Source: Blodgett, 1966

Single Horizontal Element to Single Vertical Element (cont)
Steel Beam to Steel Column

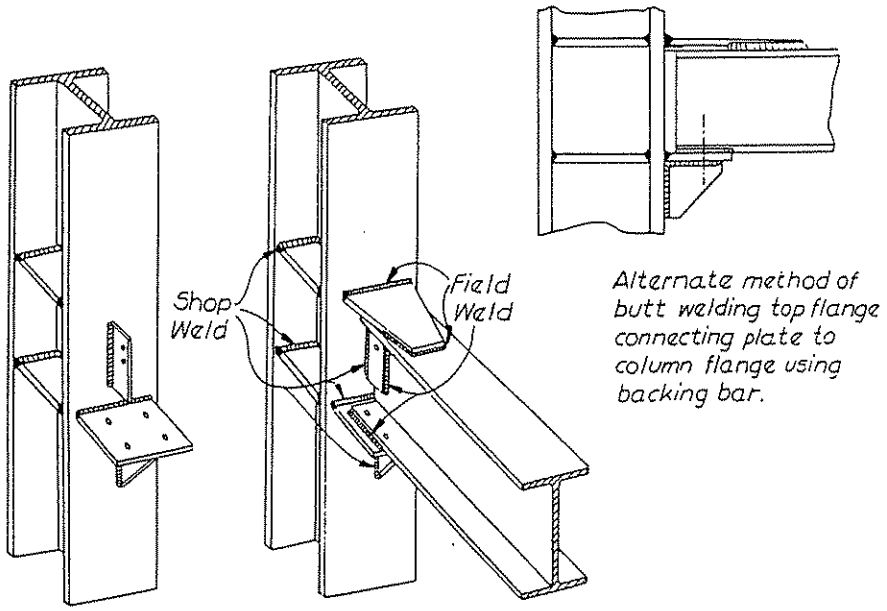


FIGURE 3

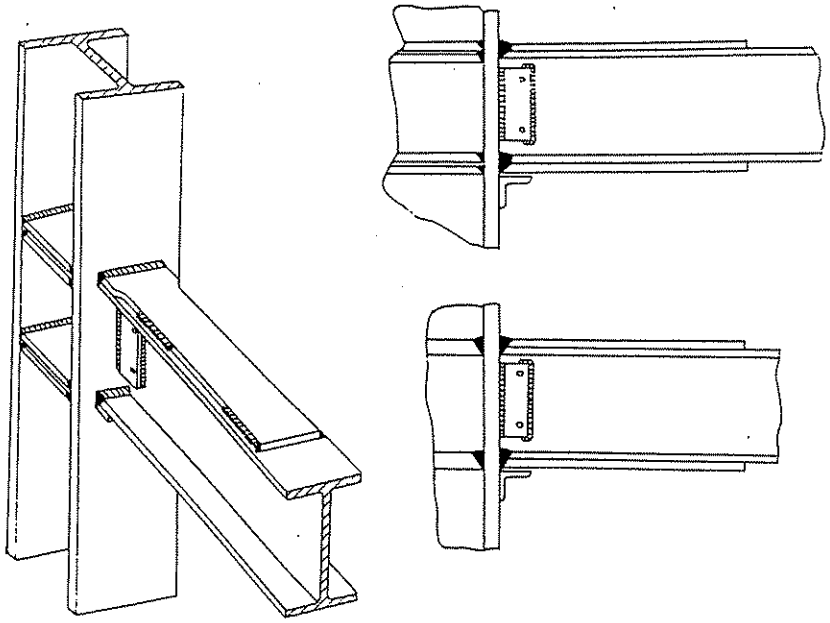


FIGURE 4

Source: Blodgett, 1966

Single Horizontal Element to Single Vertical Element (cont)

Steel Beam to Steel Column

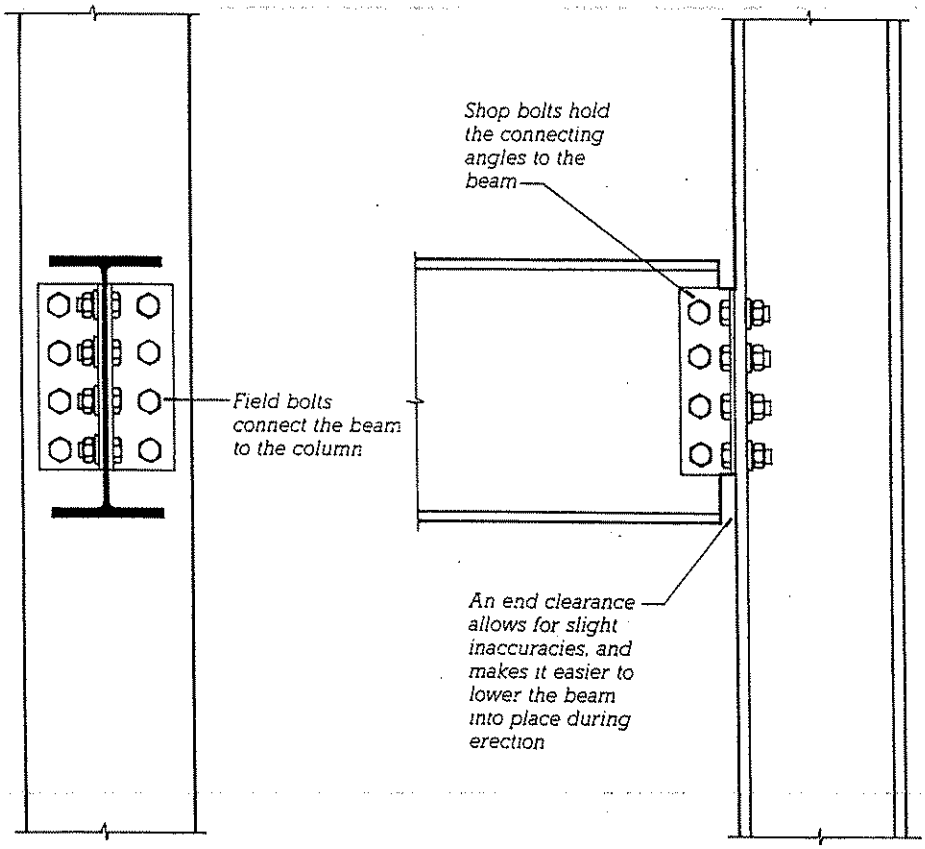


FIGURE 9.27
Two elevation views of the framed, bolted beam-to-column-flange connection shown in Figure 9.26. This is a shear connection only (AISC Type 2), because the flanges of the beam are not rigidly connected to the column.

Source: Allen, 1985

Single Horizontal Element to Single Vertical Element (cont)

Steel Beam to Steel Column

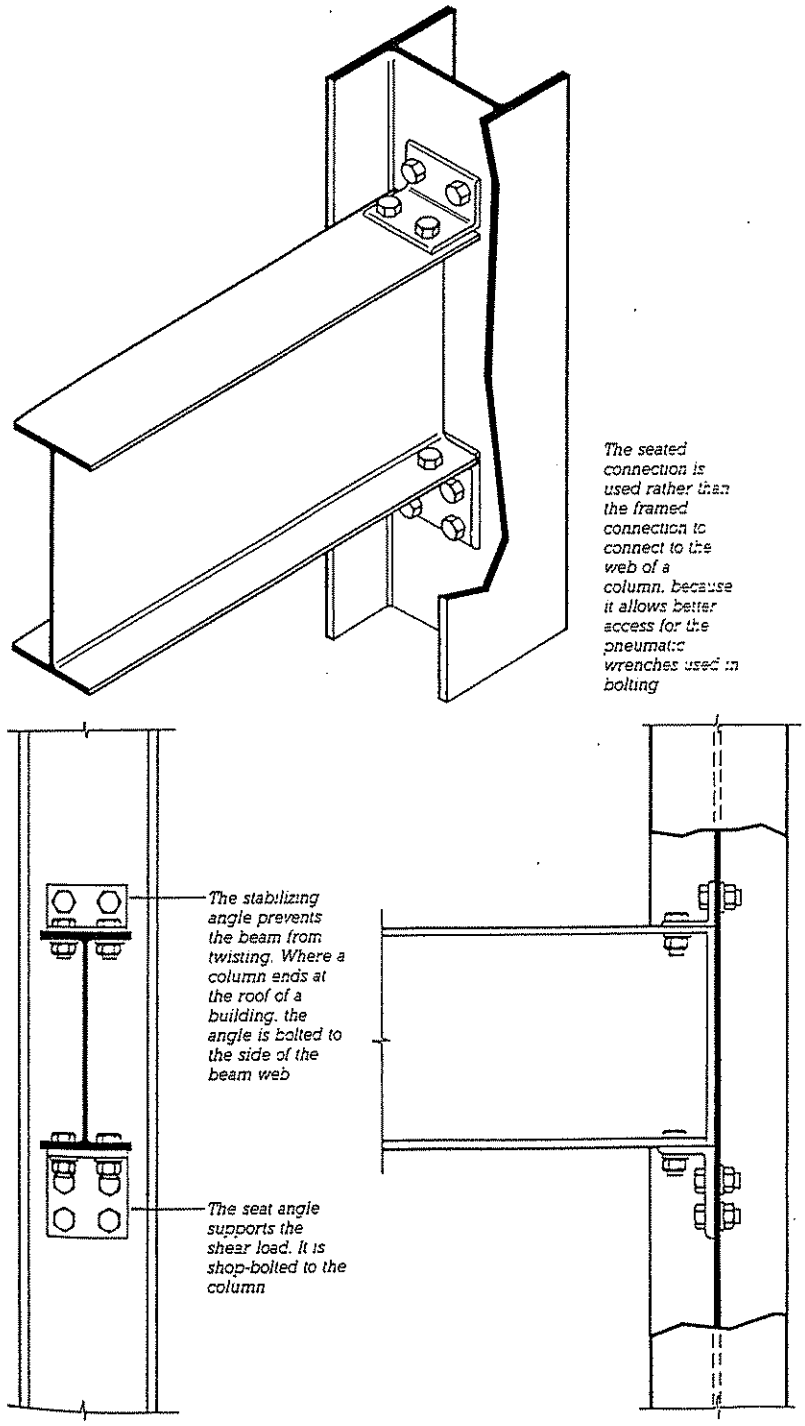


FIGURE 9.32

A seated beam-to-column-web connection. Although the beam flanges are connected to the column, this is an AISC Type 2 (shear) connection, not a moment connection, because the two bolts are incapable of developing the full strength of the beam flanges.

Source: Allen, 1985

Single Horizontal Element to Single Vertical Element (cont)
Steel Beam to Steel Column

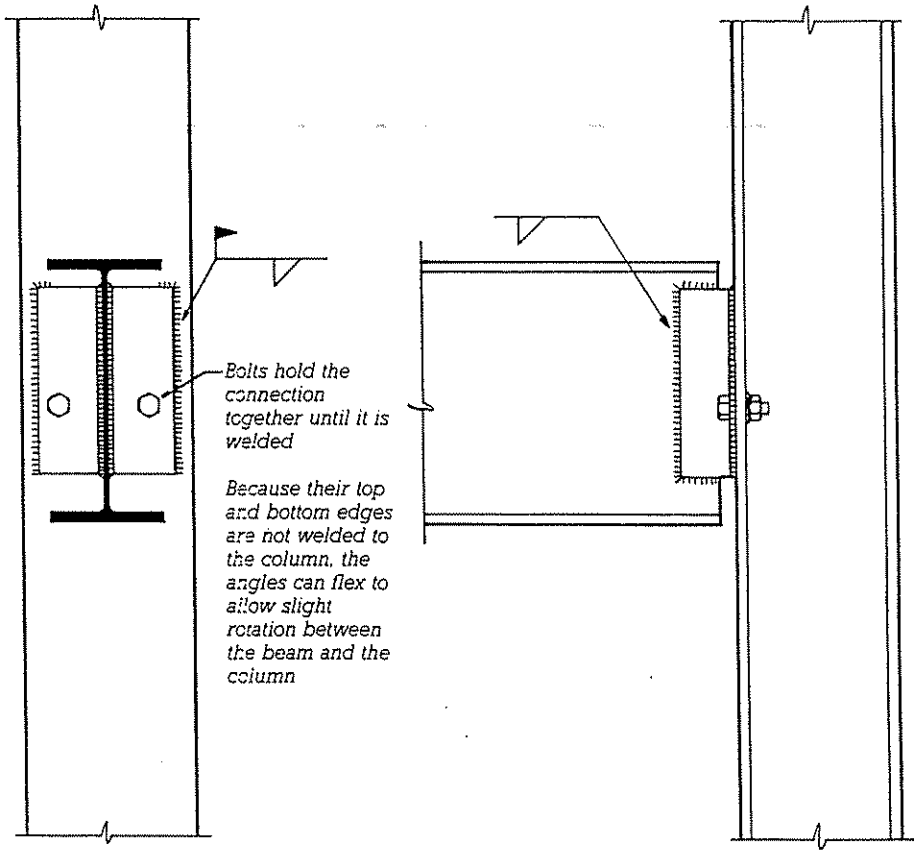
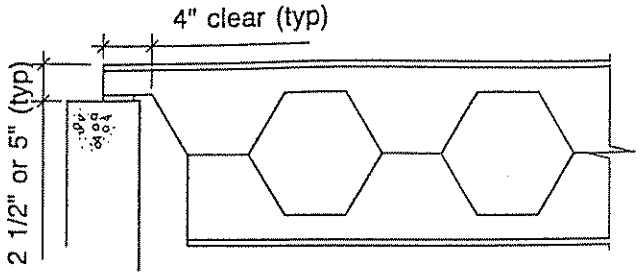


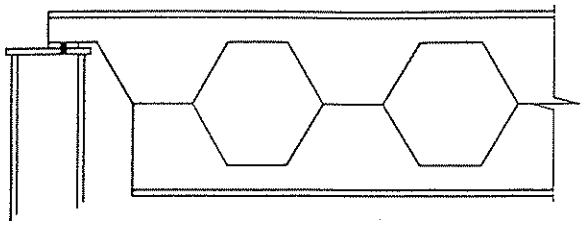
FIGURE 9.38
AISC Type 2 (shear) connections are also made by welding. The beam flanges are not connected to the column, and the angles are welded in such a way that they can flex to allow the beam to rotate away from the column.

Source: Allen, 1985

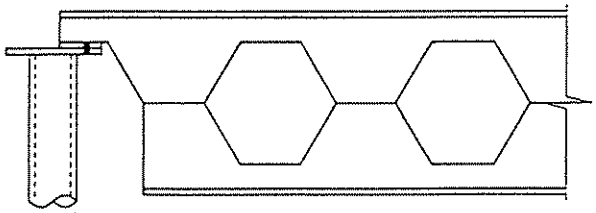
Single Horizontal Element to Single Vertical Element (cont)
Steel Castellated Beam to Steel Column



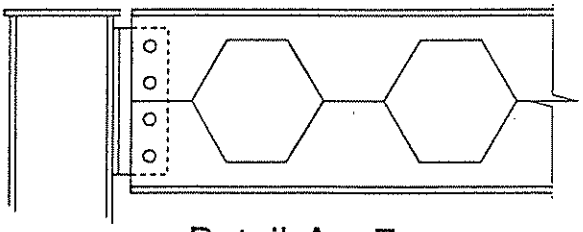
Detail A - 3



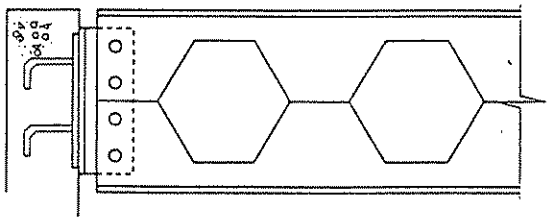
Detail A - 4



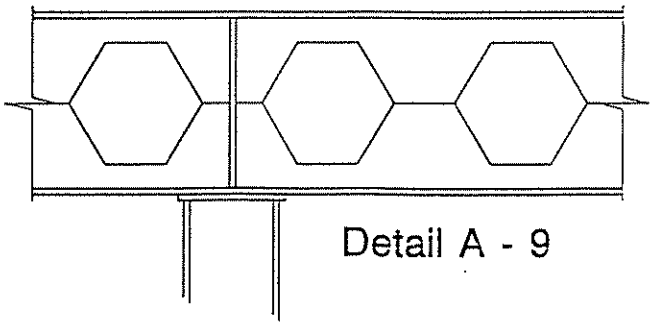
Detail A - 6



Detail A - 7



Detail A - 8



Detail A - 9

Source: Chaparral Steel

Single Horizontal Element to Single Vertical Element (cont)

Steel Beam to Steel Column

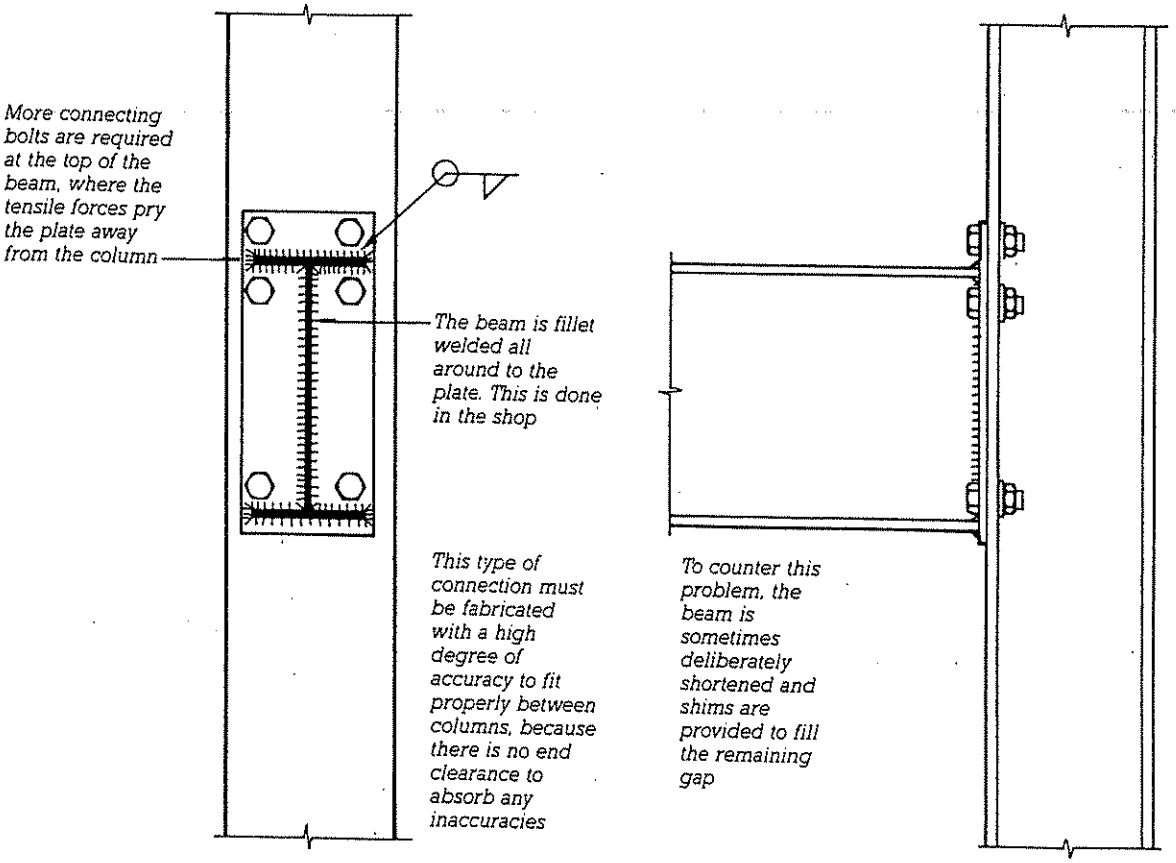


FIGURE 9.37

A welded/bolted end plate beam-column connection. The connection shown is AISC Type 3 (semi-rigid); *with more bolts an AISC Type 1 end plate connection is possible, although not common.*

Source: Allen, 1985

Single Horizontal Element to Single Vertical Element (cont)
Steel Beam to Steel Column

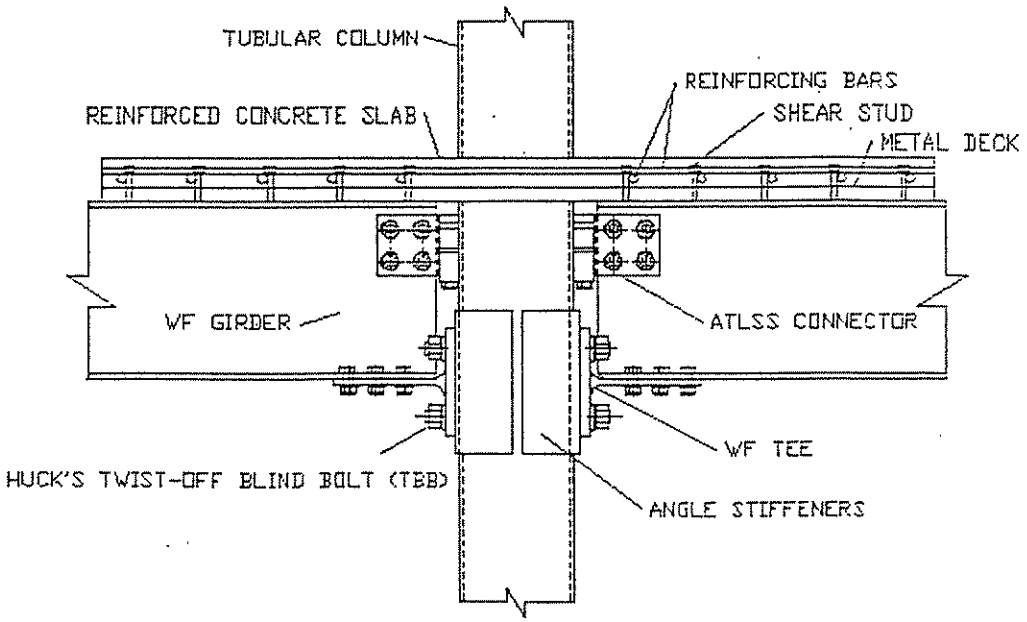
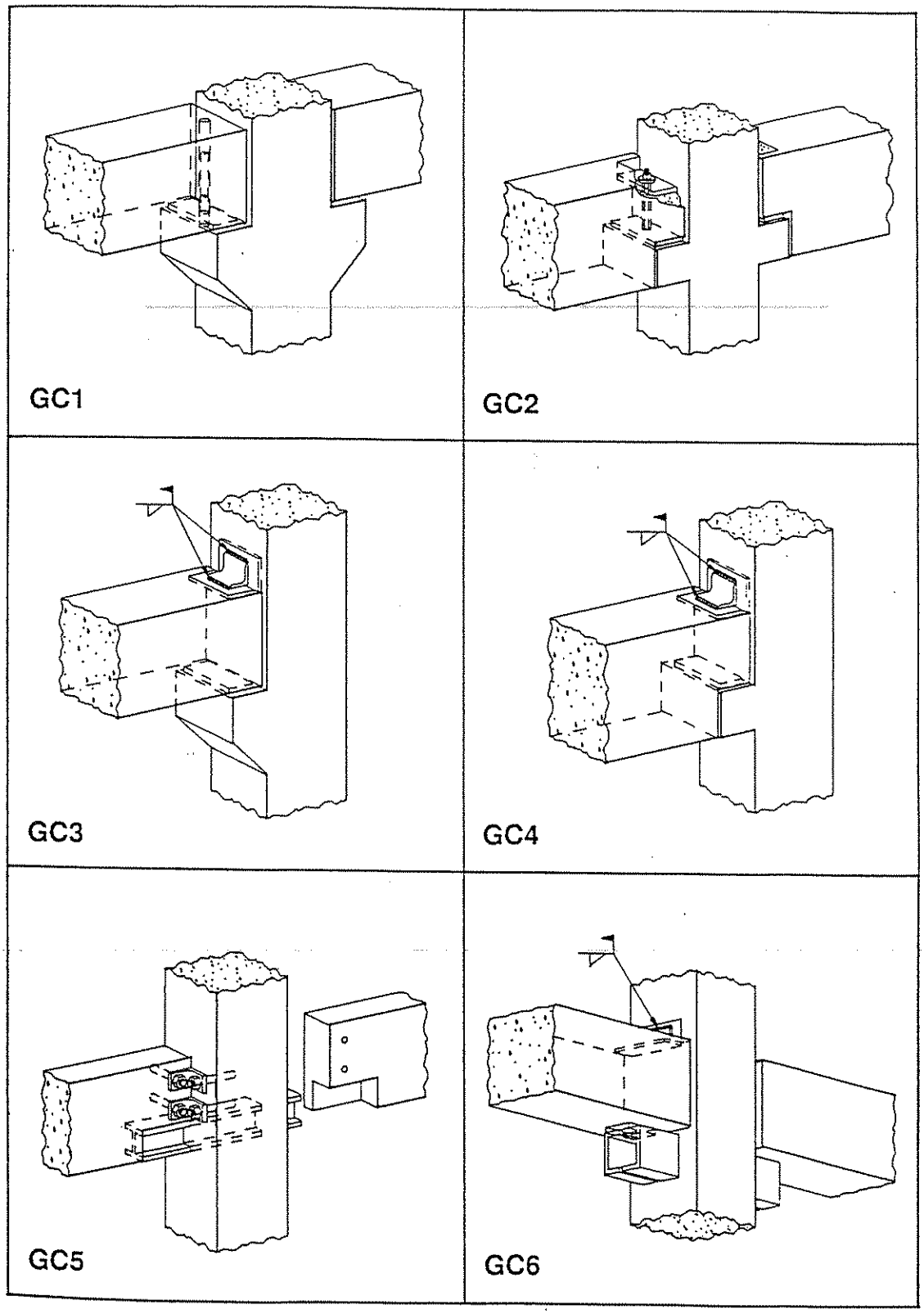


Figure 1.2

Figure 1.2 Proposed Partially Restrained Composite Connection

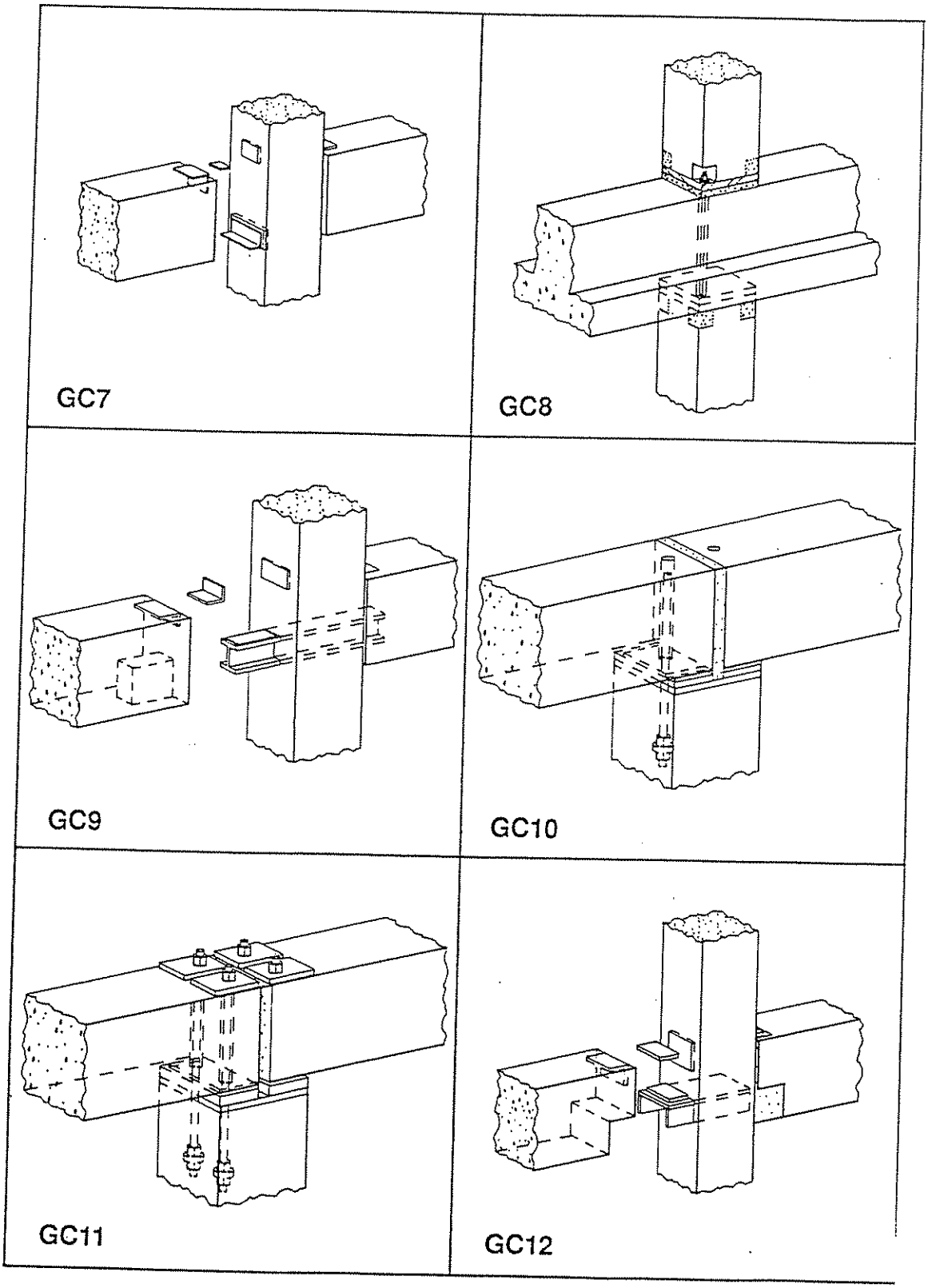
Source: Lawrence, 1994

Single Horizontal Element to Single Vertical Element (cont)
Precast Concrete Beam to Precast Concrete Column



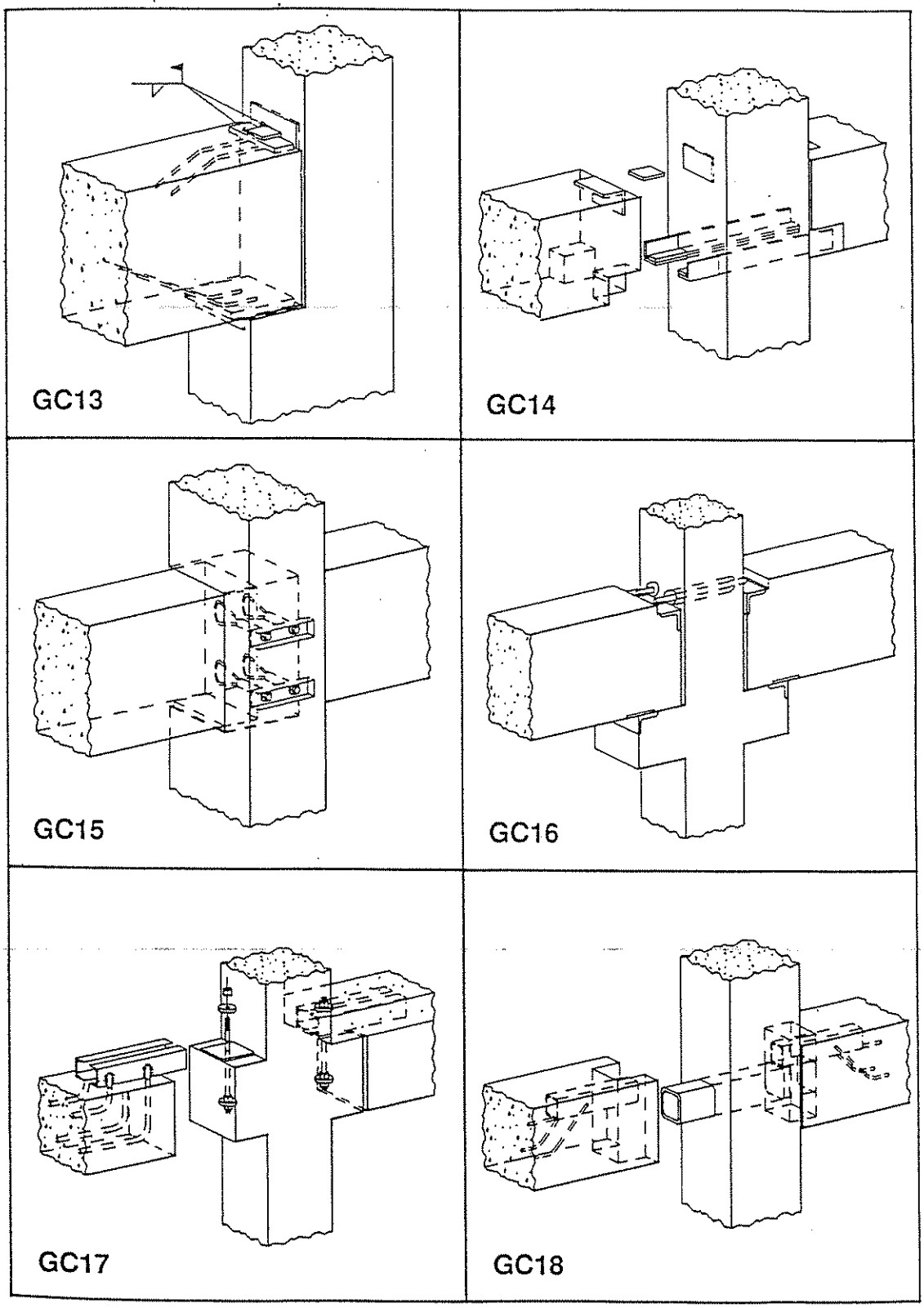
Source: PCI, 1988

Single Horizontal Element to Single Vertical Element (cont)
Precast Concrete Beam to Precast Concrete Column



Source: PCI, 1988

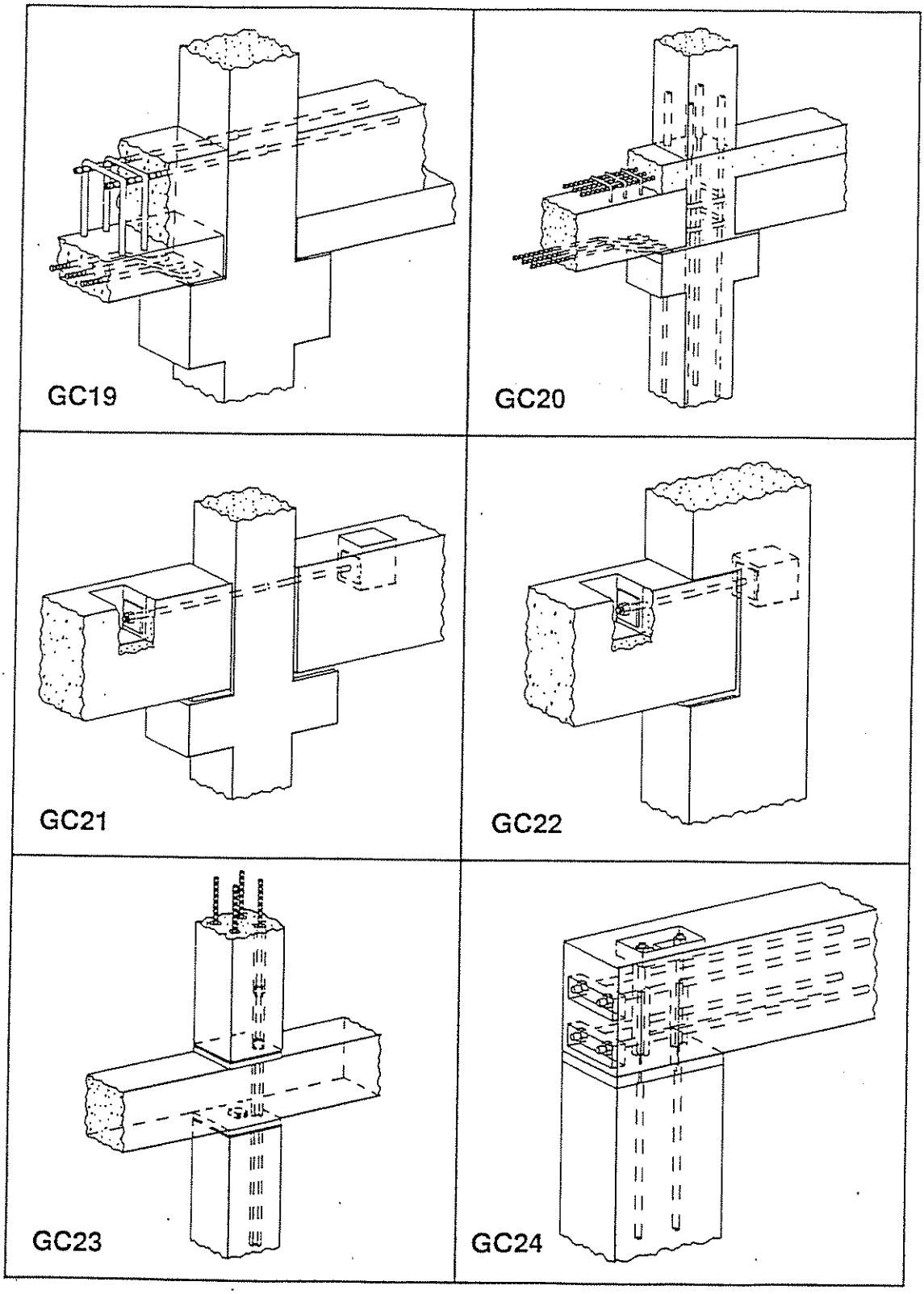
Single Horizontal Element to Single Vertical Element (cont)
Precast Concrete Beam to Precast Concrete Column



Source: PCI, 1988

Single Horizontal Element to Single Vertical Element (cont)

Precast Concrete Beam to Precast Concrete Column



Source: PCI, 1988

Single Horizontal Element to Single Vertical Element (cont)
Precast Concrete Beam to Precast Concrete Column

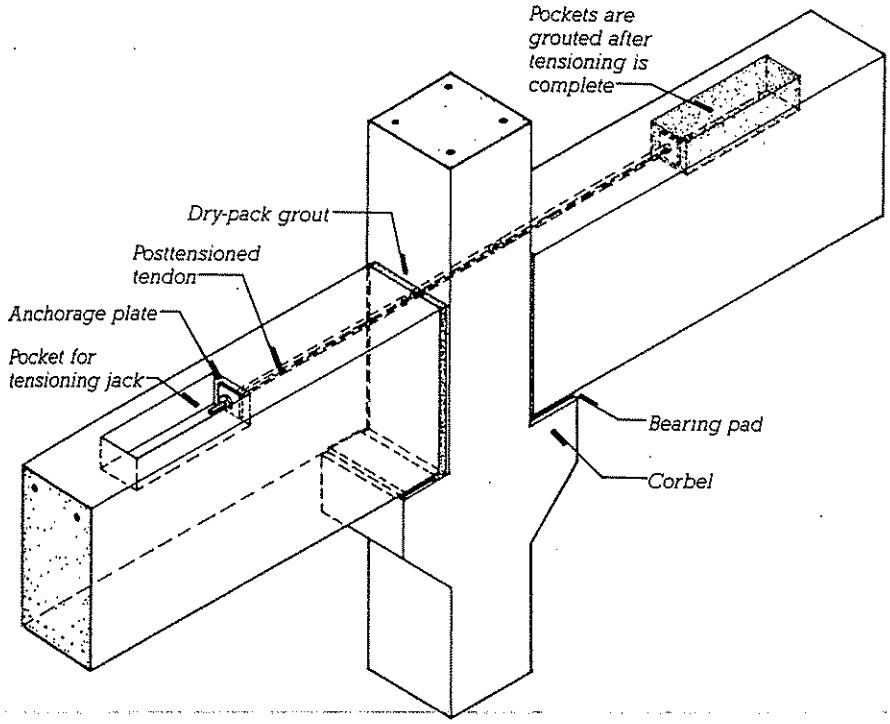


FIGURE 12.18
A possttensioned, structurally continuous beam-column connection.

Source: Allen, 1990

Single Horizontal Element to Single Vertical Element (cont)
Precast Concrete Beam to Precast Concrete Column

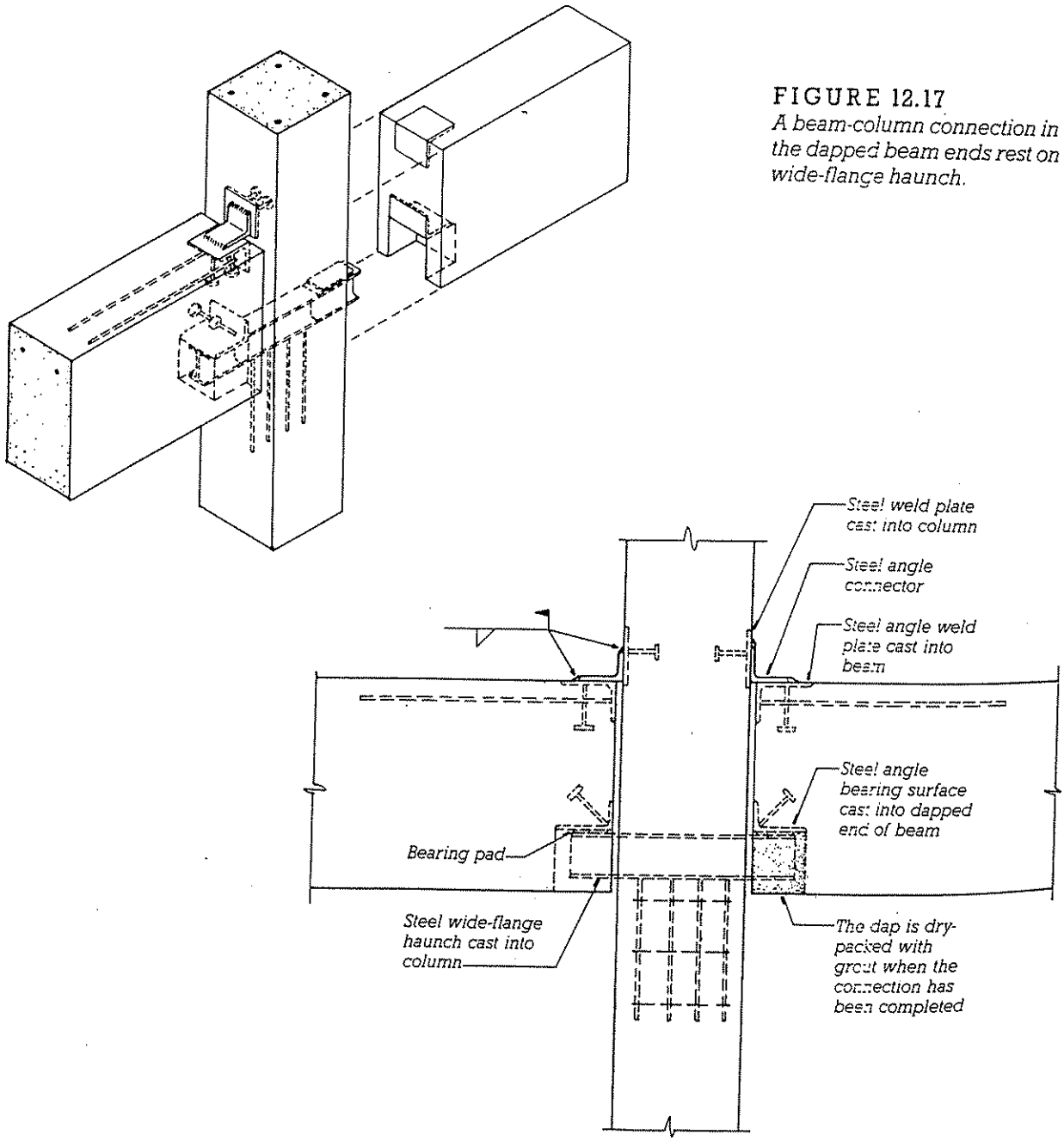


FIGURE 12.17
A beam-column connection in which the dapped beam ends rest on a steel wide-flange haunch.

Source: Allen, 1990

Single Horizontal Element to Single Vertical Element (cont)
Precast Concrete Beam to Precast Concrete Column

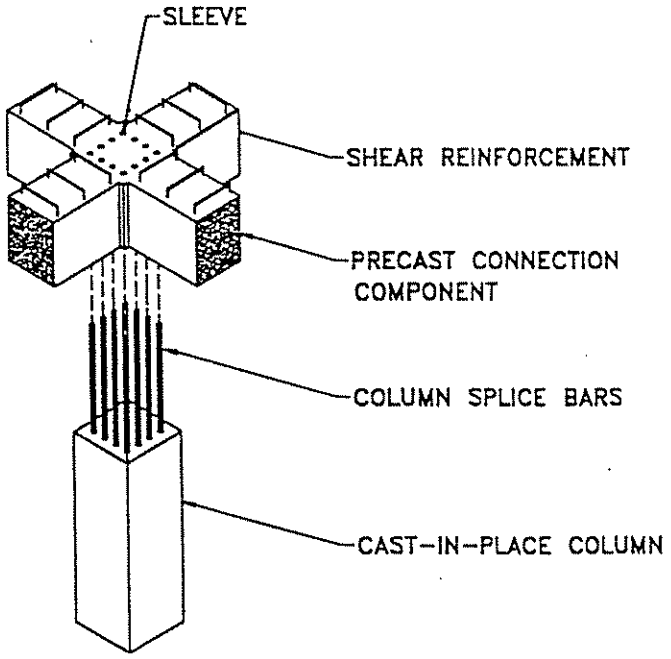


Figure 3.13. Cross-shaped beam-to-column component.

Source: Prior et al, 1993

Single Horizontal Element to Single Vertical Element (cont)
Precast Concrete Beam to Precast Concrete Column

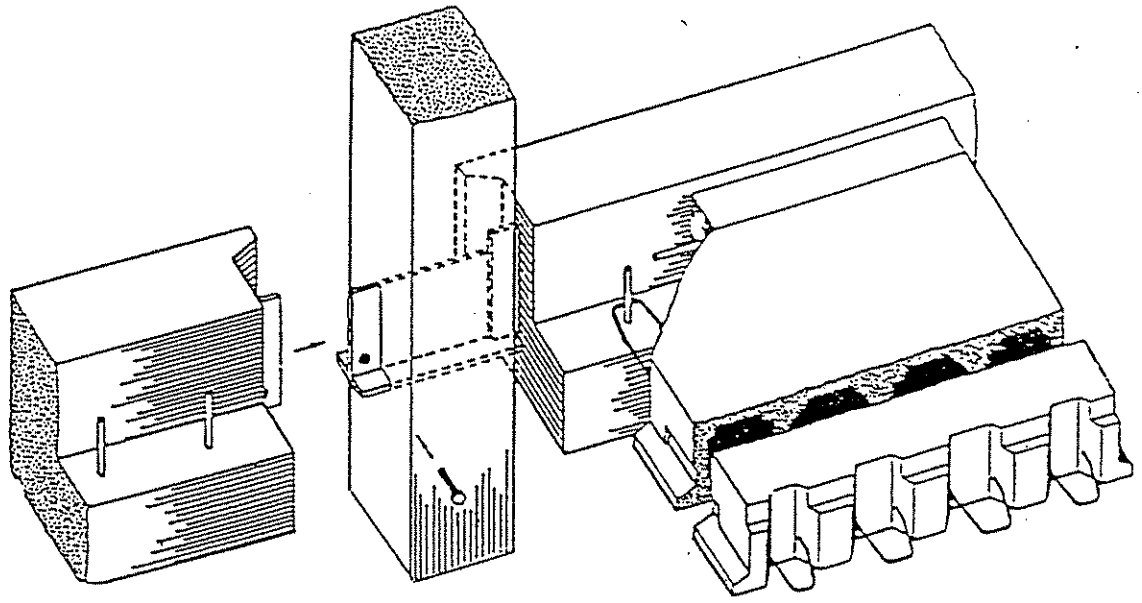


Figure 3.17. Column-to-edge beam connection detail. The steel plate from the column is bolted to the steel beam plate for stability during erection [adapted from Bison Concrete 1970].

Source: Prior et al, 1993

Single Horizontal Element to Single Vertical Element (cont)
Precast Concrete Beam to Precast Concrete Column

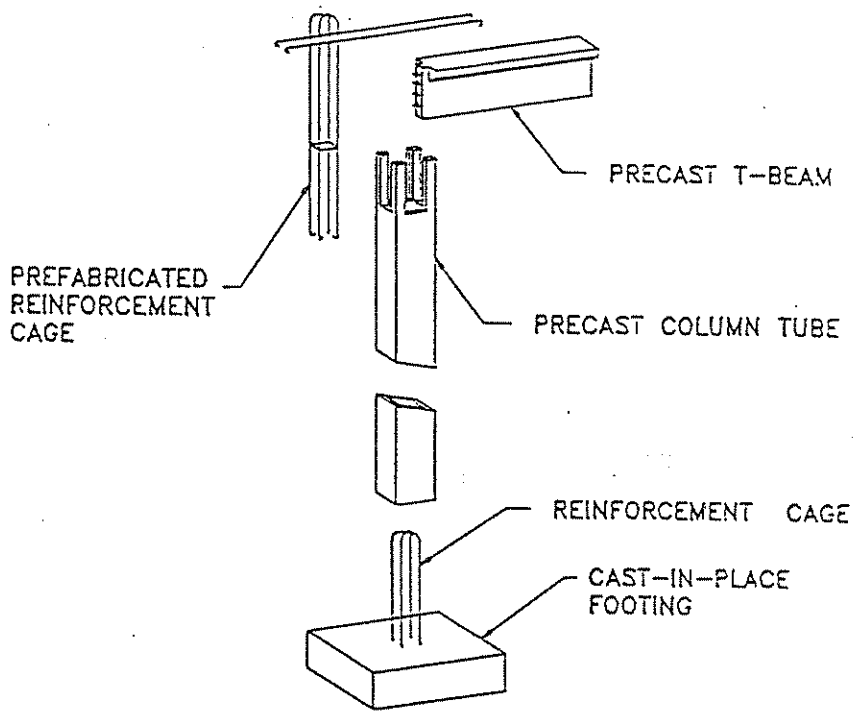


Figure 3.22. Footing-to-column and beam-to-column connection. Tongue of tee beam is dropped into slot of precast column.

Source: Prior et al, 1993

Single Horizontal Element to Single Vertical Element (cont)
Precast Concrete Beam to Precast Concrete Column

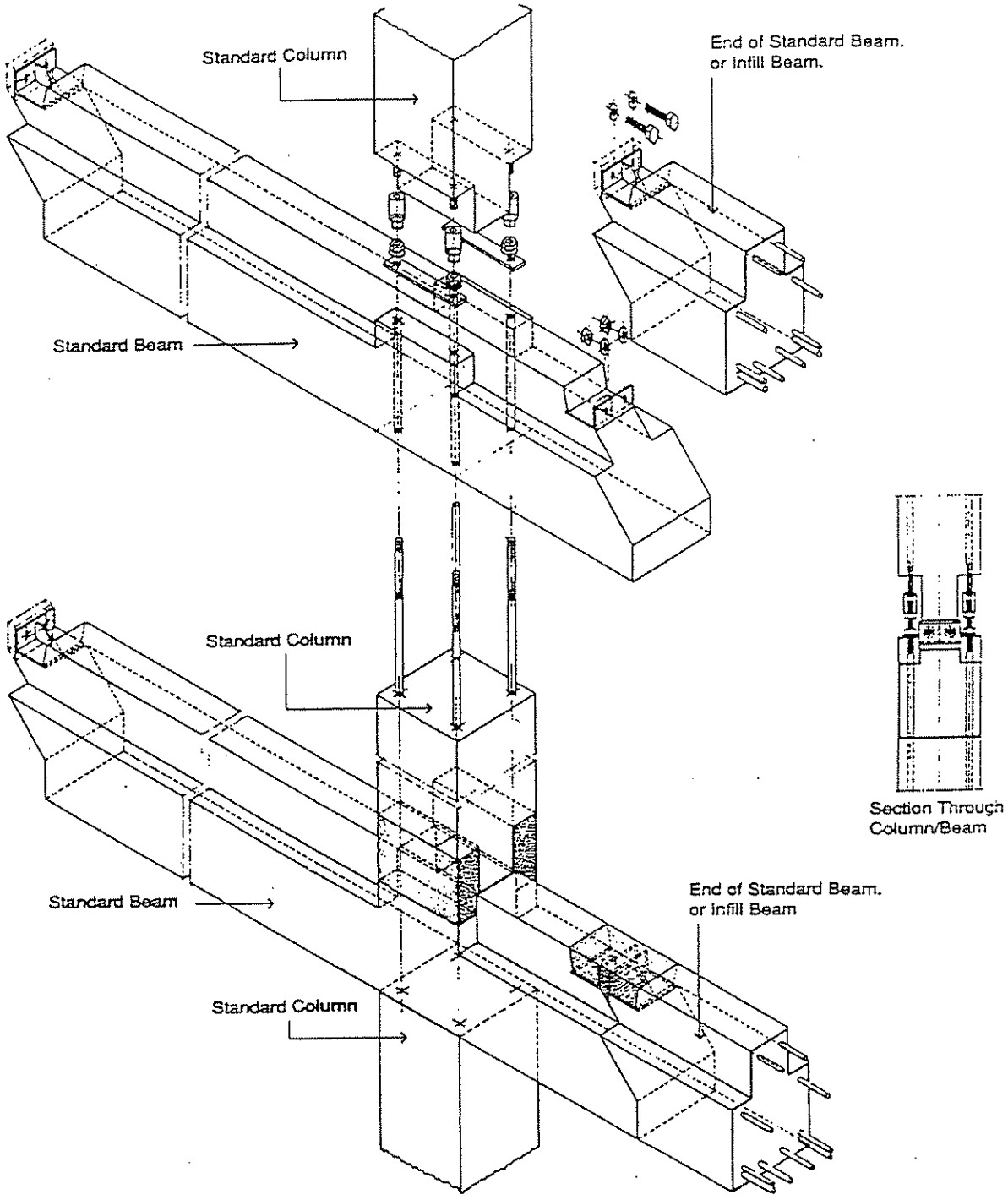


Figure 3.27. Beam-to-column connection and bolted beam-to-beam mechanical connection [adapted from Contiframe Structures 1992].

Source: Prior et al, 1993

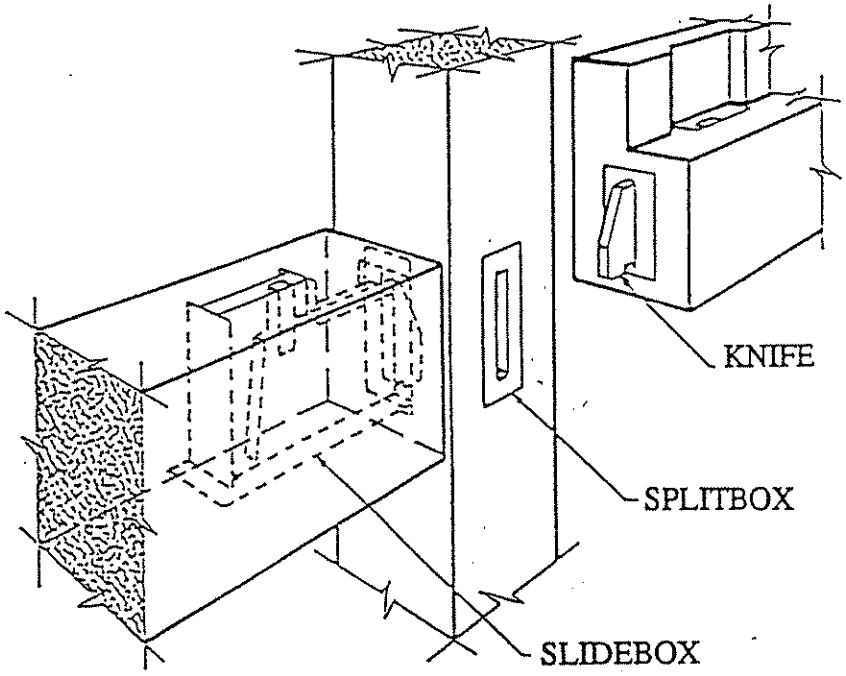


Figure 3.36. The BSF prefabricated beam-to-column shear connection. The steel knife from the beam is slipped into the column splitbox [adapted from Østspenn Holding A/S 1991].

Source: Prior et al, 1993

Single Horizontal Element to Single Vertical Element (cont)
Precast Concrete Beam to Precast Concrete Column

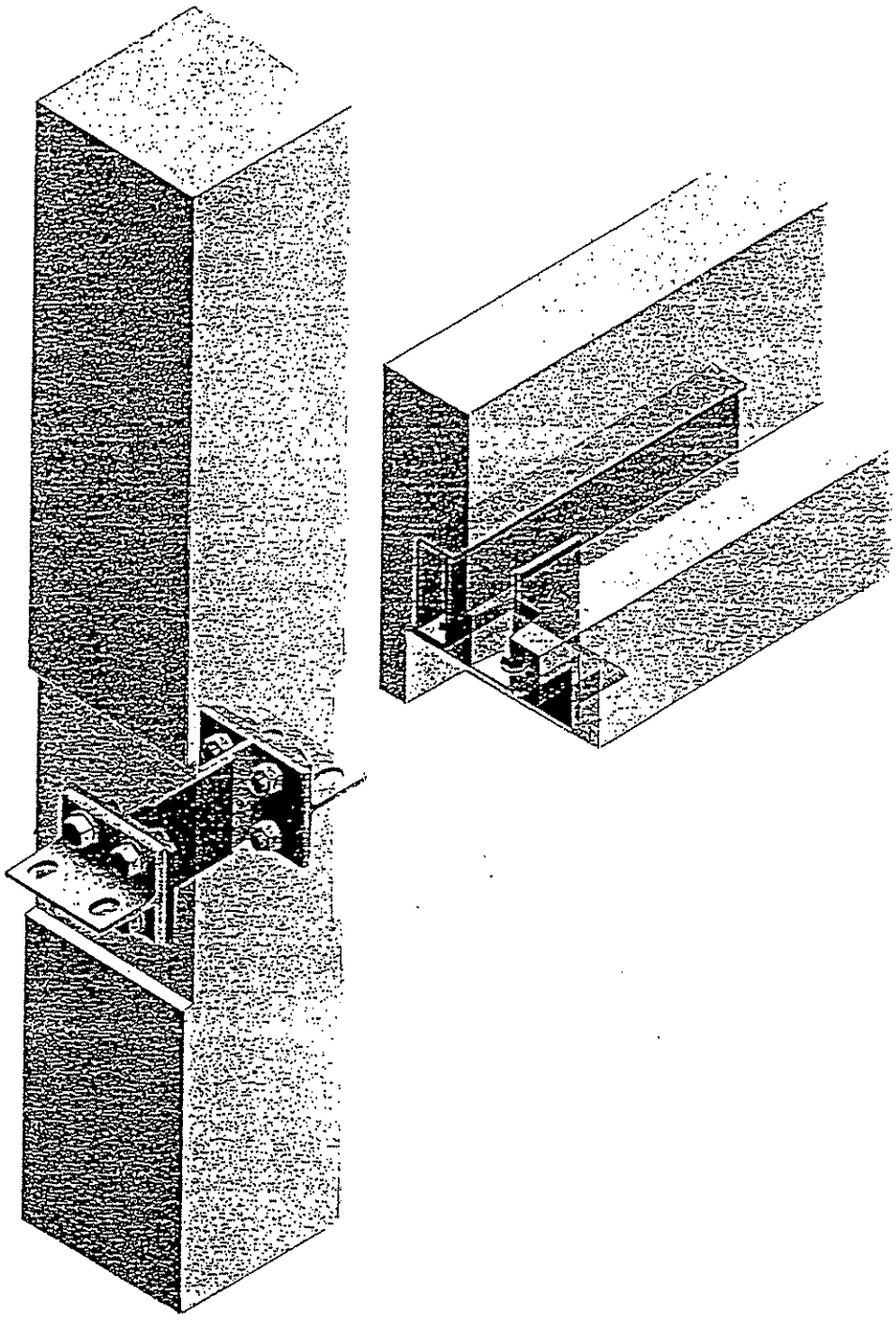
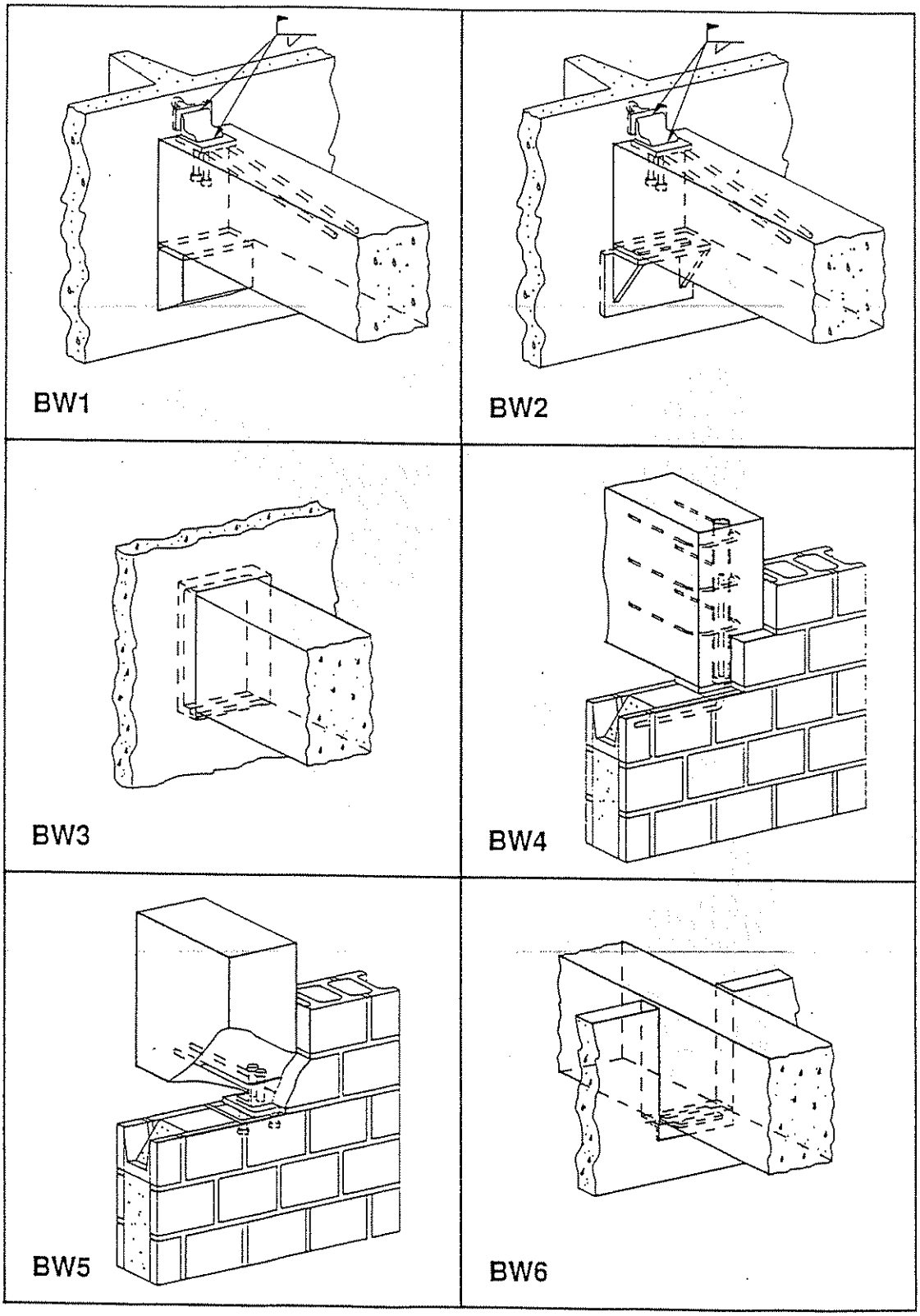


Figure 3.37. Bolted beam-to-column connector [adapted from Trent Concrete Structures 1992].

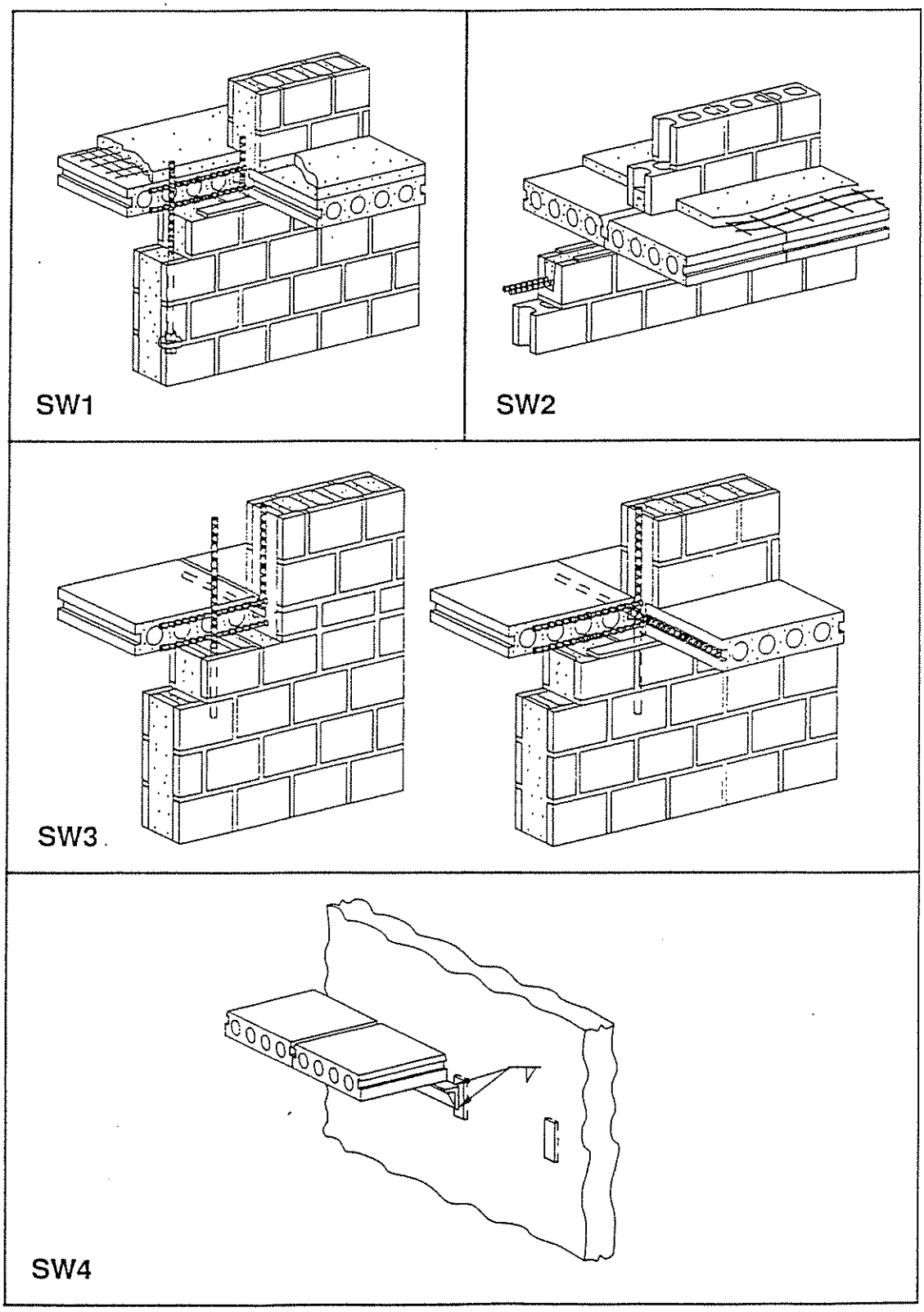
Source: Prior et al, 1993

Single Horizontal Element to Planar Vertical Element
Precast Concrete Beam to Precast Concrete Wall Slab



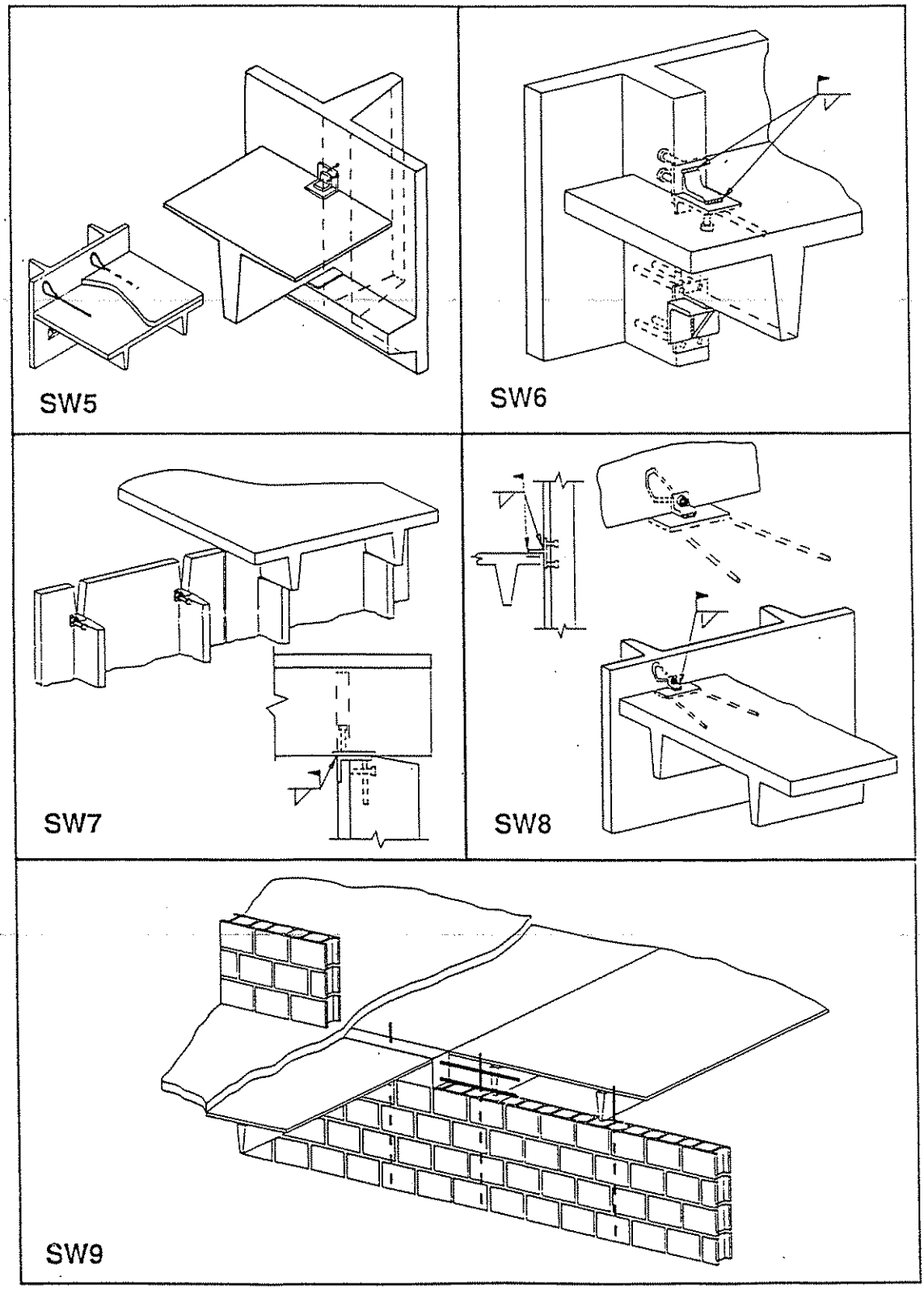
Source: PCI, 1988

Planar Horizontal Element to Planar Vertical Element
Precast Concrete Floor Slab to Precast Concrete Wall Slab



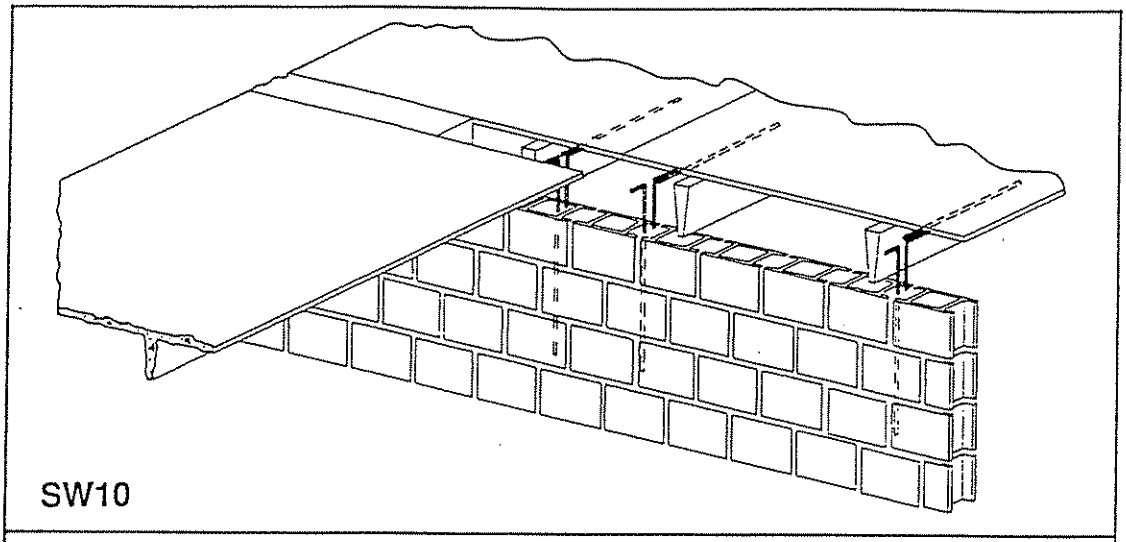
Source: PCI, 1988

Planar Horizontal Element to Planar Vertical Element (cont)
Precast Concrete Floor Slab to Precast Concrete Wall Slab

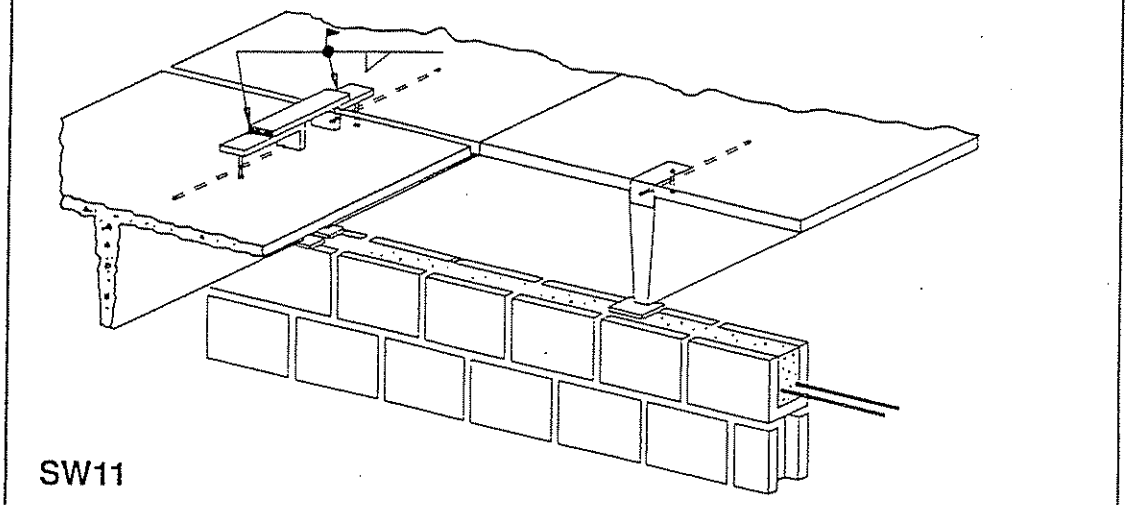


Source: PCI, 1988

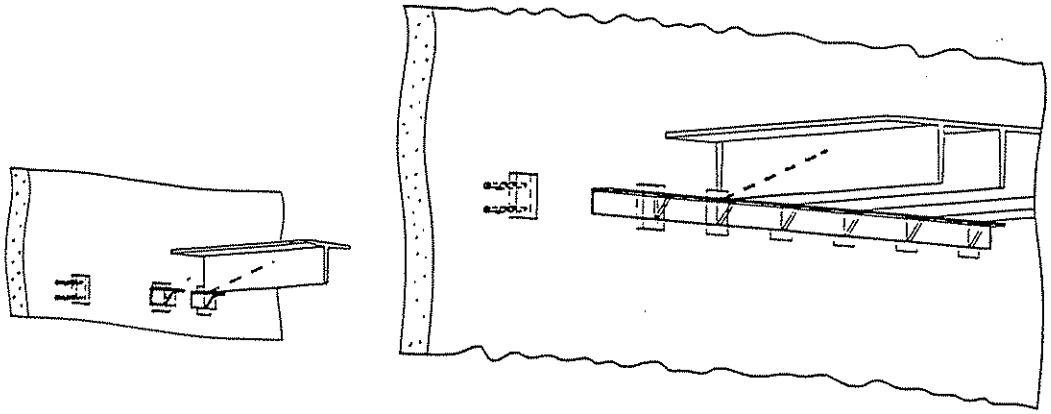
Planar Horizontal Element to Planar Vertical Element (cont)
Precast Concrete Floor Slab to Precast Concrete Wall Slab



SW10



SW11



SW12

Source: PCI, 1988

Planar Horizontal Element to Planar Vertical Element (cont)
Precast Concrete Floor Slab to Precast Concrete Wall Slab

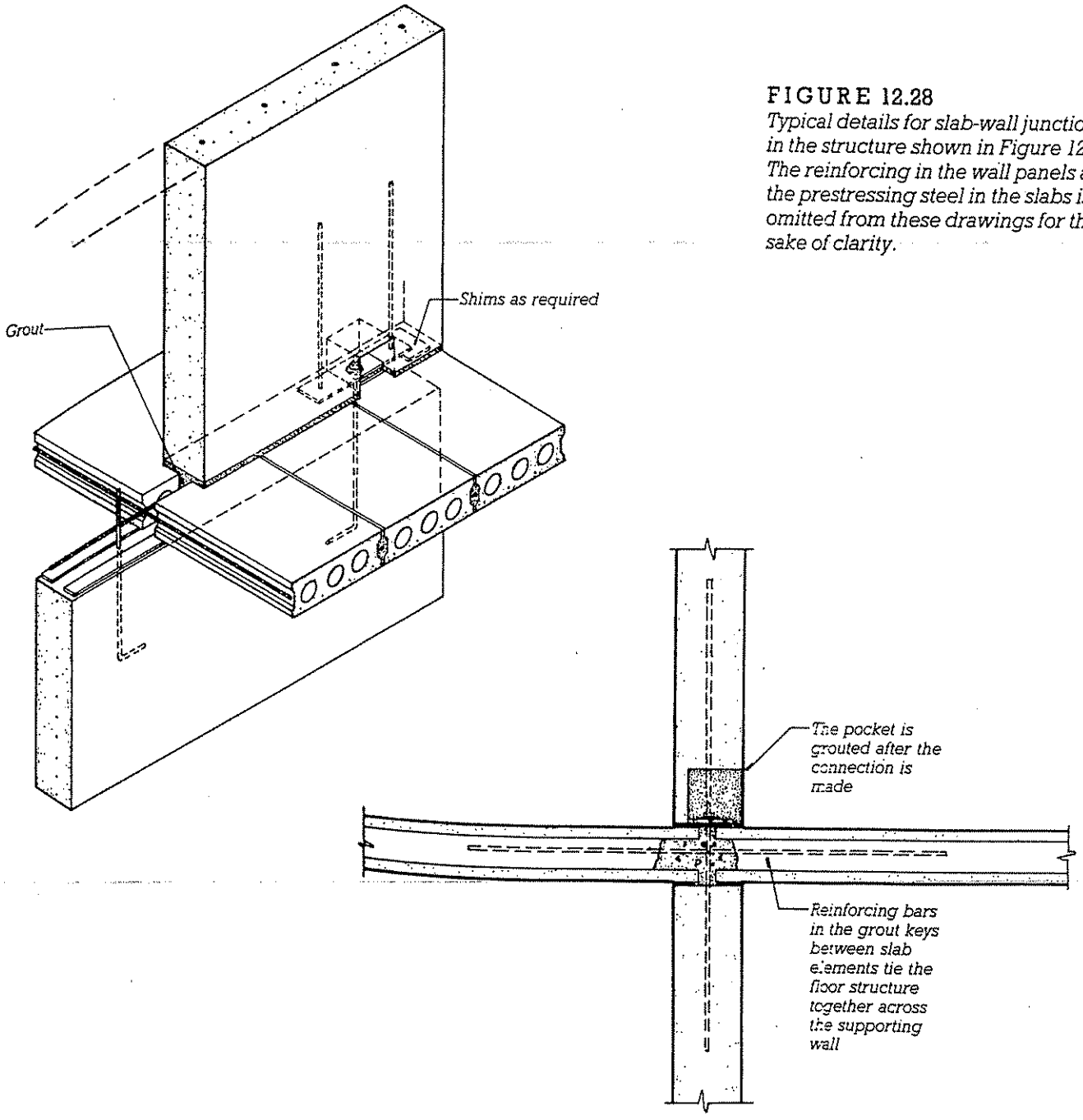


FIGURE 12.28
Typical details for slab-wall junctions in the structure shown in Figure 12.27. The reinforcing in the wall panels and the prestressing steel in the slabs is omitted from these drawings for the sake of clarity.

Source: Allen, 1990

Single Horizontal Element to Single Horizontal Element
Steel Beam to Steel Girder

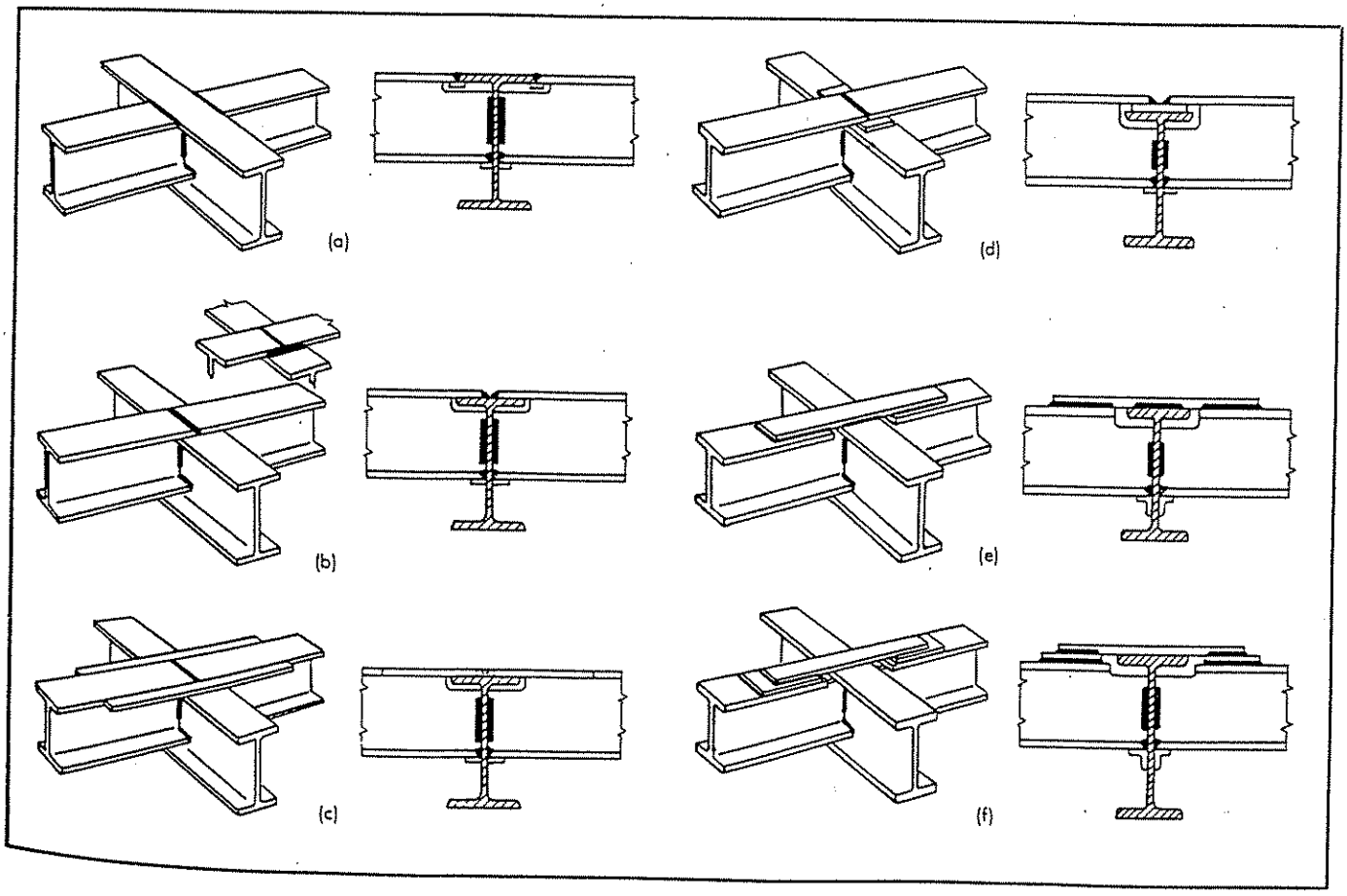


FIGURE 1

Source: Blodgett, 1966

Single Horizontal Element to Single Horizontal Element (cont)

Steel Beam to Steel Girder

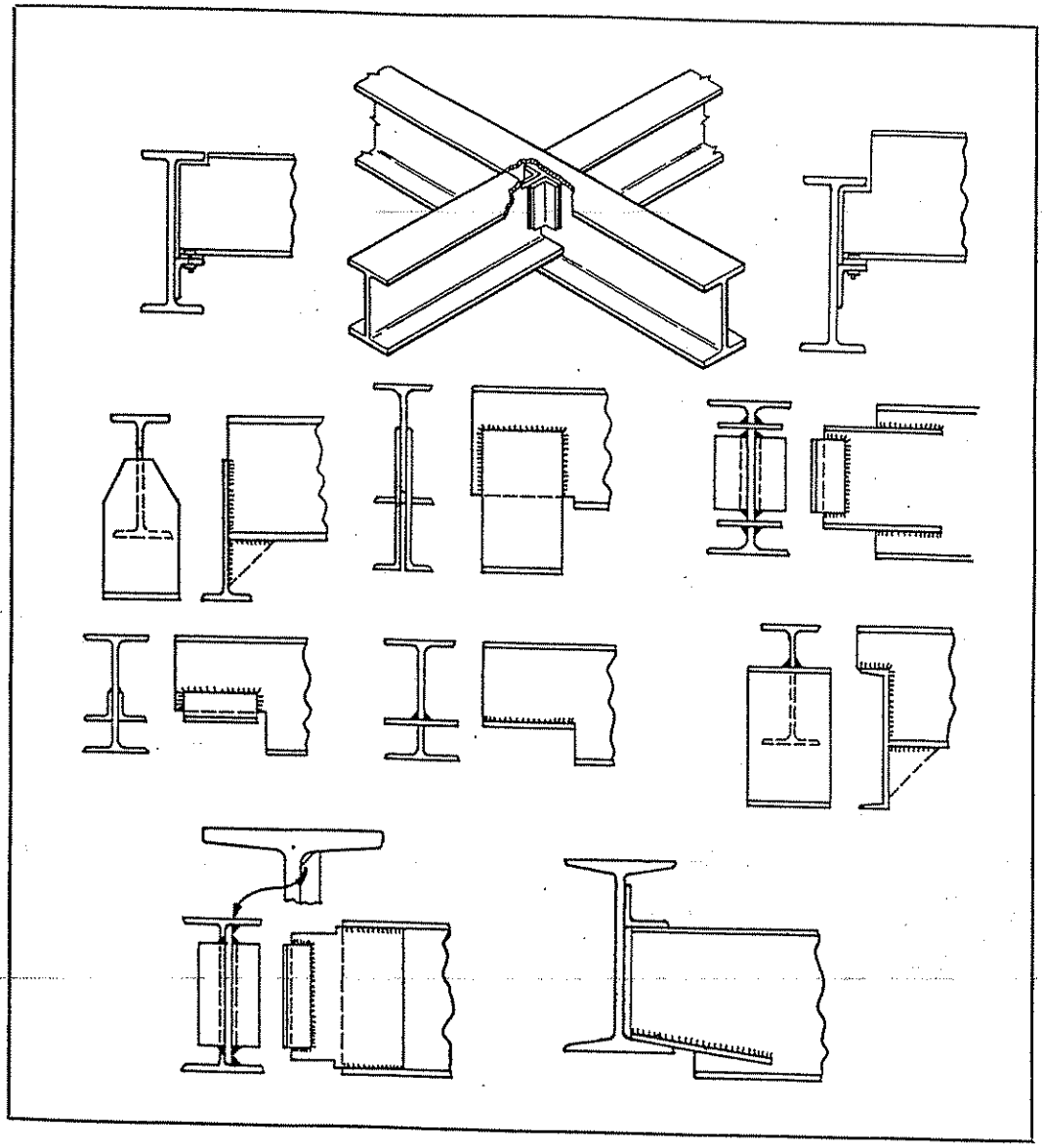


FIG. 13 Beams framing to girder web.

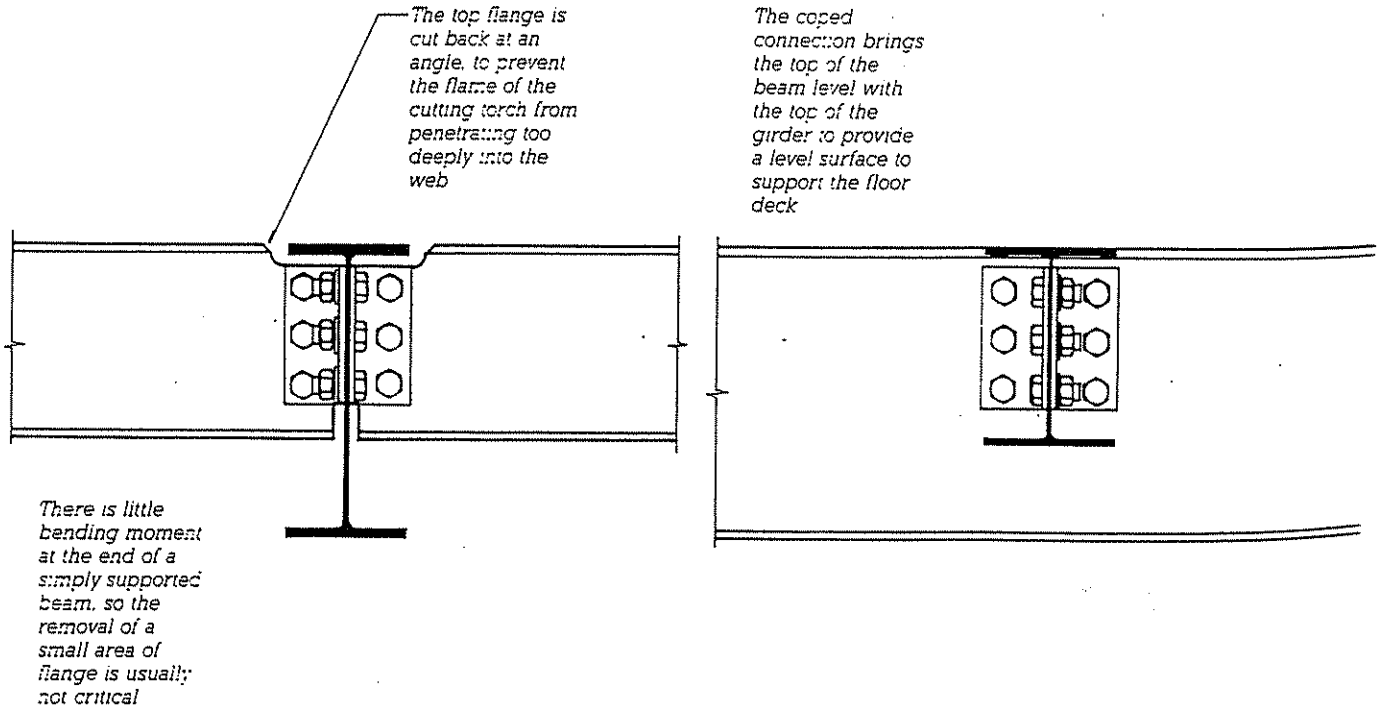
Source: Blodgett, 1966

Single Horizontal Element to Single Horizontal Element (cont)

Steel Beam to Steel Girder

FIGURE 9.33

A coped beam-girder connection (AISC Type 2). A girder is a beam that supports other beams, as shown on the framing plan in Figure 9.39.



Source: Allen, 1985

Single Horizontal Element to Single Horizontal Element (cont)

Steel Beam to Steel Girder

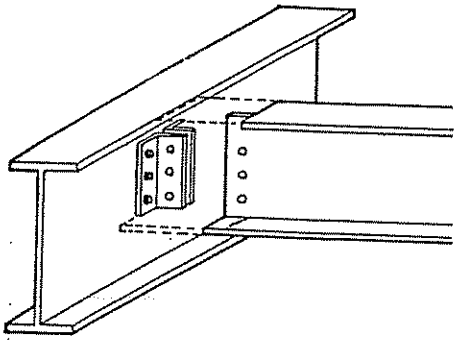


Fig. 21.22 *Beam-to-beam connection using web cleats.*

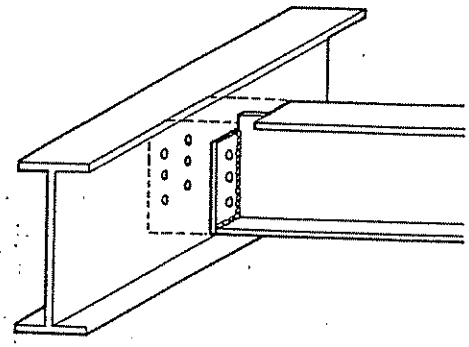


Fig. 21.23 *Schematic arrangement for a beam-to-beam connection using a welded end plate.*

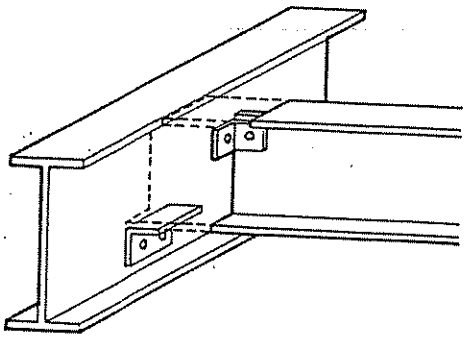
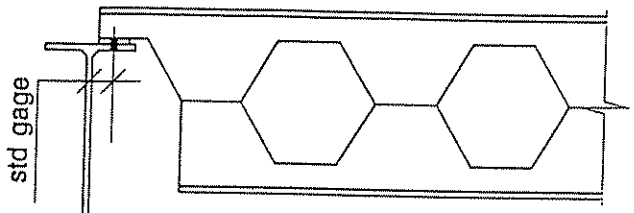


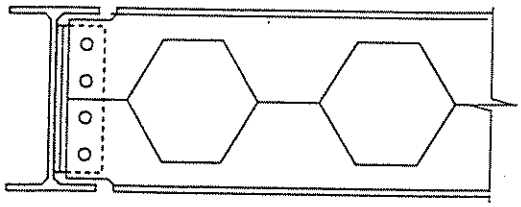
Fig. 21.25 *Beam-to-beam connection using seating and restraining cleats.*

Source: Blanc, 1993

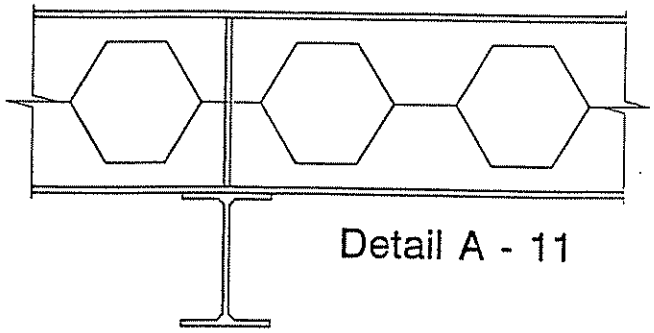
Single Horizontal Element to Single Horizontal Element (cont)
Steel Castellated Beam to Steel Girder



Detail A - 5



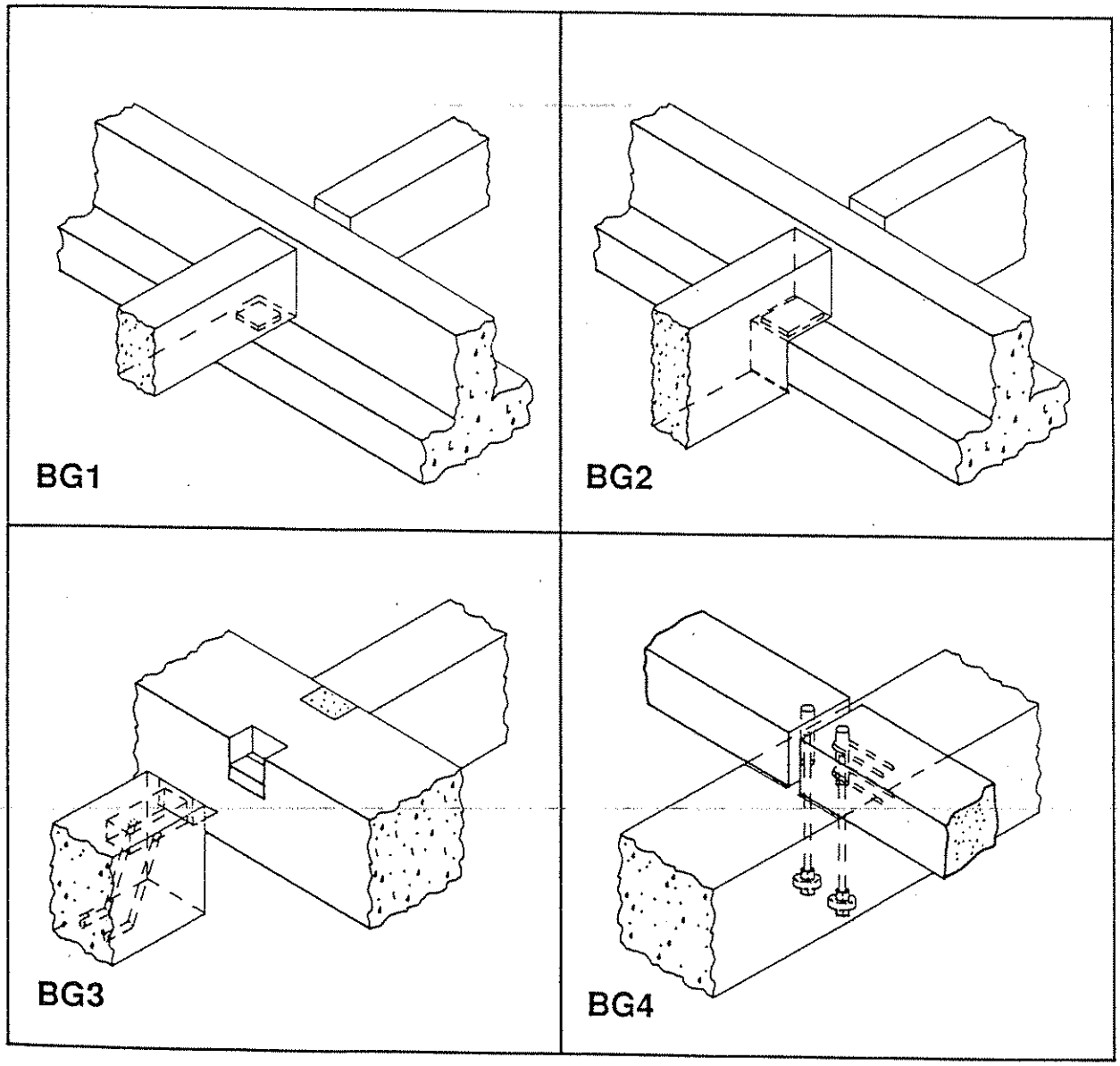
Detail A - 10



Detail A - 11

Source: Chaparral Steel Co.

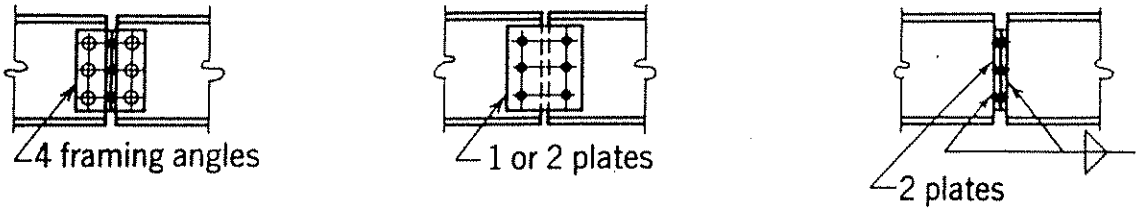
Single Horizontal Element to Single Horizontal Element (cont)
Precast Concrete Beam to Precast Concrete Girder



Source: PCI, 1988

Single Horizontal Element to Single Horizontal Element (cont)
Steel Beam to Steel Beam

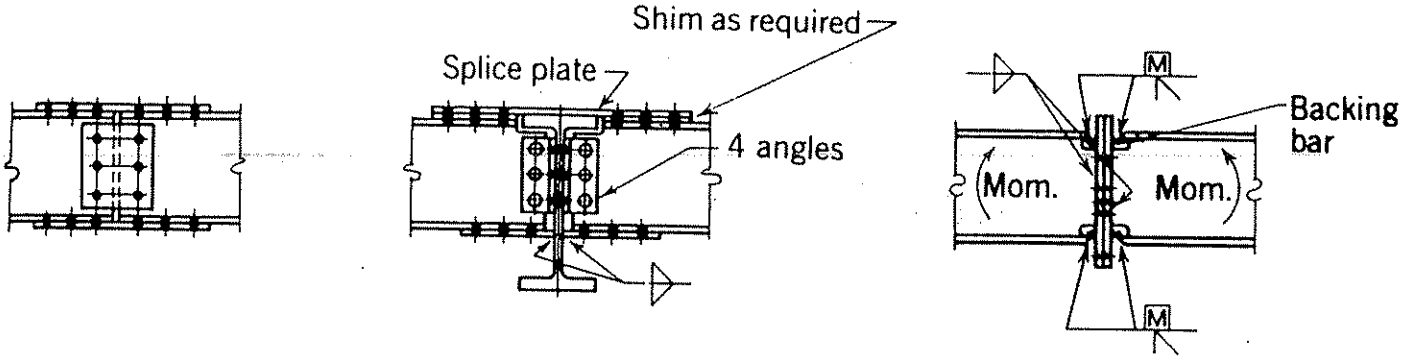
SHEAR SPLICES



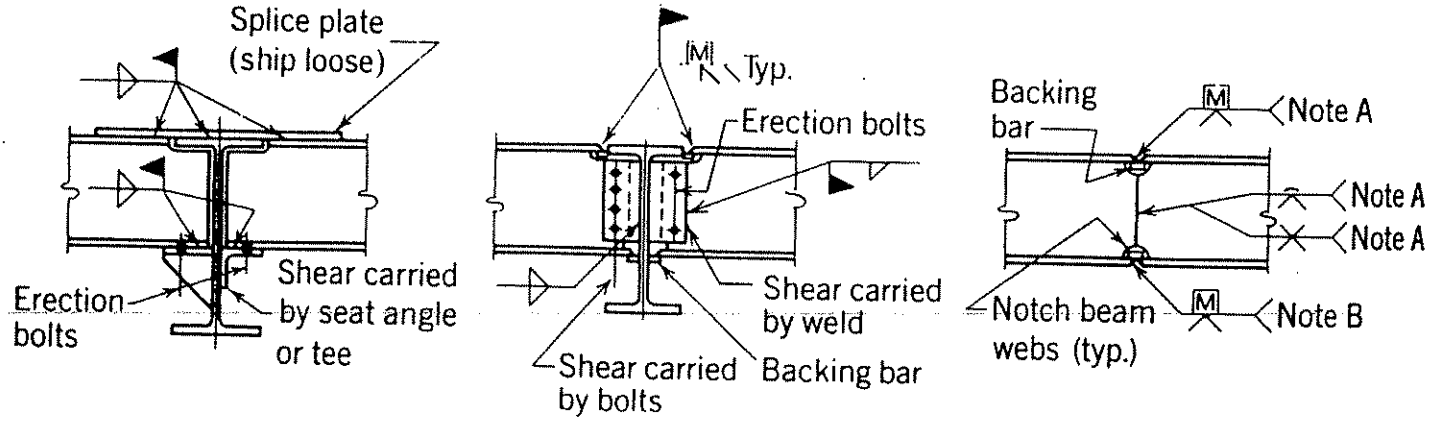
Note: Of the above types, 4 framing angles is most flexible.

Source: AISC, 1986

BOLTED MOMENT SPLICES

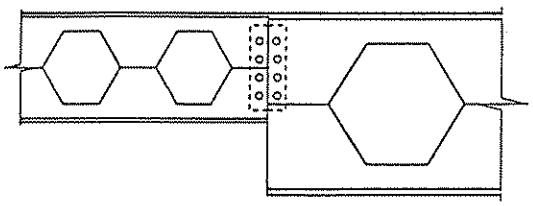


WELDED MOMENT SPLICES



Source: AISC, 1986

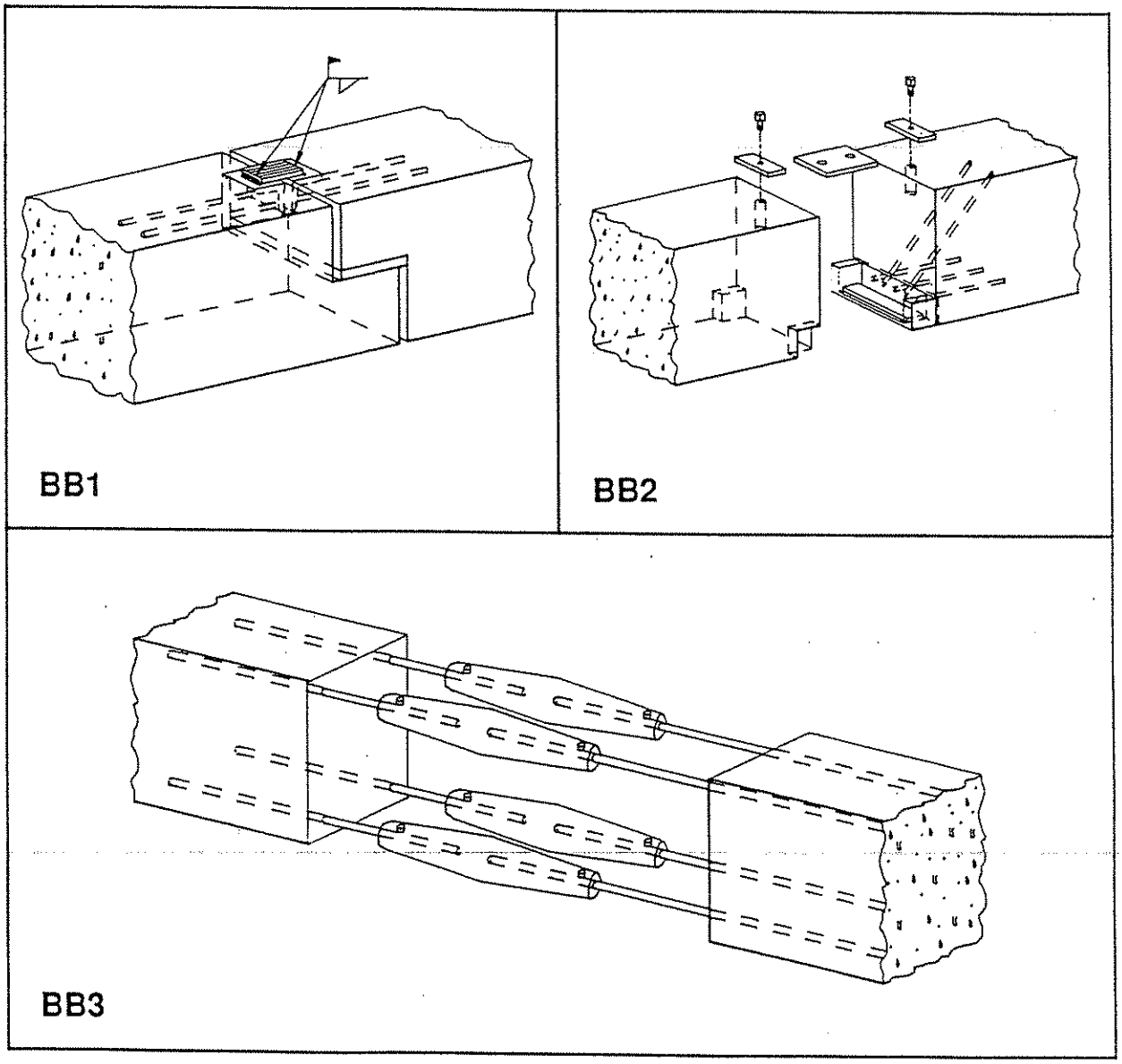
Single Horizontal Element to Single Horizontal Element (cont)
Steel Castellated Beam to Steel Castellated Beam



Detail A - 12

Source: Chaparral Steel Co.

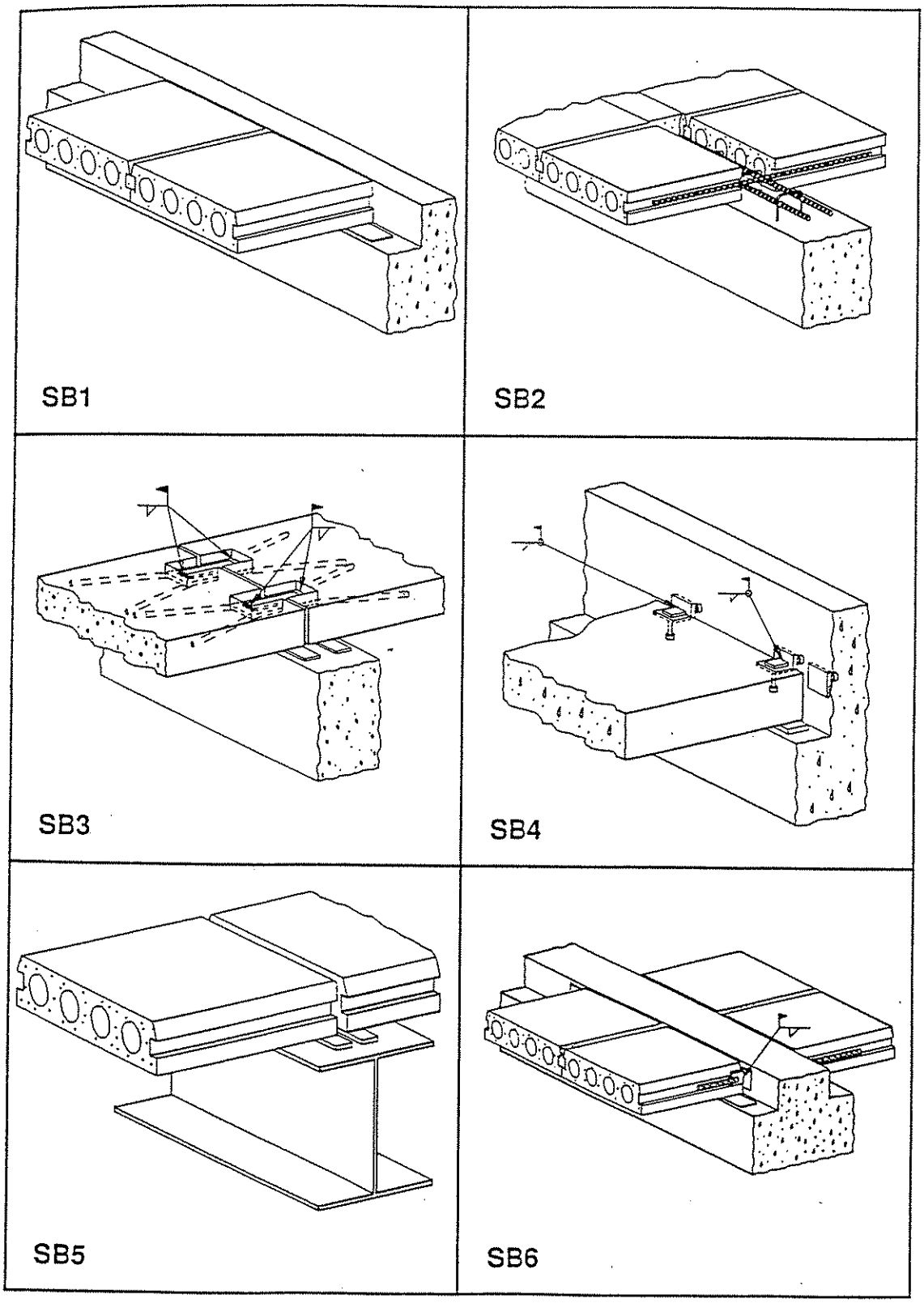
Single Horizontal Element to Single Horizontal Element (cont)
Precast Concrete Beam to Precast Concrete Beam



Source: PCI, 1988

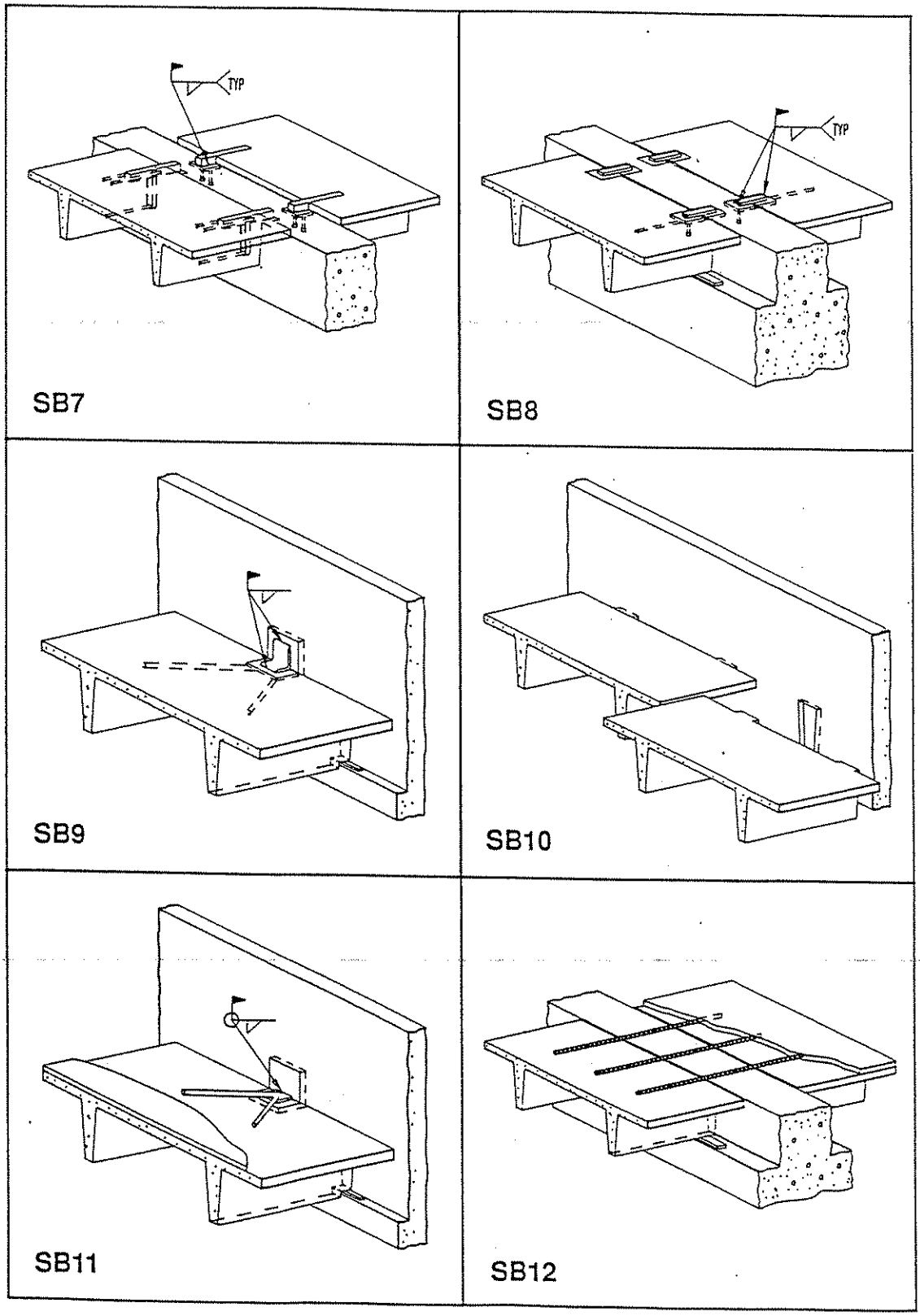
Planar Horizontal Element to Single Horizontal Element

Precast Concrete Floor Slab to Precast Concrete Beam



Source: PCI, 1988

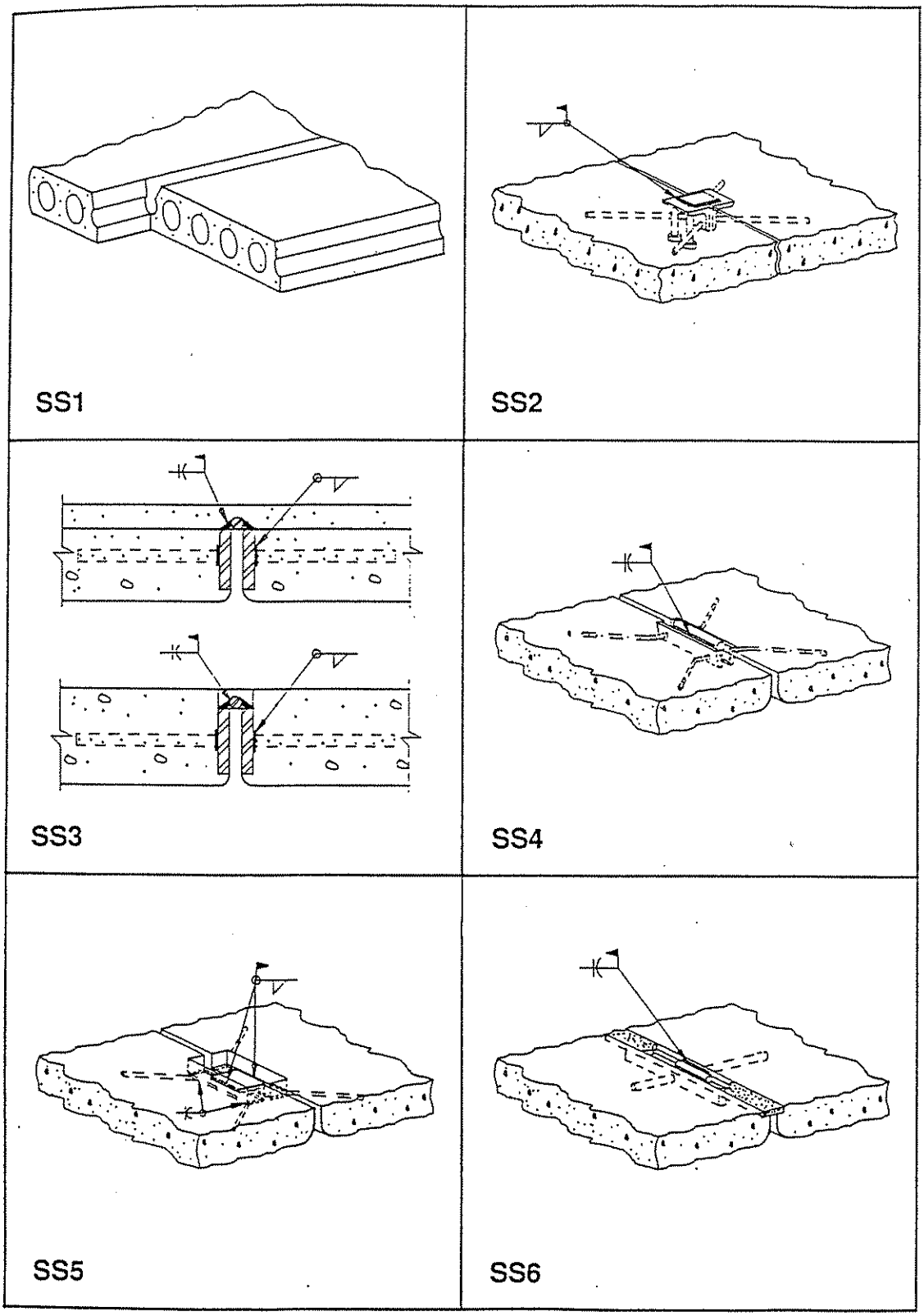
Planar Horizontal Element to Single Horizontal Element (cont)
Precast Concrete Floor Slab to Precast Concrete Beam



Source: PCI, 1988

Planar Horizontal Element to Planar Horizontal Element

Precast Concrete Floor Slab to Precast Concrete Floor Slab



Source: PCI, 1988

CHAPTER 3: Analytical Framework of Structural Elements and Connections

Description

This chapter explores all of the technically feasible combinations of elements, by orientation and assembly continuity, revealing the similarities and differences in the way elements may be combined. It provides a framework for the analysis of structural systems, specifically the interaction between the orientation, dimensionality, and continuity of the structural forms and the nature of the connections. This portion of the report goes into more detail as to the possible orientations of the elements; however, connection details are not shown and the elements are not classified by material but treated as having generic properties. This chapter is relevant to preassembly and prefabrication by establishing new ways of thinking about this issue and possibly leading to ideas for new structural systems.

This section is organized like the second part of Chapter 2 dealing with connections for load bearing elements. The organization of this section can be understood most easily with reference to Table 1. The row and column associated with each number in the table refers to the two types of elements that are being connected. In the text, examples of different possible combinations of these elements are given by the orientation and continuity of the elements. The numbers refer to the sections within this chapter under which the particular connections are represented. This analytical framework extends the analysis of the connections in Chapter 2 to consider all the technically feasible relationships between elements, rather than limiting the discussion to those that currently exist.

Table 1: Categories of Connections Among Structural Elements by Orientation

		Vertical			
		Single	Planar		
Vertical	Single	1	2	Horizontal	
	Planar	2	3	Single	Planar
Horizontal	Single	4	6	8	9
	Planar	5	7	9	10

Chapter 3 Outline

Analytical Framework of Structural Forms and Connections

I. Single Vertical Element to Single Vertical Element
   A. Column to Foundation (column base)
   B. Column to Column (column splice)

II. Planar Vertical Element to Single Vertical Element
   A. Continuous Planar Vertical to Columns
      1. Continuous Planar Vertical on top
      2. Continuous Planar Vertical on bottom
      3. Continuous Planar Vertical inside two columns
      4. Continuous Planar Vertical on exterior of columns
   B. Continuous Planar Vertical to Single Foundations
   C. Discontinuous Planar Vertical to Columns
      1. Discontinuous Planar Vertical on top
      2. Discontinuous Planar Vertical on bottom
      3. Discontinuous Planar Vertical inside two columns
      4. Discontinuous Planar Vertical on exterior of columns
   D. Discontinuous Planar Vertical to Single Foundations

III. Planar Vertical Element to Planar Vertical Element
   A. Continuous Planar Vertical to Continuous Planar Vertical
      1. One on top of the other
      2. Side by side
      3. Side by side (at corner)
   B. Discontinuous Planar Vertical to Discontinuous Planar Vertical
      1. One on top of the other
      2. Side by side
      3. Side by side (at corner)
   C. Continuous Planar Vertical to Discontinuous Planar Vertical
      1. Continuous Planar Vert. on top of Discontinuous Planar Vert.
      2. Discontinuous Planar Vert. on top of Continuous Planar Vert.
      3. Side by side
      4. Side by side (at corner)
      5. Face to face
   D. Continuous Planar Vertical to Continuous Foundation
   E. Discontinuous Planar Vertical to Continuous Foundation

IV. Single Horizontal Element to Single Vertical Element
   A. Beam connected to Column
   B. Beam simply supported over Column
   C. Beam continuous over Column

V. Planar Horizontal Element to Single Vertical Element
   A. Continuous Planar Horizontal to Columns

1. Continuous Planar Horizontal connected to Columns
2. Continuous Planar Horizontal simply supported over Columns
3. Continuous Planar Horizontal continuous over Column(s)
4. Continuous Planar Horizontal "surrounding" Column
5. Column(s) simply supported over Continuous Planar Horizontal

B. Discontinuous Planar Horizontal to Columns

1. Discontinuous Planar Horizontal connected to Columns
2. Discontinuous Planar Horizontal simply supported over Columns
3. Discontinuous Planar Horizontal continuous over Columns
4. Discontinuous Planar Horizontal "surrounding" Column
5. Column(s) simply supported over Discontinuous Planar Horizontal

VI. Single Horizontal Element to Planar Vertical Element

A. Beam to Continuous Planar Vertical

1. Continuous Planar Vertical connected to Beam(s) along length
2. Continuous Planar Vertical connected to Beam end(s)
3. Continuous Planar Vertical simply supported over Beam(s) along length
4. Continuous Planar Vertical simply supported over Beam end(s)
5. Continuous Planar Vertical continuous over Beam
6. Beam connected to Continuous Planar Vertical(s)
7. Beam simply supported over Continuous Planar Vertical(s)
8. Beam continuous over Continuous Planar Vertical

B. Beam to Discontinuous Planar Vertical

1. Discontinuous Planar Vertical connected to Beam(s) along length
2. Discontinuous Planar Vertical connected to Beam end(s)
3. Discontinuous Planar Vertical simply supported over Beam(s) along length
4. Discontinuous Planar Vertical simply supported over Beam end(s)
5. Discontinuous Planar Vertical continuous over Beam
6. Beam connected to Discontinuous Planar Vertical(s)
7. Beam simply supported over Discontinuous Planar Vertical(s)
8. Beam continuous over Discontinuous Planar Vertical

VII. Planar Horizontal Element to Planar Vertical Element

A. Continuous Planar Horizontal to Continuous Planar Vertical

1. Continuous Planar Horizontal connected to two Cont. Planar Vert.
2. Continuous Planar Horizontal simply supported over two Continuous Planar Vertical
3. Continuous Planar Horizontal continuous over one Cont. Planar Vert.
4. Continuous Planar Vertical connected to Cont. Planar Horizontal
5. Continuous Planar Vertical simply supported over Continuous Planar Horizontal
6. Continuous Planar Vertical continuous over Cont. Planar Horizontal

B. Discontinuous Planar Horizontal to Discontinuous Planar Vertical

1. Discontinuous Planar Horizontal connected to two Discontinuous Planar Vertical

2. Discontinuous Planar Horizontal simply supported over two Discontinuous Planar Vertical
3. Discontinuous Planar Horizontal continuous over one Discontinuous Planar Vertical
4. Discontinuous Planar Vertical connected to Discontinuous Planar Horizontal
5. Discontinuous Planar Vertical simply supported over Discontinuous Planar Horizontal
6. Discontinuous Planar Vertical continuous over Discontinuous Planar Horizontal*

C. Continuous Planar Horizontal to Discontinuous Planar Vertical*
D. Discontinuous Planar Horizontal to Continuous Planar Vertical*

VIII. Single Horizontal Element to Single Horizontal Element
A. Beam connected to Girder
B. Beam simply supported over Girder
C. Beam continuous over Girder
D. Beam splice

IX. Planar Horizontal Element to Single Horizontal Element
A. Continuous Planar Horizontal to Beams
1. Continuous Planar Horizontal connected to Beam(s) along length
2. Continuous Planar Horizontal connected to Beam end(s)
3. Continuous Planar Horizontal simply supported over Beam(s) along length
4. Continuous Planar Horizontal simply supported over Beam end(s)
5. Continuous Planar Horizontal continuous over Beam
6. Beam connected to Continuous Planar Horizontal
7. Beam simply supported over Continuous Planar Horizontal
8. Beam continuous over Continuous Planar Horizontal

B. Discontinuous Planar Horizontal to Beams
1. Discontinuous Planar Horizontal connected to Beam(s) along length
2. Discontinuous Planar Horizontal connected to Beam end(s)
3. Discontinuous Planar Horizontal simply supported over Beam(s) along length
4. Discontinuous Planar Horizontal simply supported over Beam end(s)
5. Discontinuous Planar Horizontal continuous over Beam
6. Beam connected to Discontinuous Planar Horizontal
7. Beam simply supported over Discontinuous Planar Horizontal
8. Beam continuous over Discontinuous Planar Horizontal

X. Planar Horizontal Element to Planar Horizontal Element
A. Continuous Planar Horizontal to Continuous Planar Horizontal
1. Side to side (splice)
2. Face to face (one on top of the other)

B. Discontinuous Planar Horizontal to Discontinuous Planar Horizontal
1. Side to side (splice)

*Not illustrated.

2. Face to face (one on top of the other)

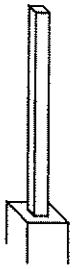
C. Continuous Planar Horizontal to Discontinuous Planar Horizontal
   1. Side to side (splice)
   2. Face to face (one on top of the other)

XI. Other Connections
   A. Truss panel point connection*
   B. Bracing member to column*
   C. Bracing member to beam*

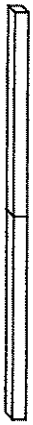
*Not illustrated.

Single Vertical Element to Single Vertical Element

A. Column to Foundation (Column base)



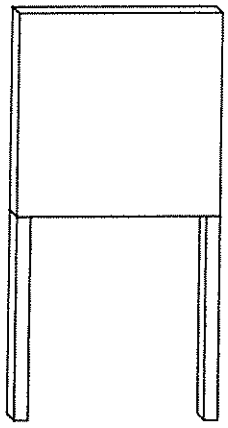
B. Column to Column (Column splice)



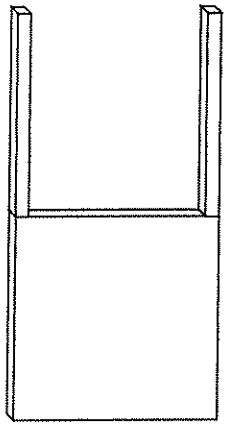
Planar Vertical Element to Single Vertical Element

A. Continuous Planar Vertical to Columns

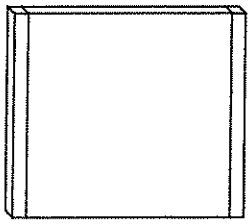
1. Continuous Planar Vertical on top



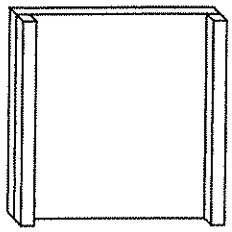
2. Continuous Planar Vertical on bottom



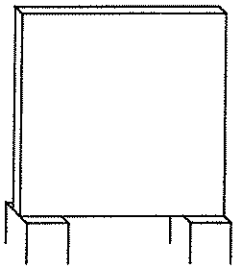
3. Continuous Planar Vertical inside two columns



4. Continuous Planar Vertical on exterior of columns



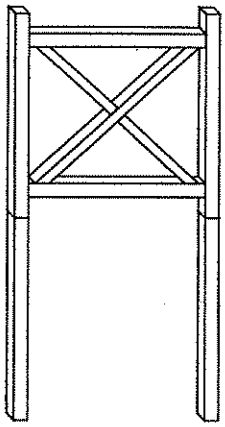
B. Continuous Planar Vertical to Single Foundations



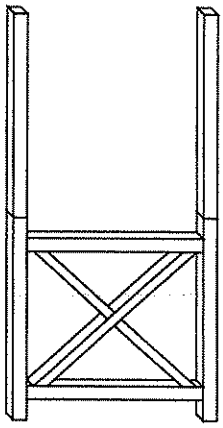
Planar Vertical Element to Single Vertical Element (cont)

C. Discontinuous Planar Vertical to Columns

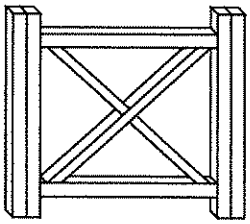
1. Discontinuous Planar Vertical on top



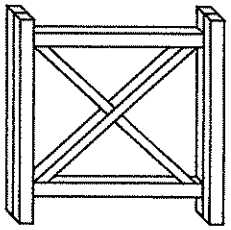
2. Discontinuous Planar Vertical on bottom



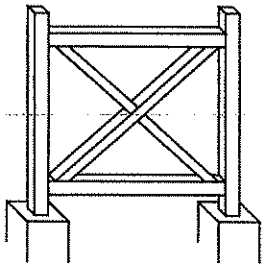
3. Discontinuous Planar Vertical inside two columns



4. Discontinuous Planar Vertical on exterior of columns



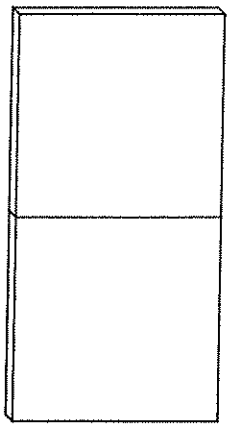
D. Discontinuous Planar Vertical to Single Foundations



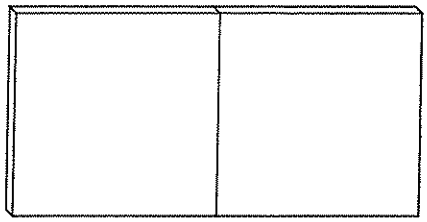
Planar Vertical Element to Planar Vertical Element

A. Continuous Planar Vertical to Continuous Planar Vertical

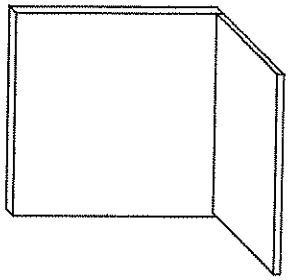
1. One on top of the other



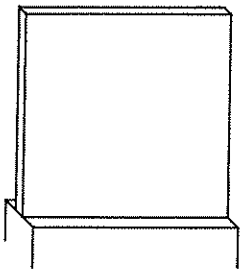
2. Side by side



3. Side by side at corner

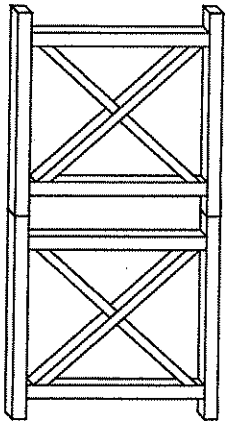


B. Continuous Planar Vertical to Continuous Foundation

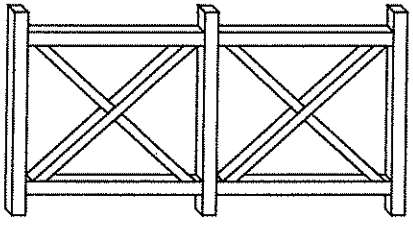


C. Discontinuous Planar Vertical to Discontinuous Planar Vertical

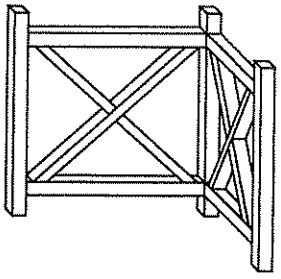
1. One on top of the other



2. Side by side

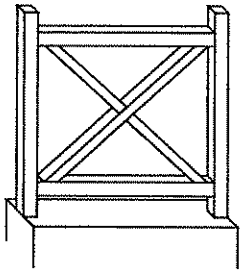


3. Side by side at corner



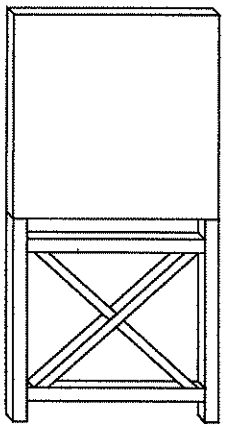
Planar Vertical Element to Planar Vertical Element (cont)

D. Discontinuous Planar Vertical to Continuous Foundation

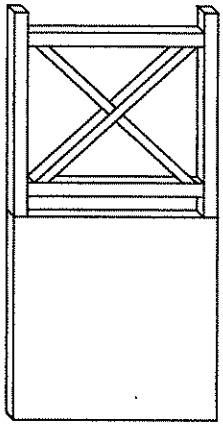


E. Continuous Planar Vertical to Discontinuous Planar Vertical

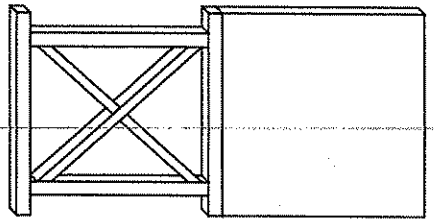
1. Continuous Planar Vertical on top of Discontinuous Planar Vertical



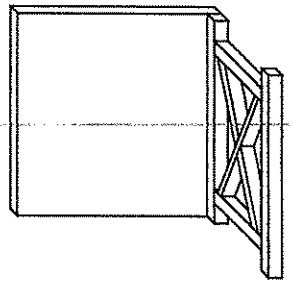
2. Discontinuous Planar Vertical on top of Continuous Planar Vertical



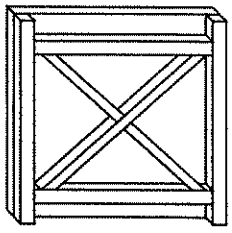
3. Side by side



4. Side by side at corner

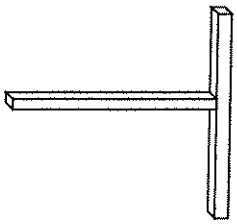


5. Face to face

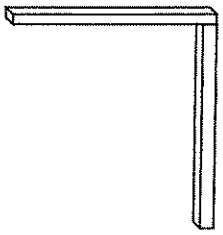


Single Horizontal Element to Single Vertical Element

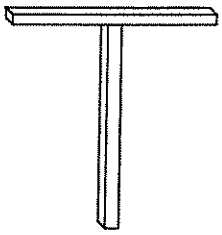
A. Beam connected to Column



B. Beam simply supported over Column



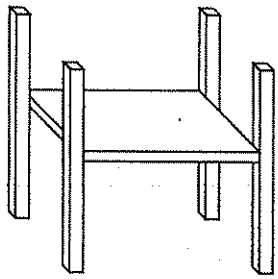
C. Beam continuous over Column



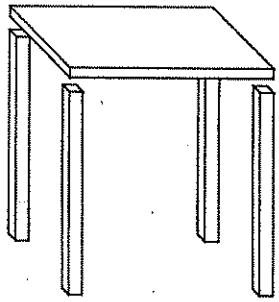
Planar Horizontal Element to Single Vertical Element

A. Continuous Planar Horizontal to Columns

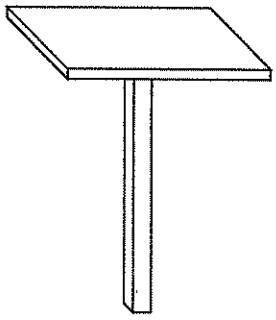
1. Continuous Planar Horizontal connected to Columns



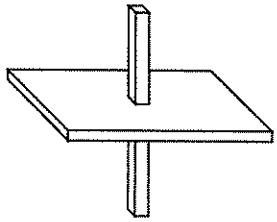
2. Continuous Planar Horizontal simply supported over Columns



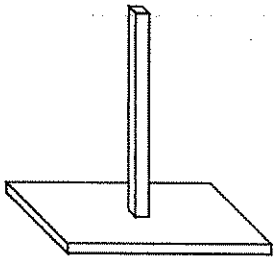
3. Continuous Planar Horizontal continuous over Column(s)



4. Continuous Planar Horizontal "surrounding" Column



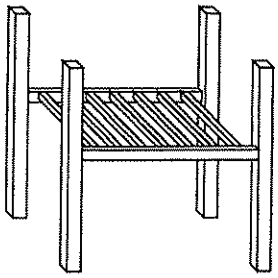
5. Column simply supported over Continuous Planar Horizontal



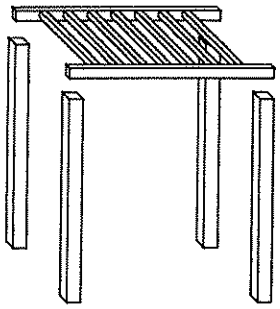
Planar Horizontal Element to Single Vertical Element (cont)

B. Discontinuous Planar Horizontal to Columns

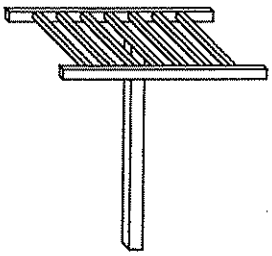
1. Discontinuous Planar Horizontal connected to Columns



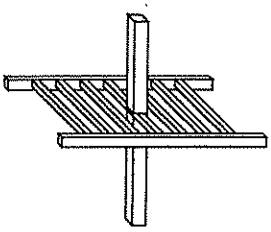
2. Discontinuous Planar Horizontal simply supported over Columns



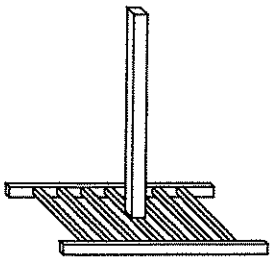
3. Discontinuous Planar Horizontal continuous over Column(s)



4. Discontinuous Planar Horizontal "surrounding" Column



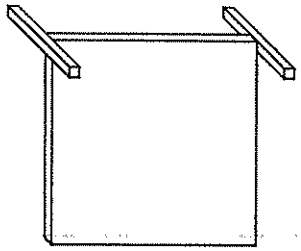
5. Column simply supported over Discontinuous Planar Horizontal



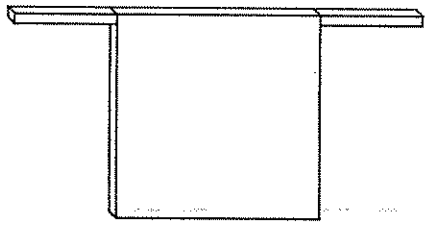
Single Horizontal Element to Planar Vertical Element

A. Beam to Continuous Planar Vertical

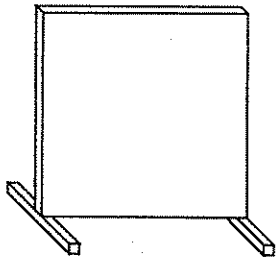
1. Continuous Planar Vertical connected to Beam(s) along length



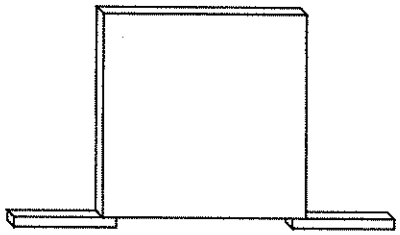
2. Continuous Planar Vertical connected to beam end(s)



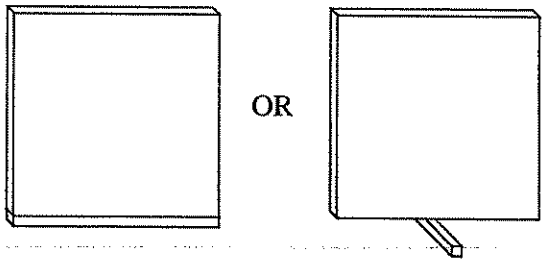
3. Continuous Planar Vertical simply supported over Beam(s) along length



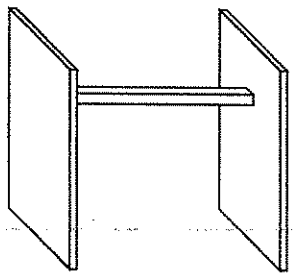
4. Continuous Planar Vertical simply supported over Beam end(s)



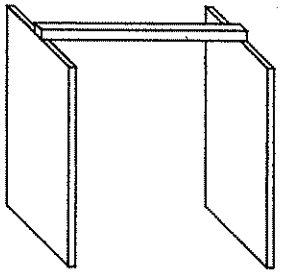
5. Continuous Planar Vertical continuous over Beam



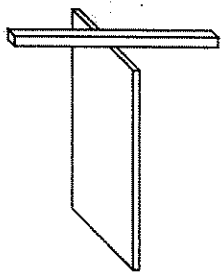
6. Beam connected to Continuous Planar Vertical(s)



7. Beam simply supported over Continuous Planar Vertical(s)



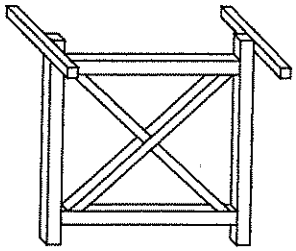
8. Beam continuous over Continuous Planar Vertical



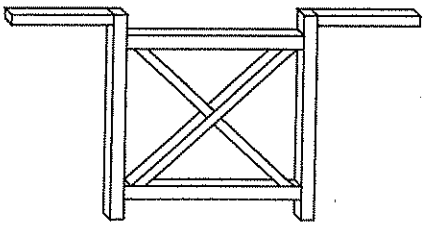
Single Horizontal Element to Planar Vertical Element (cont)

B. Beam to Discontinuous Planar Vertical

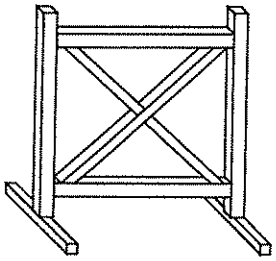
1. Discontinuous Planar Vertical connected to Beam(s) along length



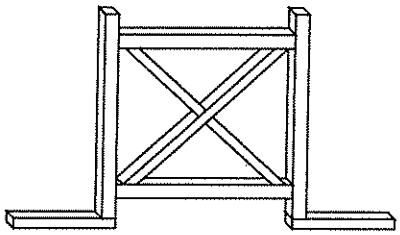
2. Discontinuous Planar Vertical connected to beam end(s)



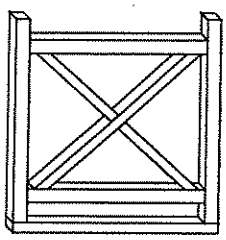
3. Discontinuous Planar Vertical simply supported over Beam(s) along length



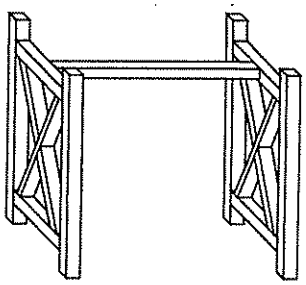
4. Discontinuous Planar Vertical simply supported over Beam end(s)



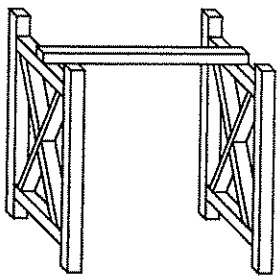
5. Discontinuous Planar Vertical continuous over Beam



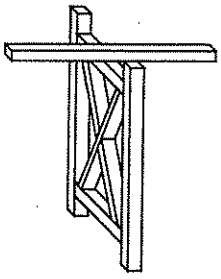
6. Beam connected to Discontinuous Planar Vertical(s)



7. Beam simply supported over Discontinuous Planar Vertical(s)



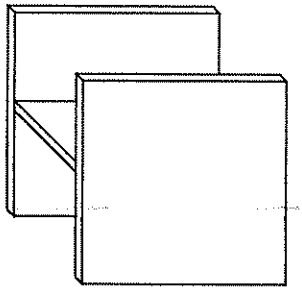
8. Beam continuous over Discontinuous Planar Vertical



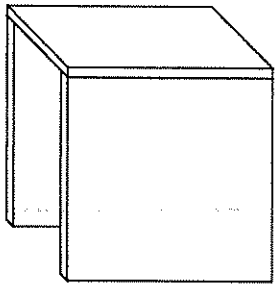
Planar Horizontal Element to Planar Vertical Element

A. Continuous Planar Horizontal to Continuous Planar Vertical

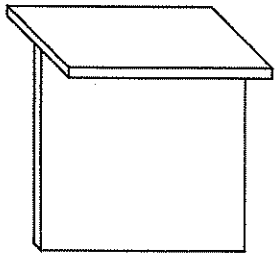
1. Continuous Planar Horizontal connected to two Continuous Planar Verticals



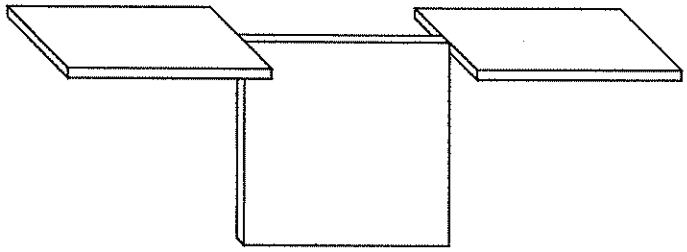
2. Continuous Planar Horizontal simply supported over two Continuous Planar Vertical



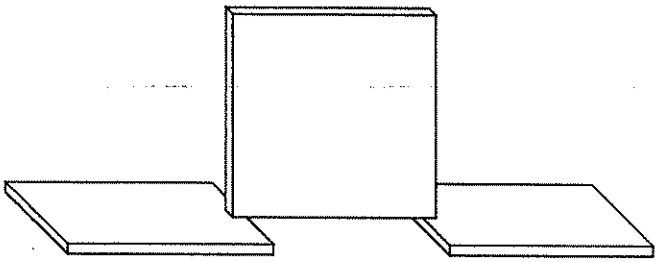
3. Continuous Planar Horizontal continuous over one Continuous Planar Vertical



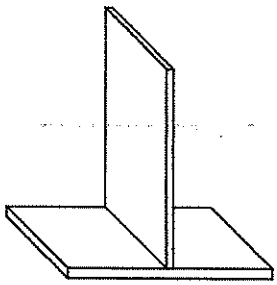
4. Continuous Planar Vertical connected to Continuous Planar Horizontal



5. Continuous Planar Vertical simply supported over Continuous Planar Horizontal



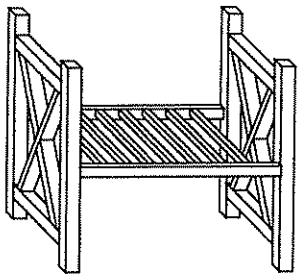
6. Continuous Planar Vertical continuous over Continuous Planar Horizontal



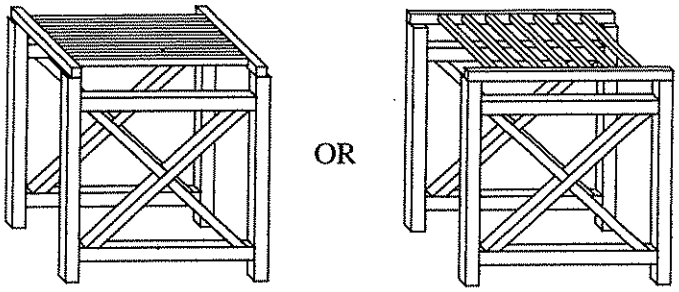
Planar Horizontal Element to Planar Vertical Element (cont)

B. Discontinuous Planar Horizontal to Discontinuous Planar Vertical

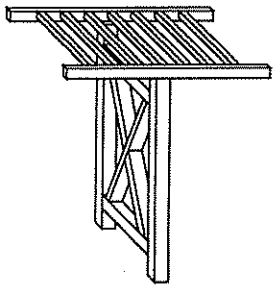
1. Discontinuous Planar Horizontal connected to two Discontinuous Planar Verticals



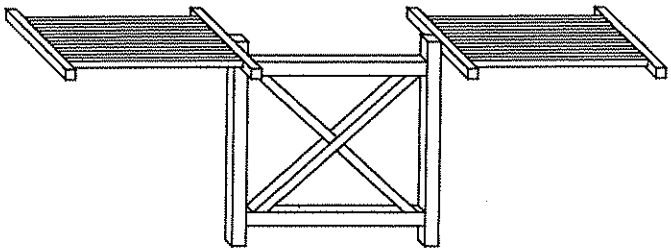
2. Discontinuous Planar Horizontal simply supported over two Discontinuous Planar Vertical



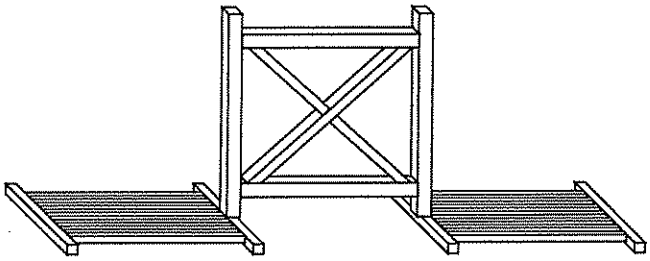
3. Discontinuous Planar Horizontal continuous over one Discontinuous Planar Vertical



4. Discontinuous Planar Vertical connected to Discontinuous Planar Horizontal

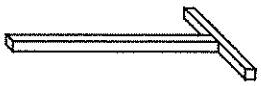


5. Discontinuous Planar Vertical simply supported over Discontinuous Planar Horizontal

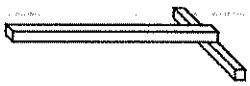


Single Horizontal Element to Single Horizontal Element

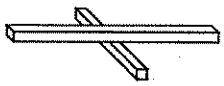
A. Beam connected to Girder



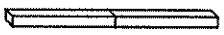
B. Beam simply supported over Girder



C. Beam continuous over Girder



D. Beam splice

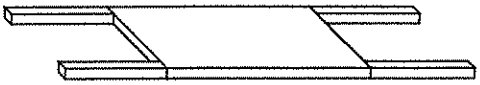


Planar Horizontal Element to Single Horizontal Element

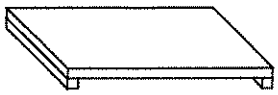
A. Continuous Planar Horizontal to Beams

1. Continuous Planar Horizontal connected to Beam(s) along length

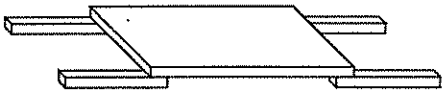
2. Continuous Planar Horizontal connected to Beam end(s)



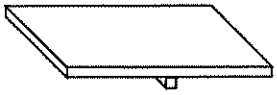
3. Continuous Planar Horizontal simply supported over Beam(s) along length



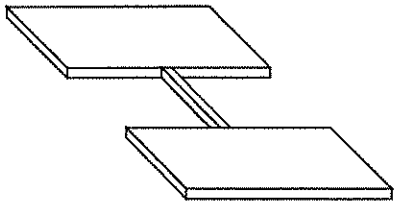
4. Continuous Planar Horizontal simply supported over Beam end(s)



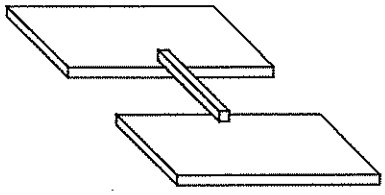
5. Continuous Planar Horizontal continuous over Beam



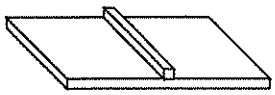
6. Beam connected to Continuous Planar Horizontal



7. Beam simply supported over Continuous Planar Horizontal



8. Beam continuous over Continuous Planar Horizontal



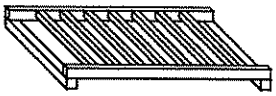
Planar Horizontal Element to Single Horizontal Element (cont)

B. Discontinuous Planar Horizontal to Beams

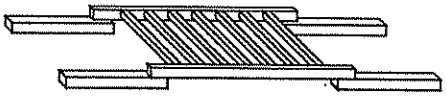
1. Discontinuous Planar Horizontal connected to Beam(s) along length

2. Discontinuous Planar Horizontal connected to Beam end(s)

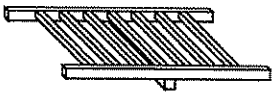
3. Discontinuous Planar Horizontal simply supported over Beam(s) along length



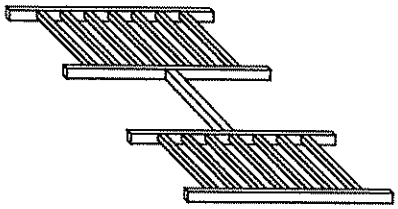
4. Discontinuous Planar Horizontal simply supported over Beam end(s)



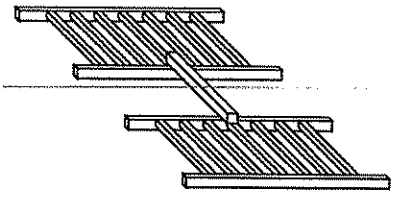
5. Discontinuous Planar Horizontal continuous over Beam



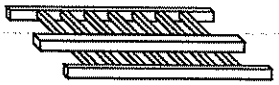
6. Beam connected to Discontinuous Planar Horizontal



7. Beam simply supported over Discontinuous Planar Horizontal



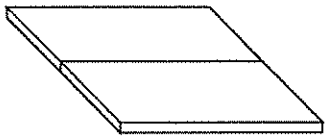
8. Beam continuous over Discontinuous Planar Horizontal



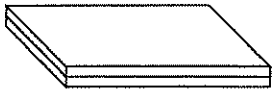
Planar Horizontal Element to Planar Horizontal Element

A. Continuous Planar Horizontal to Continuous Planar Horizontal

1. Side to side

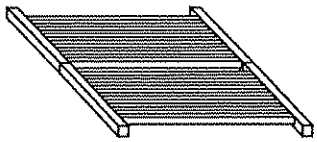


2. Face to face (one on top of the other)

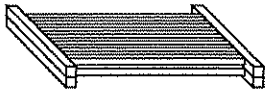


B. Discontinuous Planar Horizontal to Discontinuous Planar Horizontal

1. Side to side

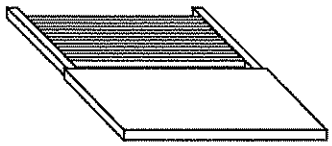


2. Face to face (one on top of the other)

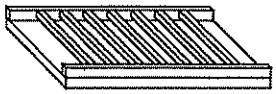


C. Continuous Planar Horizontal to Discontinuous Planar Horizontal

1. Side to side



2. Face to face (one on top of the other)



CHAPTER 4: Examples of Structural Systems

Description

With the intention of providing more efficient methods of construction than the traditional method of stick-building members, new structural systems have been developed. For our purposes, a "structural system" refers to a set of structural elements specially designed to fit together using specific connections to simplify erection. Structural systems are designed for certain conditions or loads and they are most efficient when the elements and connections are used together.

In this chapter, examples of structural systems specifically designed with complementary elements and connections are represented. These examples provide insight into different approaches that may be taken in response to the need for new systems for efficient prefabrication and preassembly.

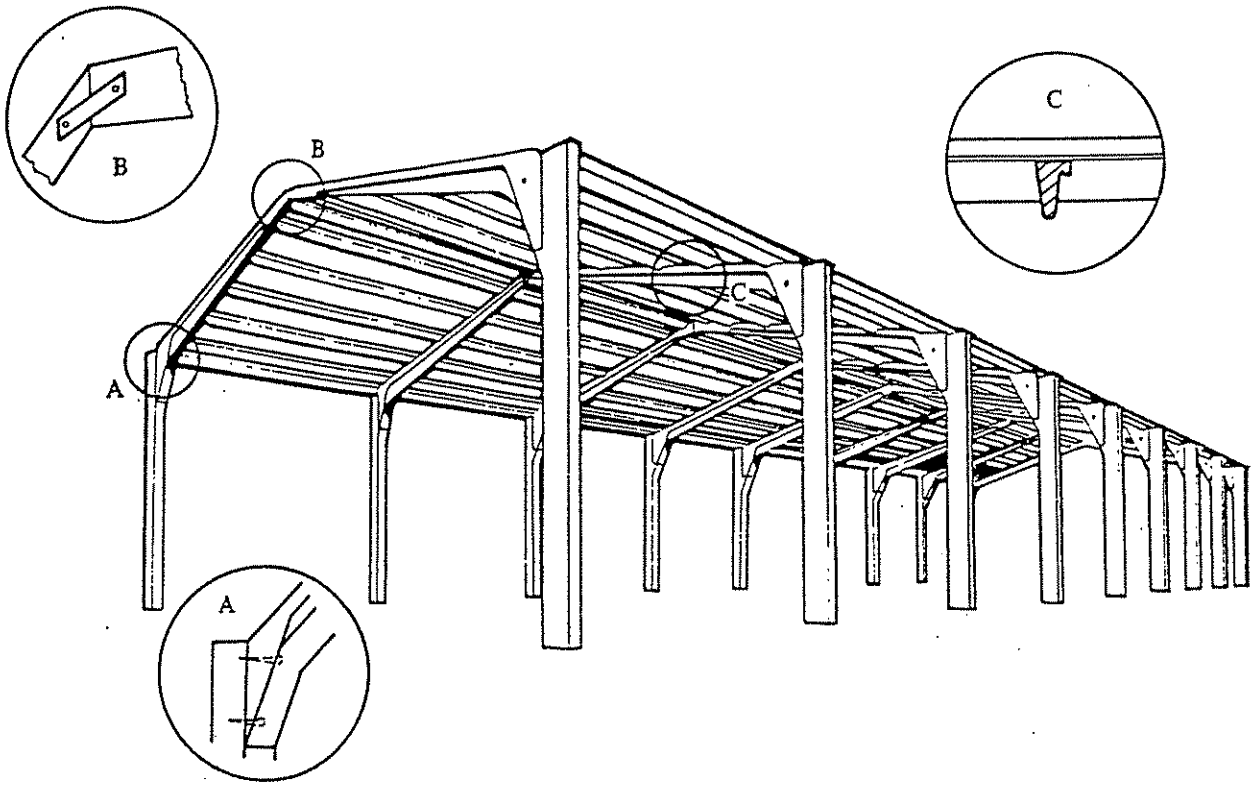
The major references used in this chapter were "Minimization of Floor Thickness in Precast Prestressed Concrete Multistory Buildings" (Low et al, 1991) and *Industrialization and Robotics in Building, A Managerial Approach* (Warszawski, 1990).

Chapter 4 Outline

Examples of structural systems

1. *Atcost* System
2. *BVM-TIP* System
3. Composite *Dy-Core* System
4. *Etoile* System
5. *Field plant* System
6. *Hojgaard and Schultz* System
7. *IMS* System
8. *Milz* System
9. *MSF* Wideslab System
10. *Nebraska* System
11. *Opera* System
12. *PSI* System
13. *Quickfloor* System
14. *Spanclad* System
15. *Tracoba* System
16. *Univaz* System
17. *Vescom* System
18. *Yuval Gad* System

Atcost **System** (United Kingdom)



Source: Warszawski, 1990

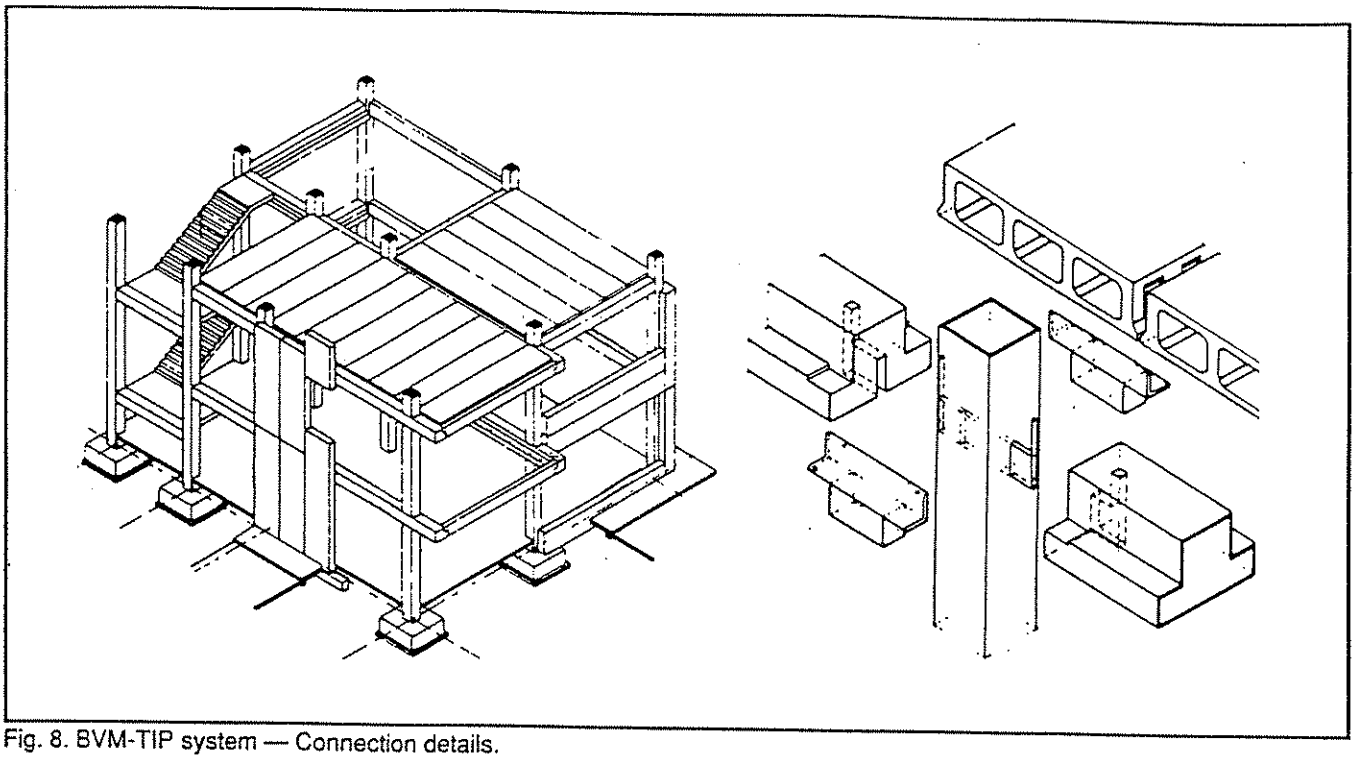


Fig. 8. BVM-TIP system — Connection details.

Source: Low et al, 1991

Composite *Dy-Core* System

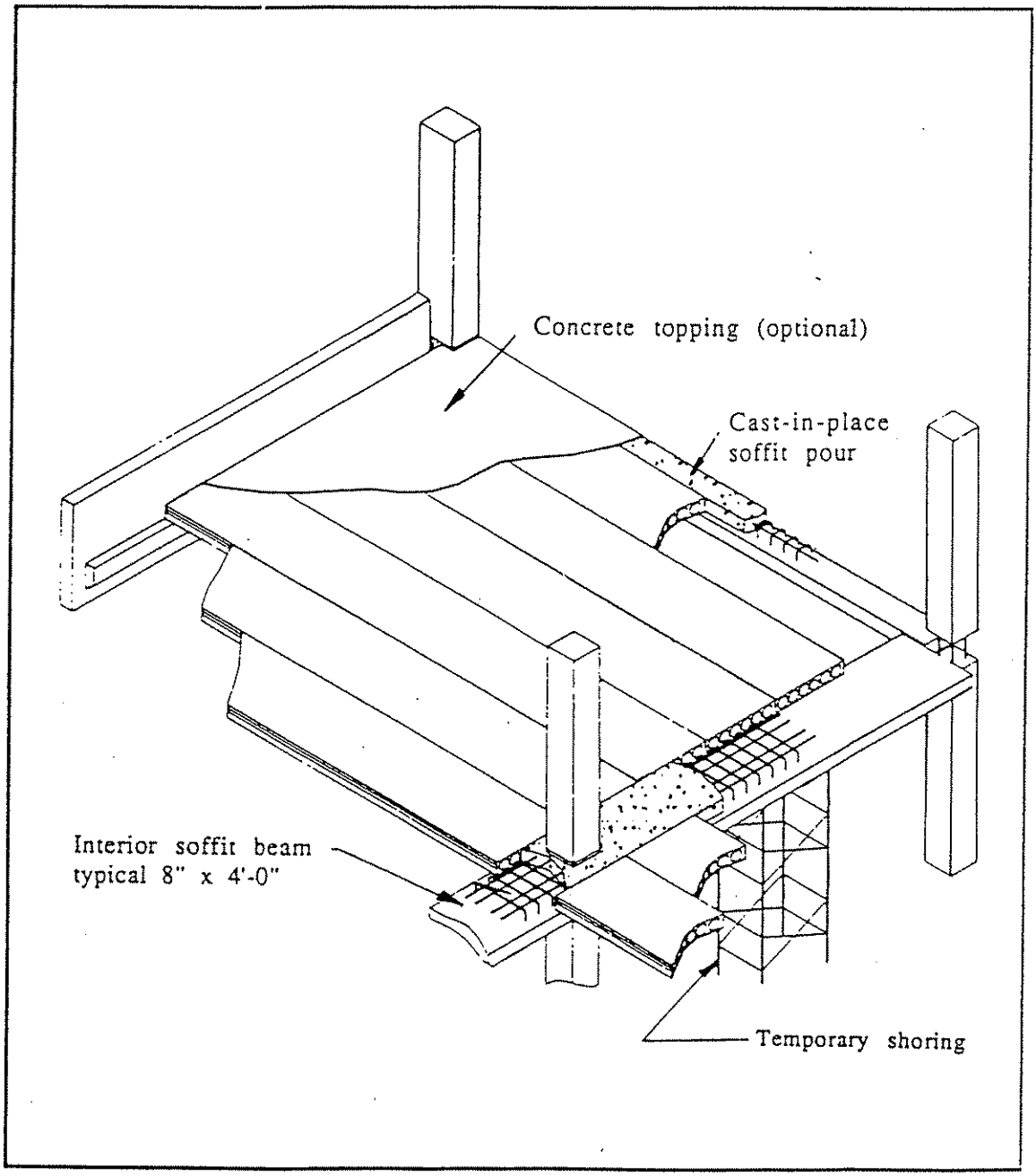


Fig. 2. Composite Dy-Core system.

Source: Low et al, 1991

Etoile System (France)

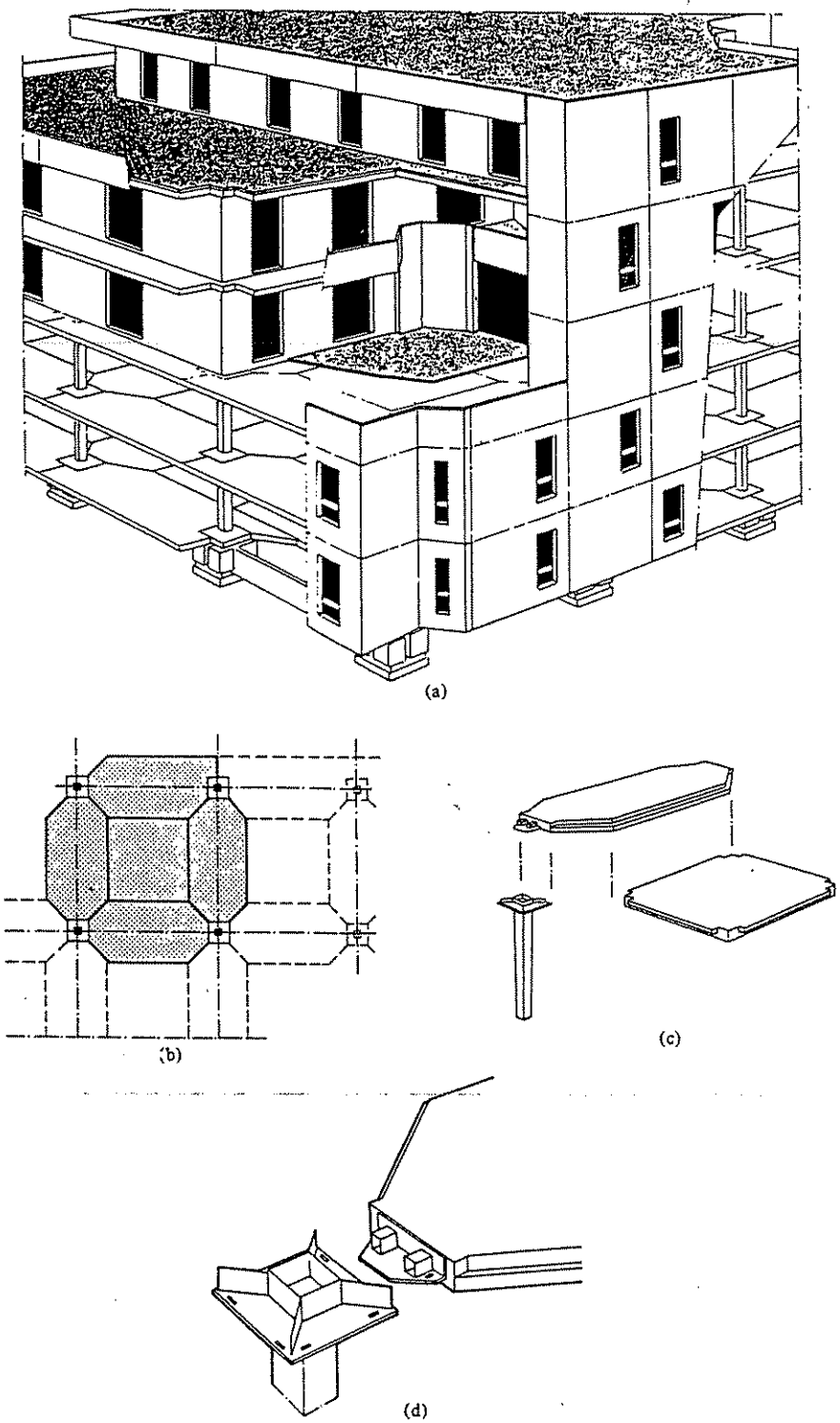


Figure 2.19 Etoile school system (France): (a) general scheme; (b),(c) structural elements; (d) connection detail.

Source: Warszawski, 1990

Field Plant System (Israel)

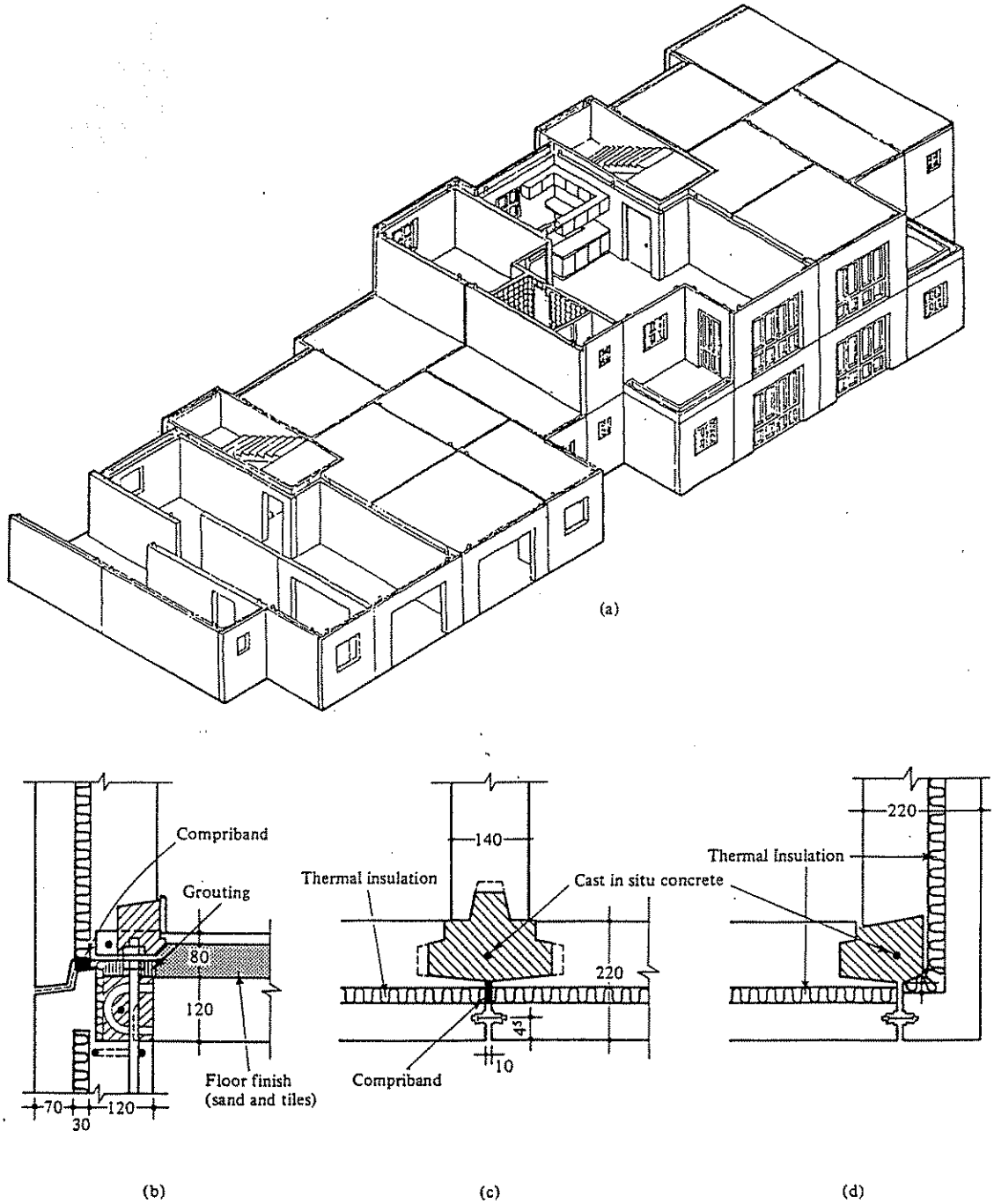


Figure 2.16 Field plant system (Israel): (a) general scheme; (b) vertical section; (c),(d) horizontal sections.

Source: Warszawski, 1990

Hojgaard and Schultz System

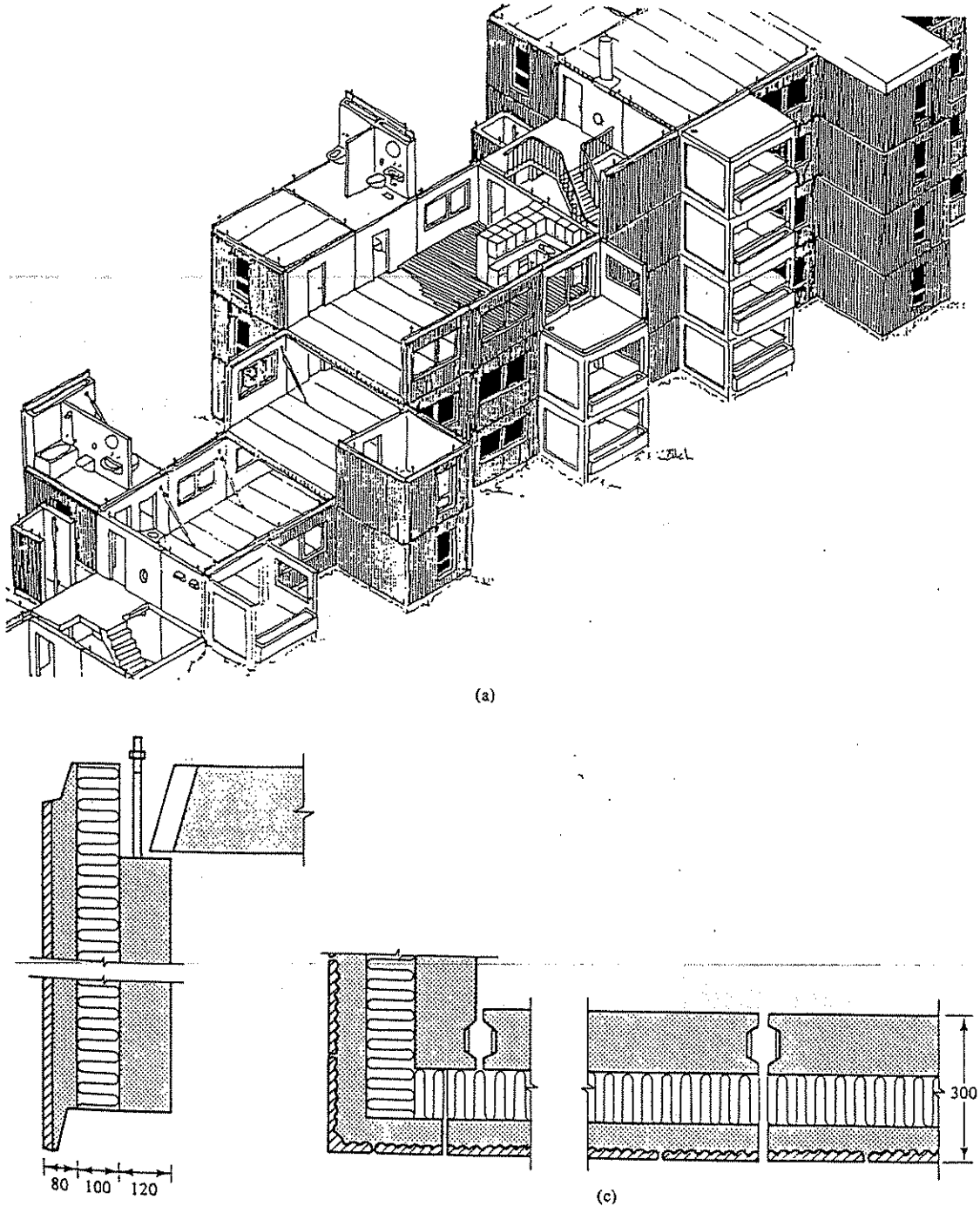


Figure 2.15 Hojgaard and Schultz system: (a) axonometric view, (b) vertical section through wall and joint, and (c) horizontal section through wall and joint.

Source: Warszawski, 1990

IMS System (Yugoslavia)

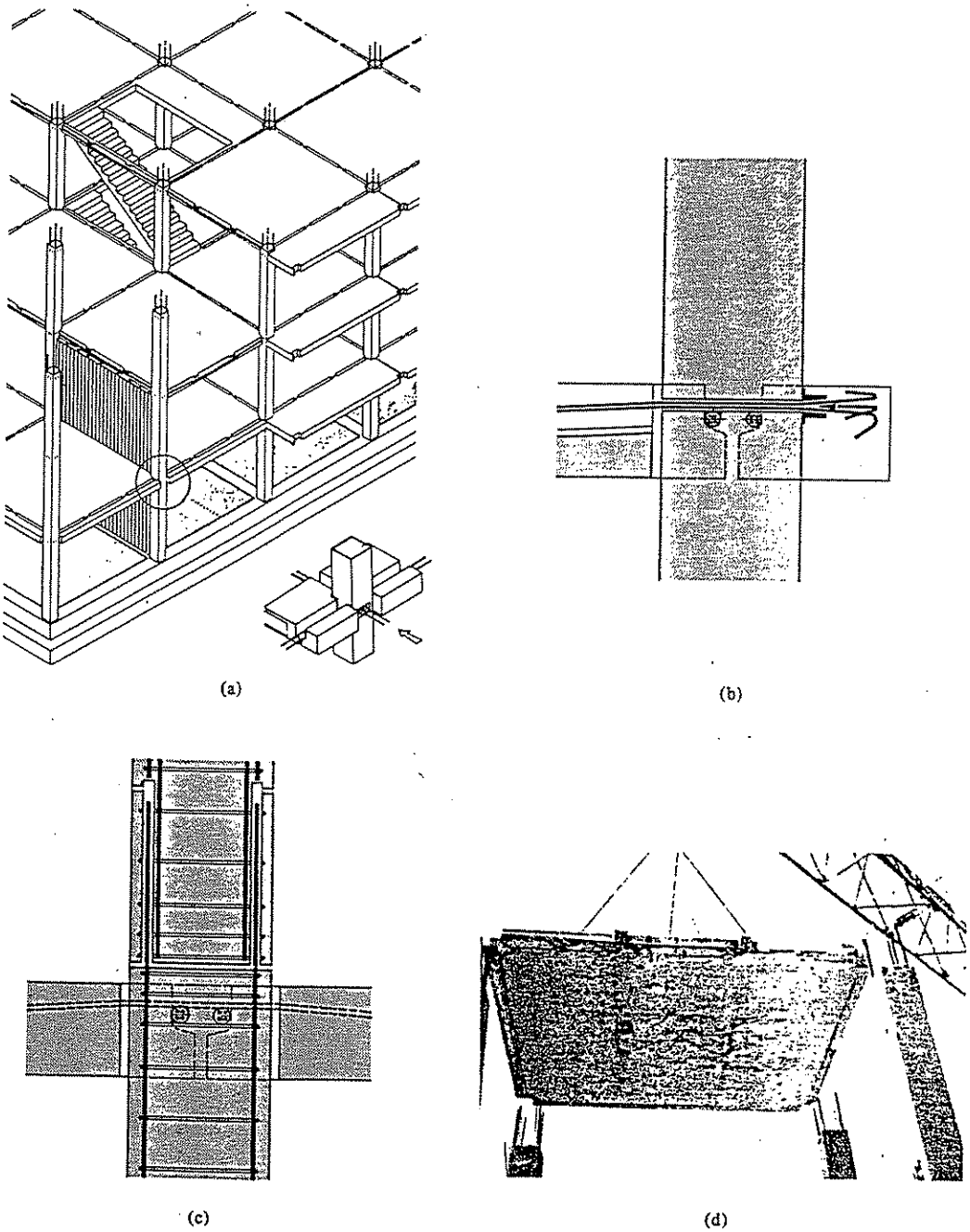


Figure 2.21 IMS system (Yugoslavia): (a) general scheme; (b),(c) prestressing and columns connection; and (d) picture.

Source: Warszawski, 1990

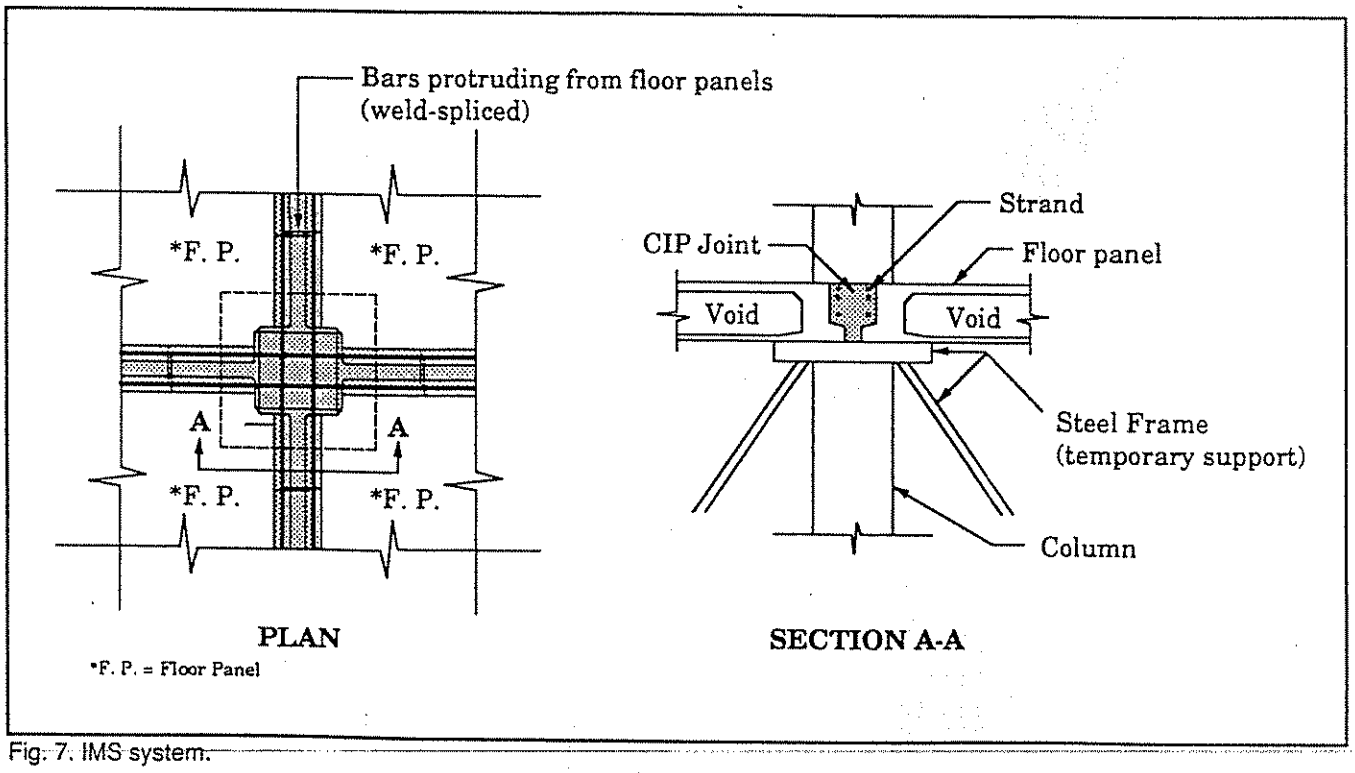
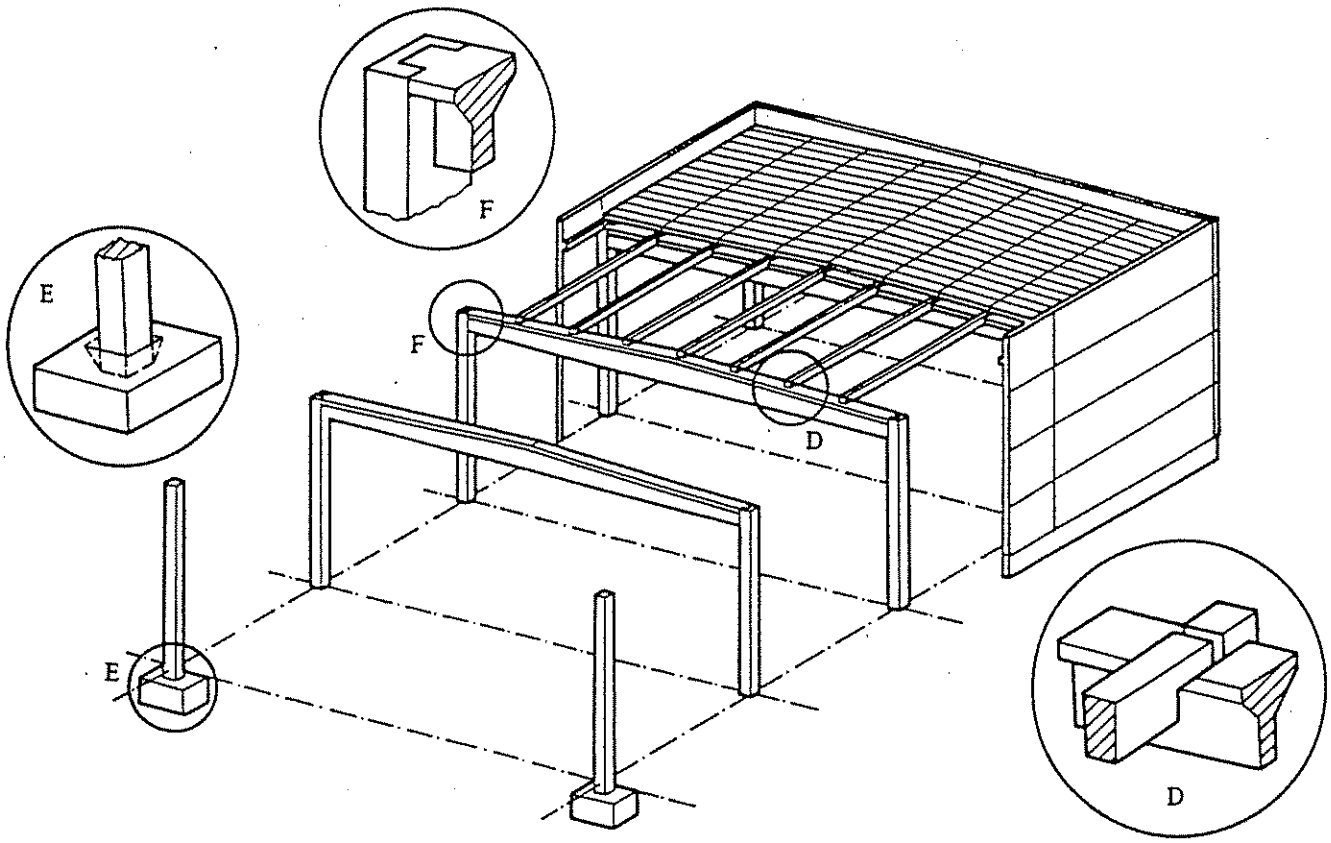


Fig. 7. IMS system.

Source: Low et al, 1991

Milz **System** (Germany)



Source: Warszawski, 1990

MSF Wideslab System (United Kingdom)

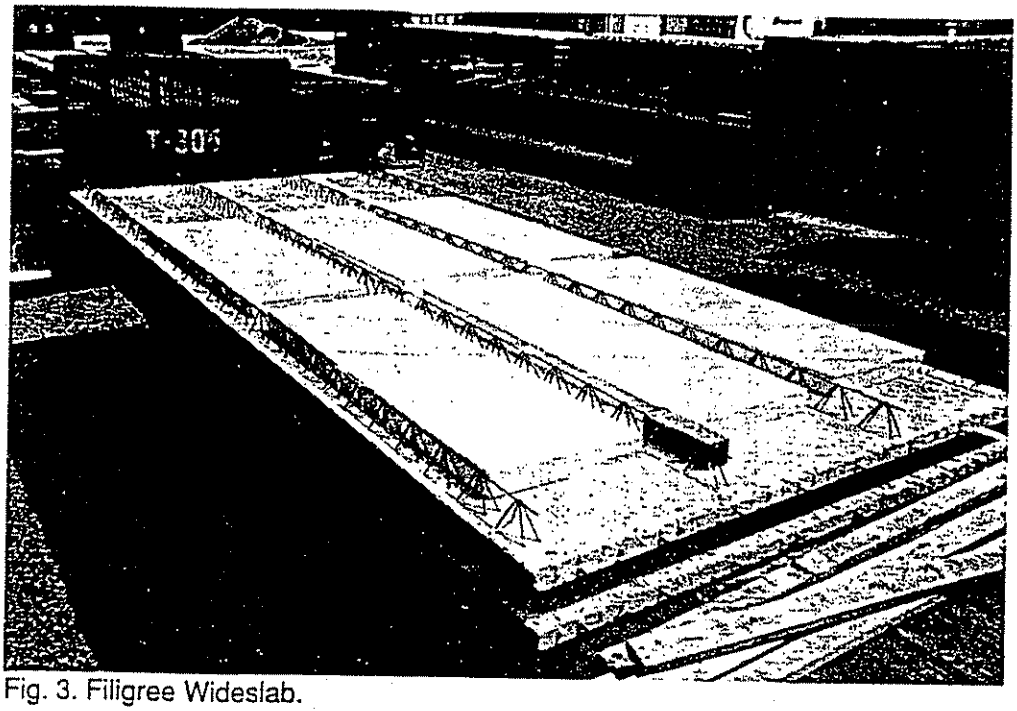


Fig. 3. Filigree Wideslab.

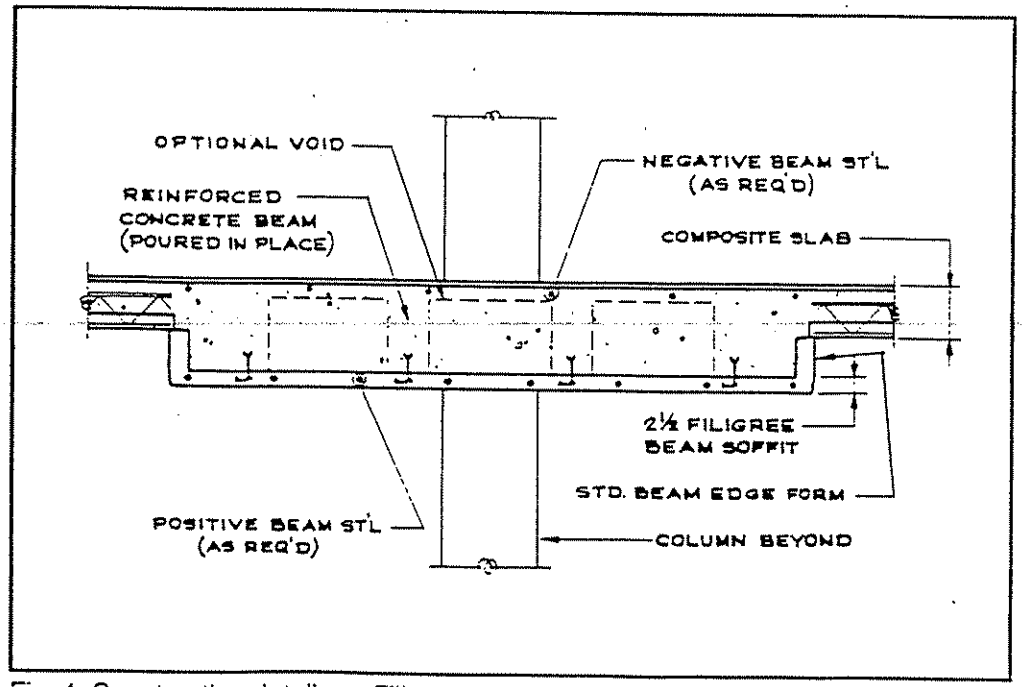


Fig. 4. Construction details — Filigree beam and slab.

Source: Low et al, 1991

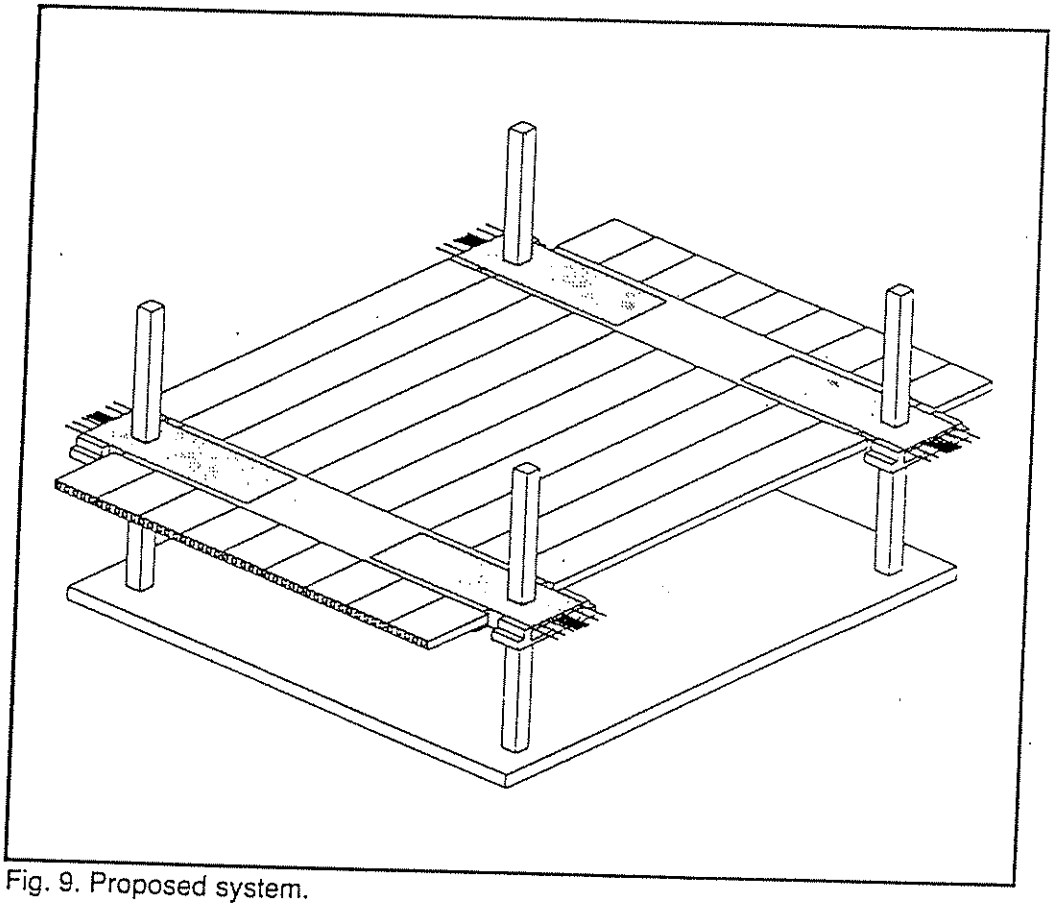


Fig. 9. Proposed system.

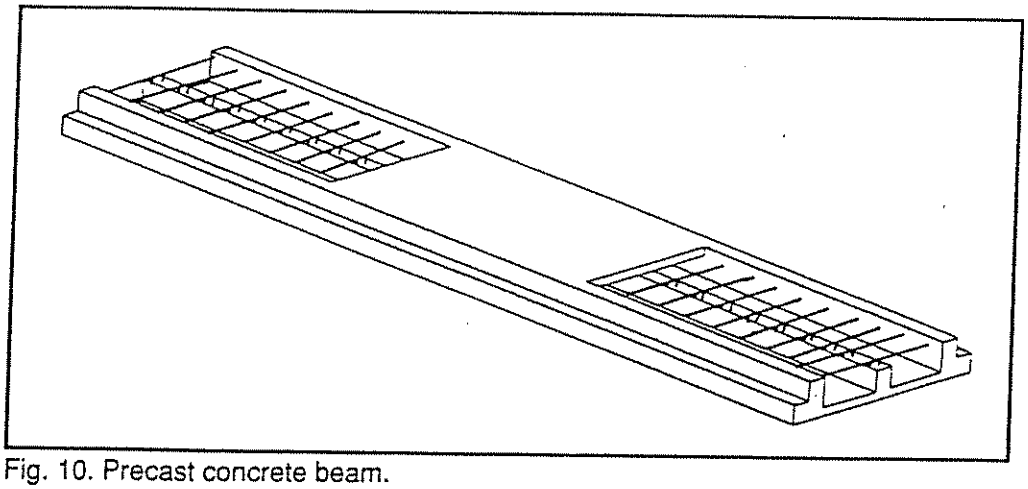


Fig. 10. Precast concrete beam.

Source: Low et al, 1991

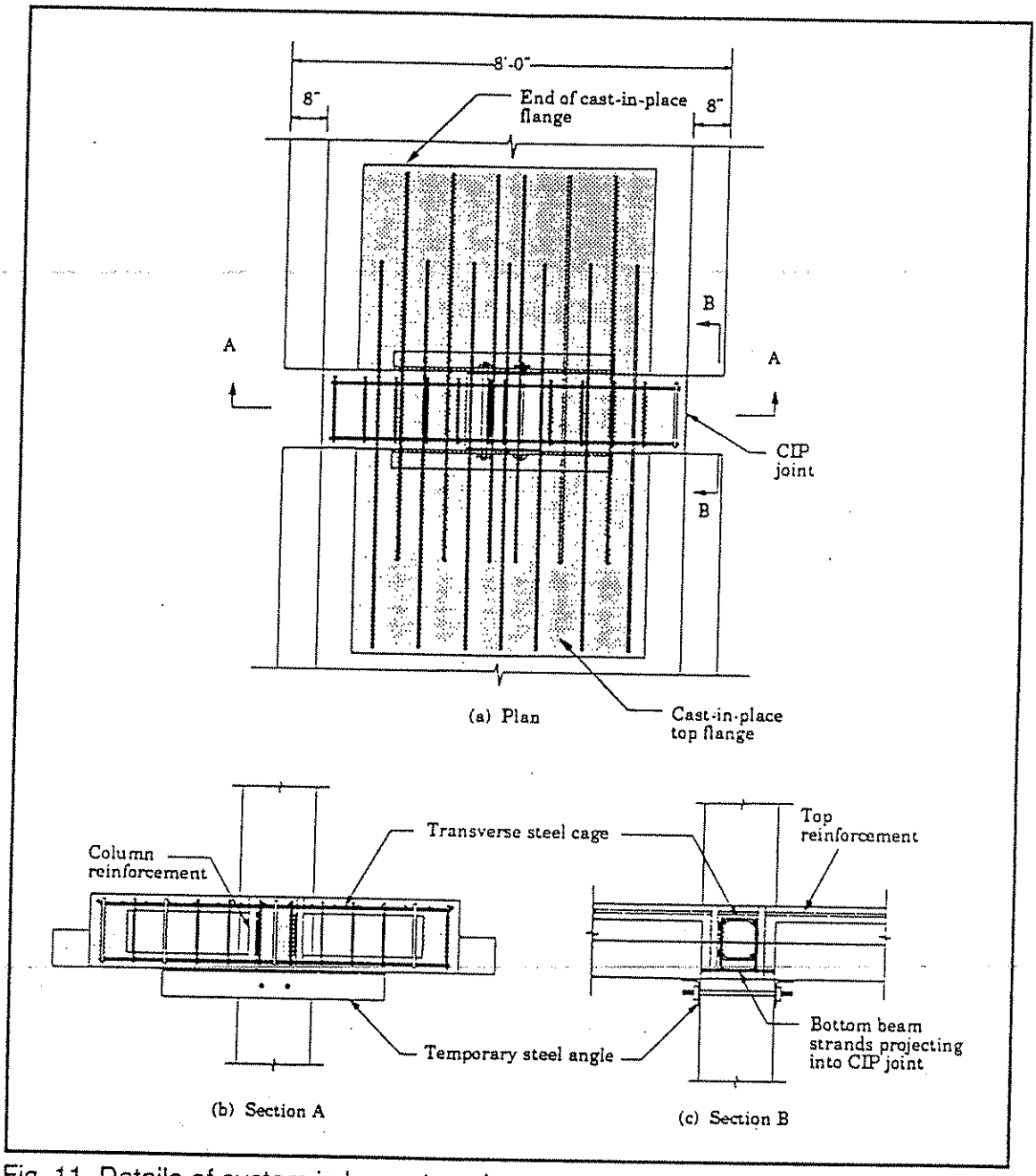


Fig. 11. Details of system in beam-to-column area.

Source: Low et al, 1991

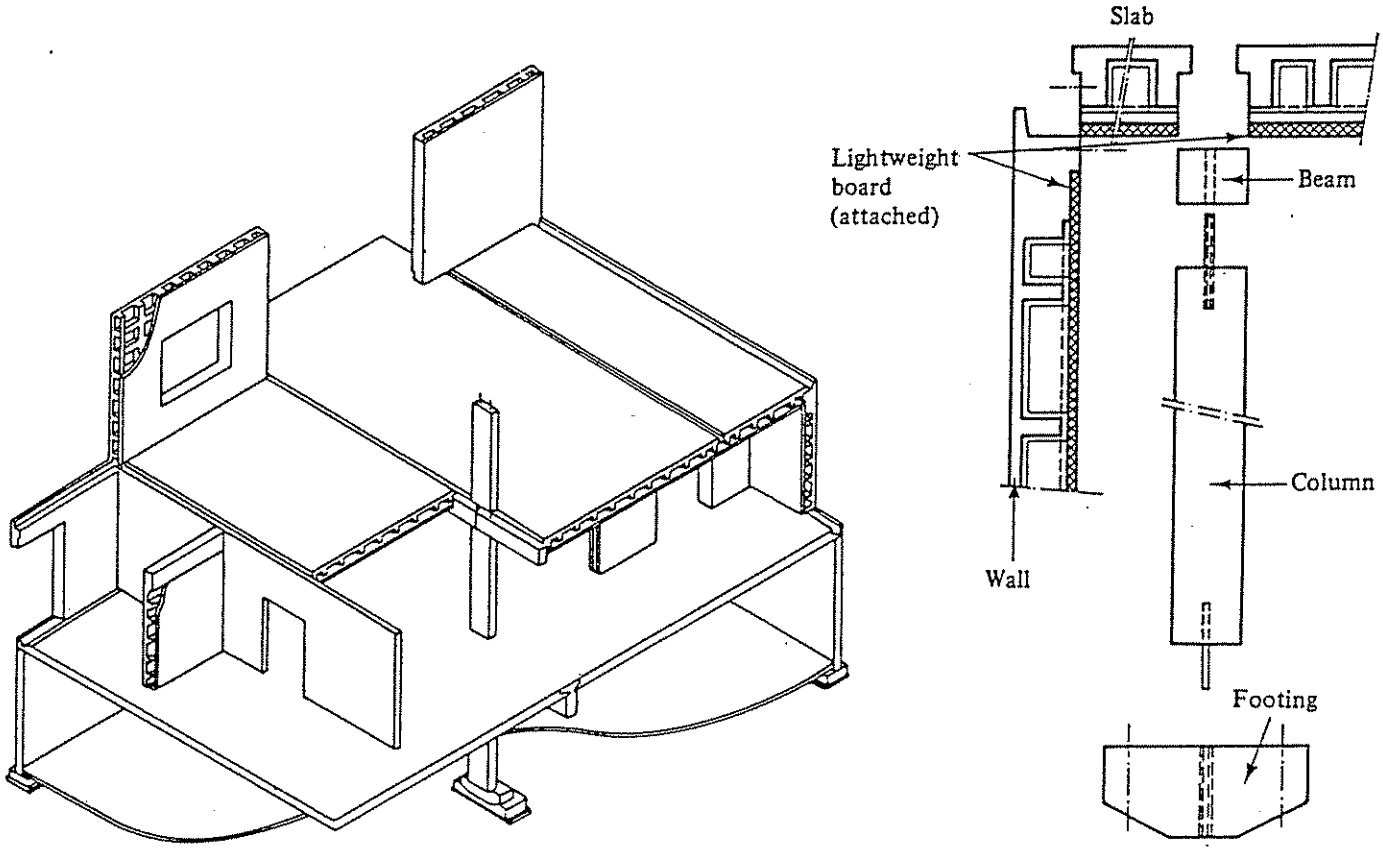


Figure 2.17 The Opera system (France): (a) general scheme and (b) schematic details of elements and connections.

Source: Warszawski, 1991

PSI System

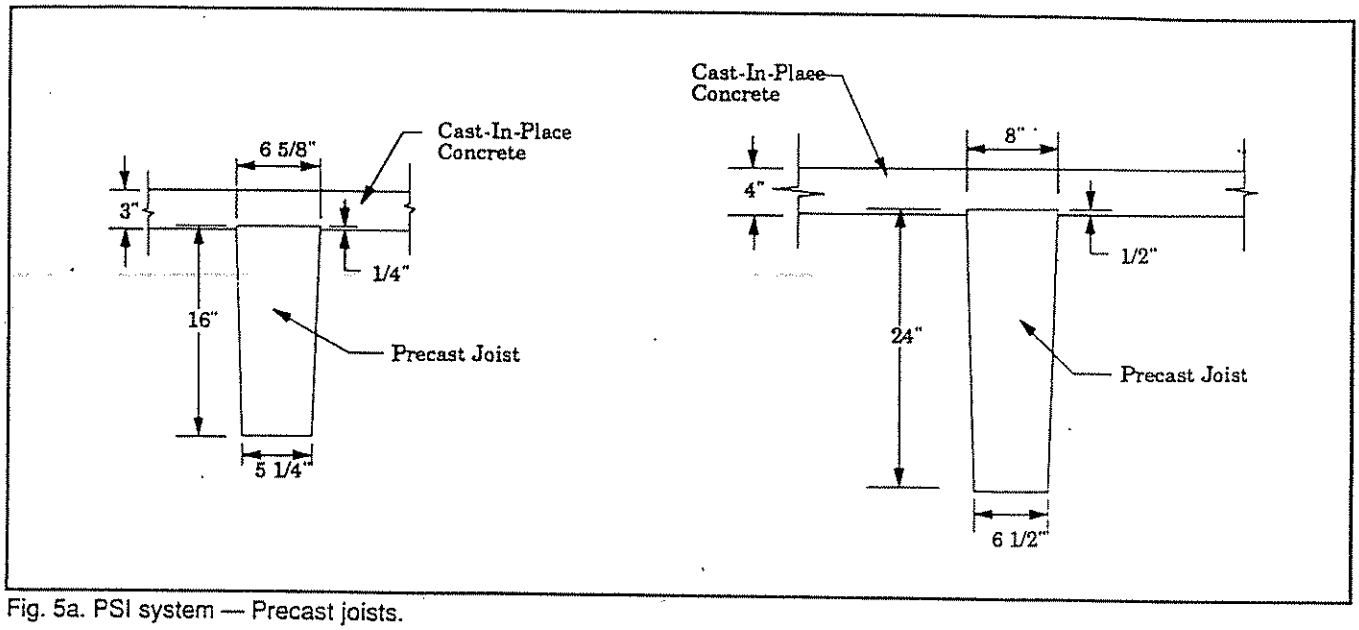


Fig. 5a. PSI system — Precast joists.

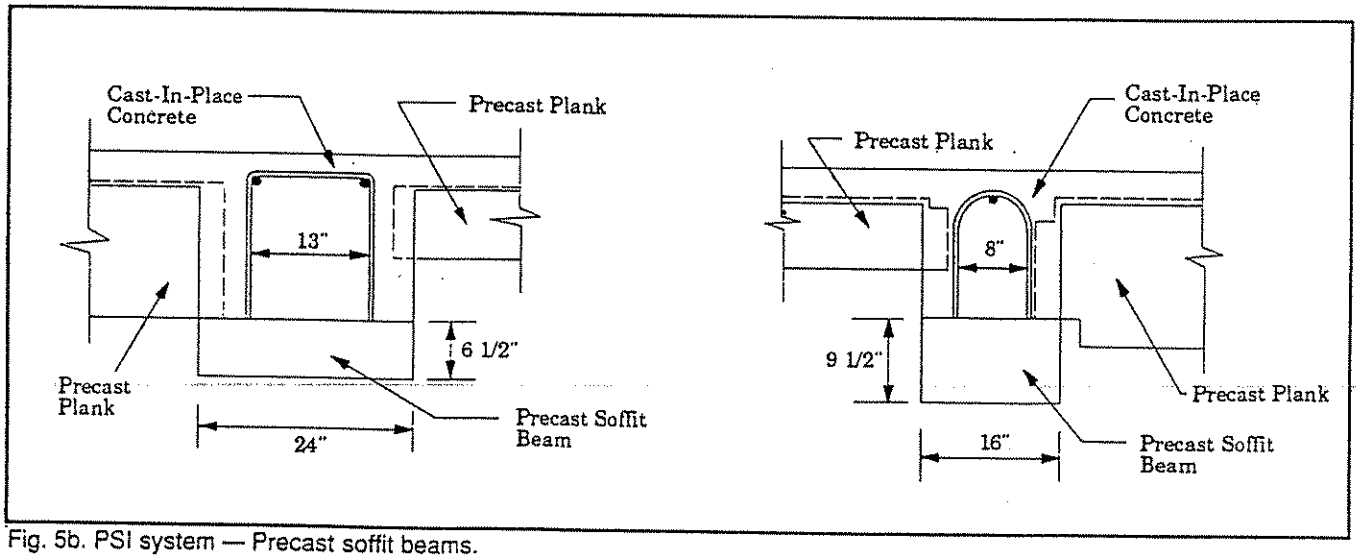


Fig. 5b. PSI system — Precast soffit beams.

Source: Low et al, 1991

Quickfloor System

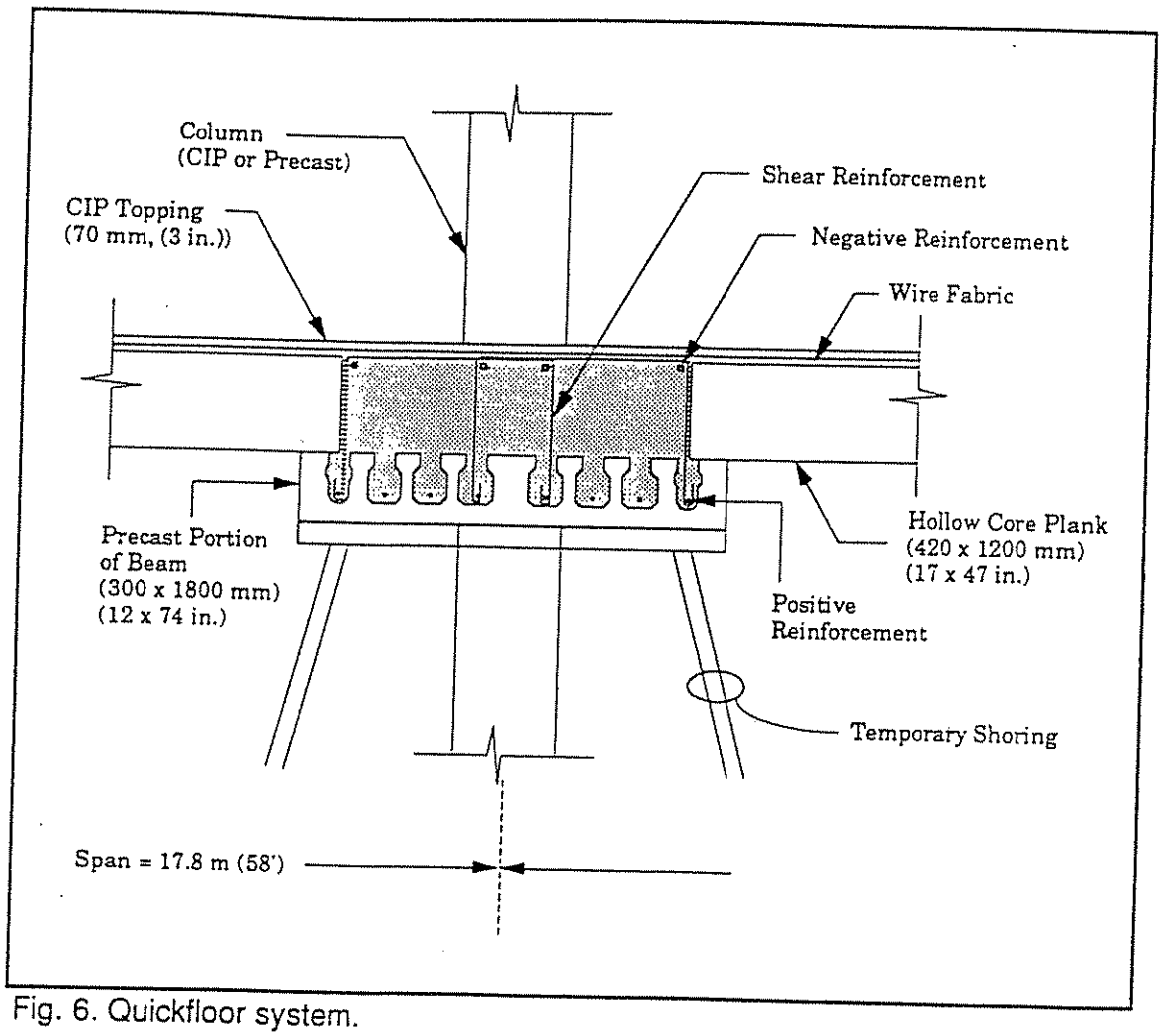
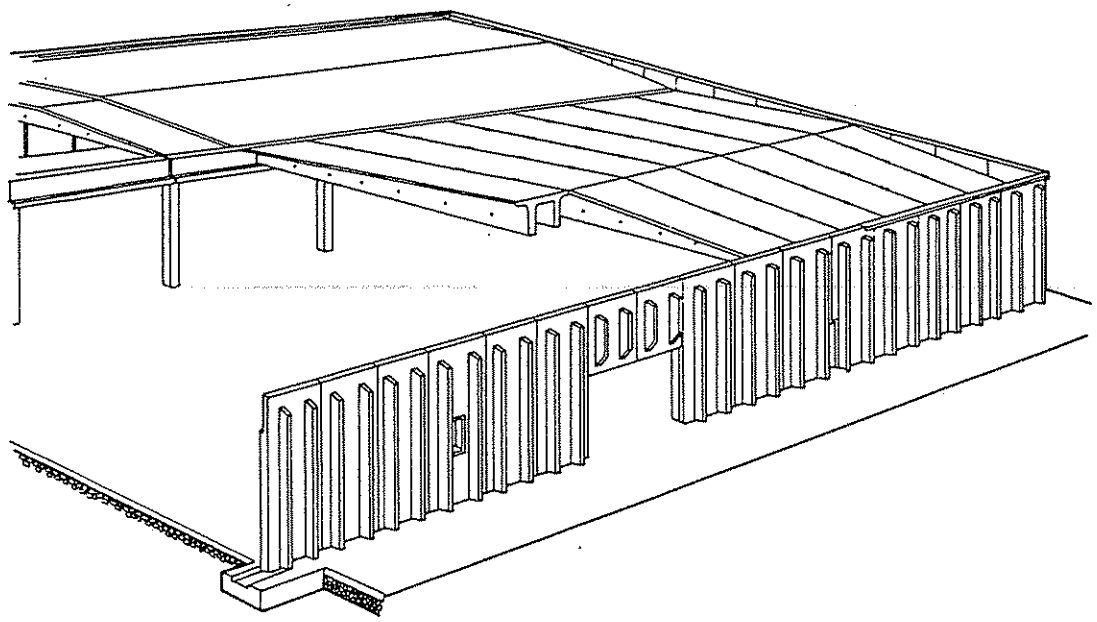


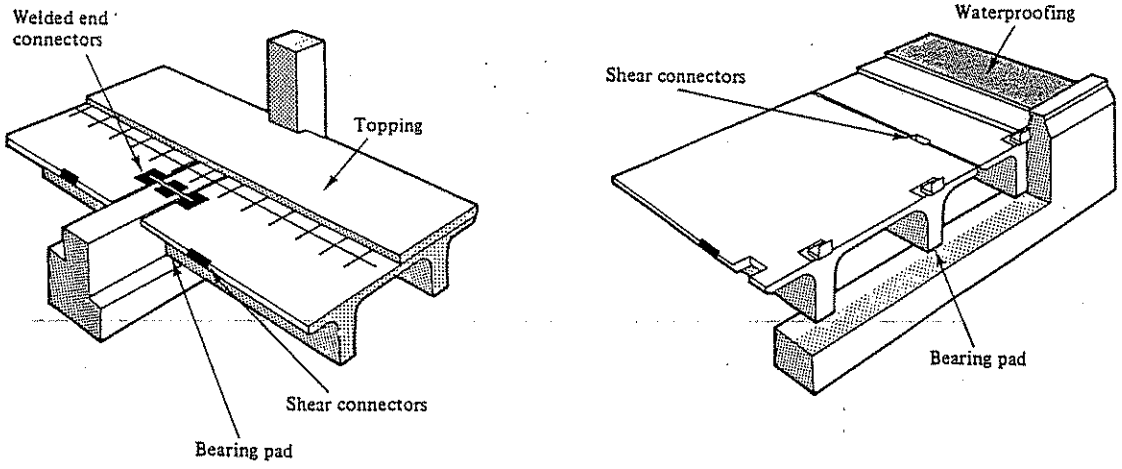
Fig. 6. Quickfloor system.

Source: Low et al, 1991

Spanclad System (United Kingdom)



(a)

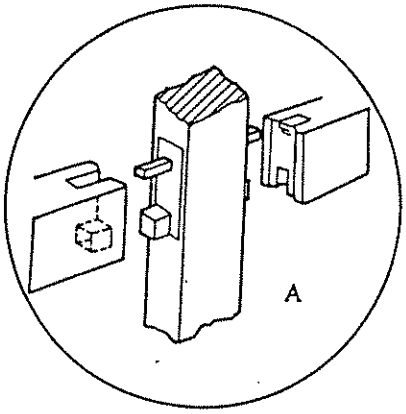


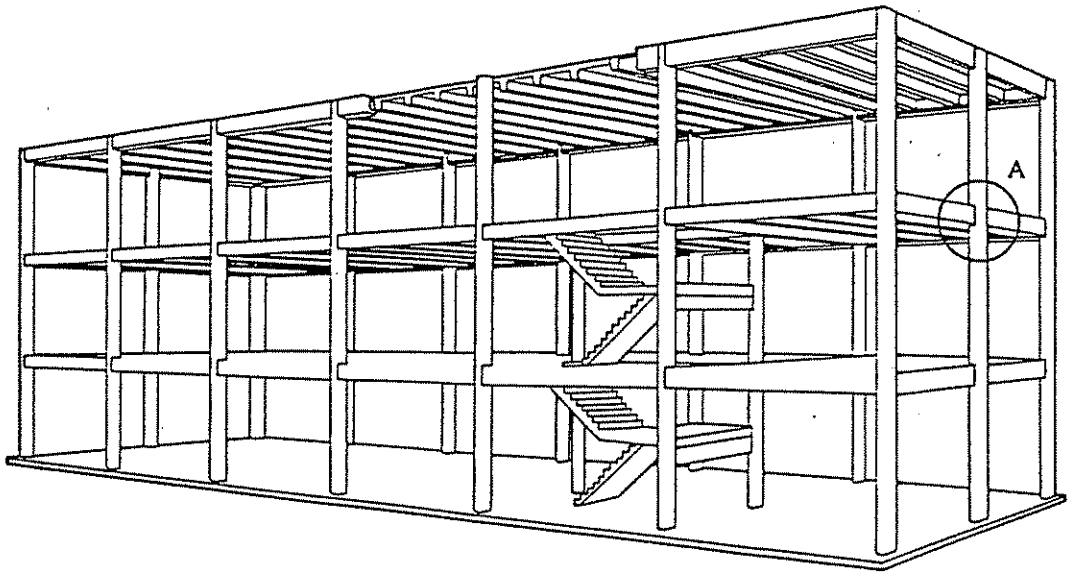
(b) (c)

Figure 2.20 The Spanclad system (United Kingdom): (a) general scheme, (b) support of slabs on a girder, and (c) support of slabs on exterior wall.

Source: Warszawski, 1990

Spanclad **System** (cont)





Source: Warszawski, 1990

Tracoba System (France)

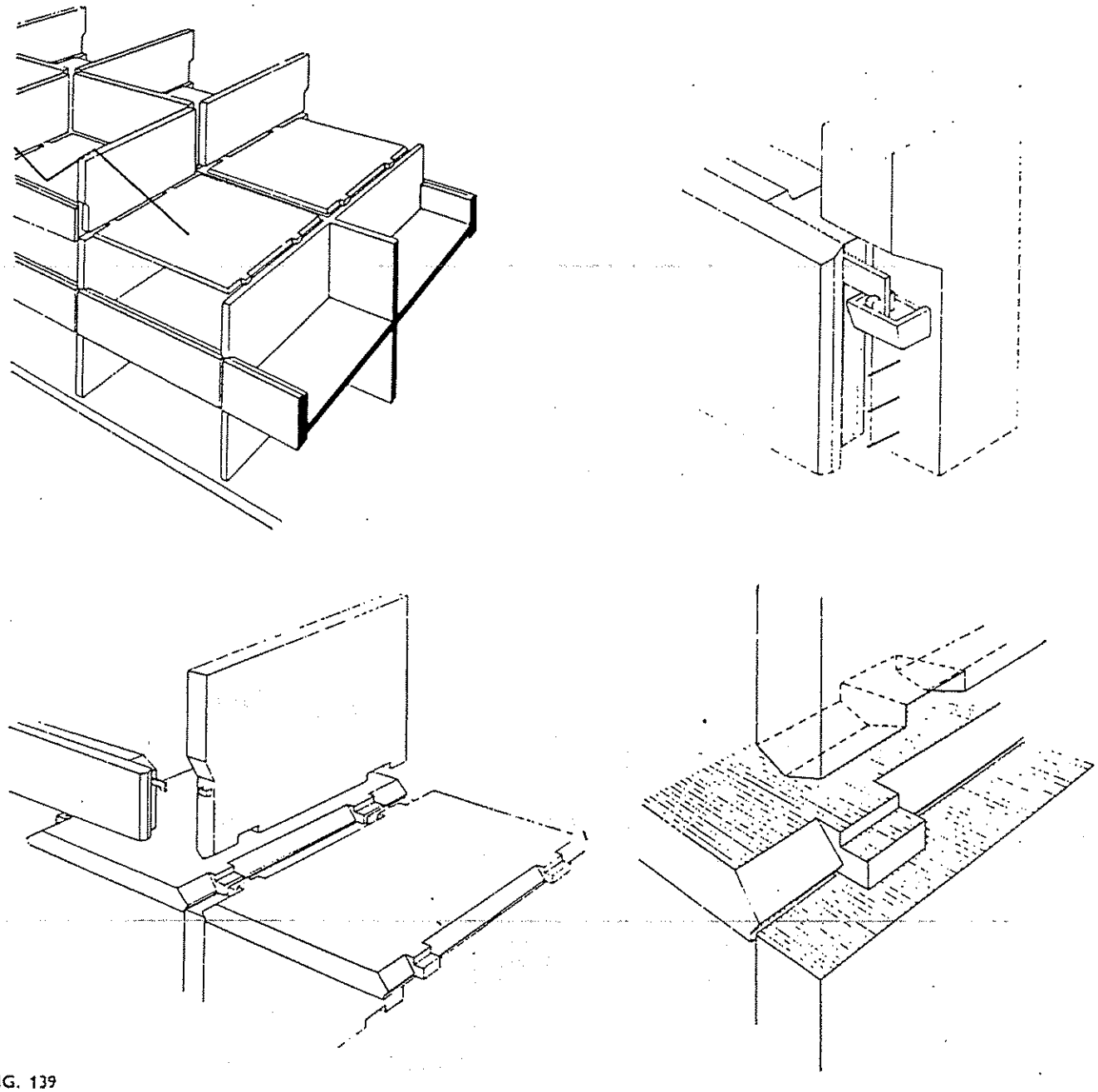
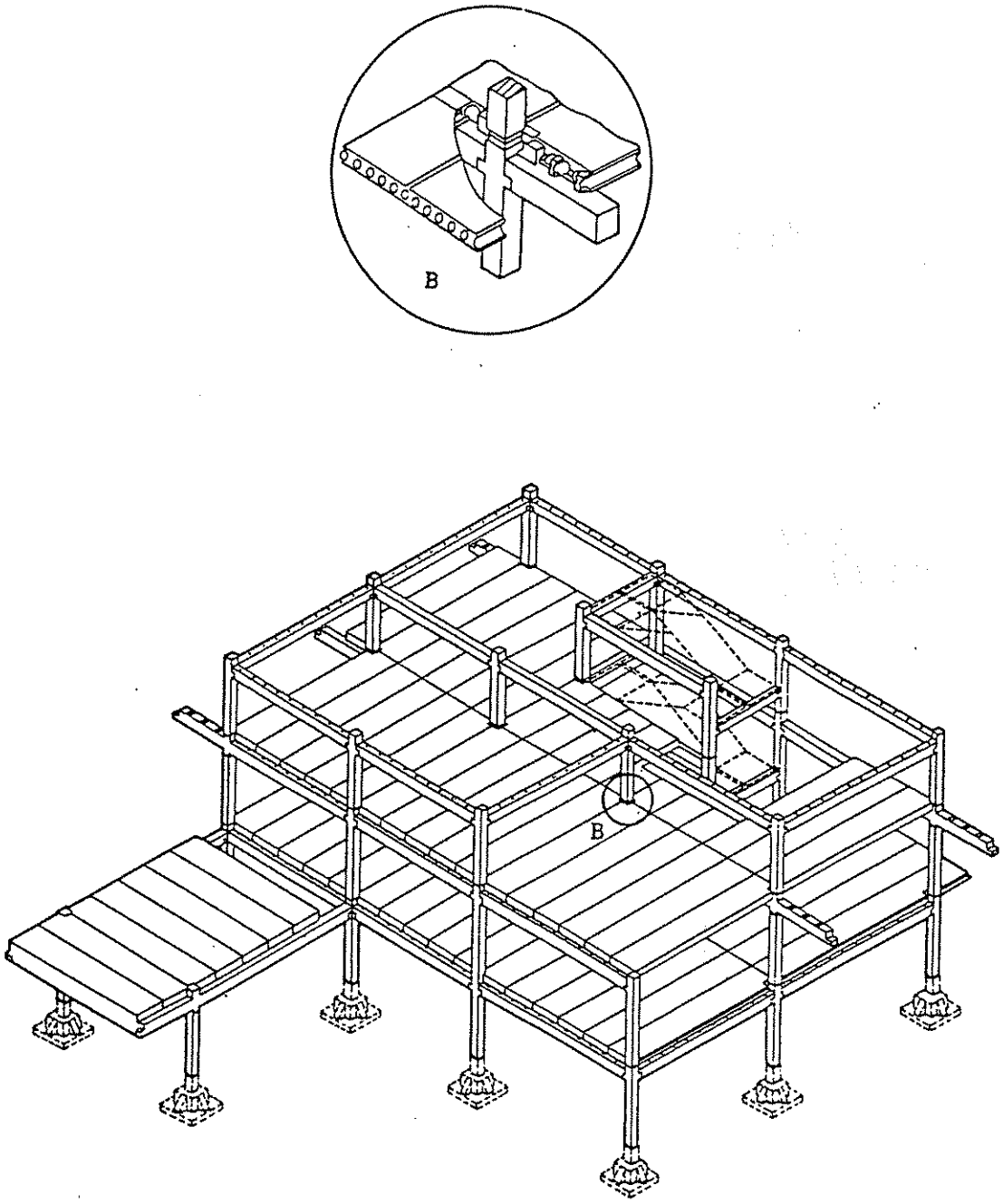


FIG. 139

Tracoba system (Meaux, France). Suspended external wall panels, joint between cross-wall panel and external wall panel

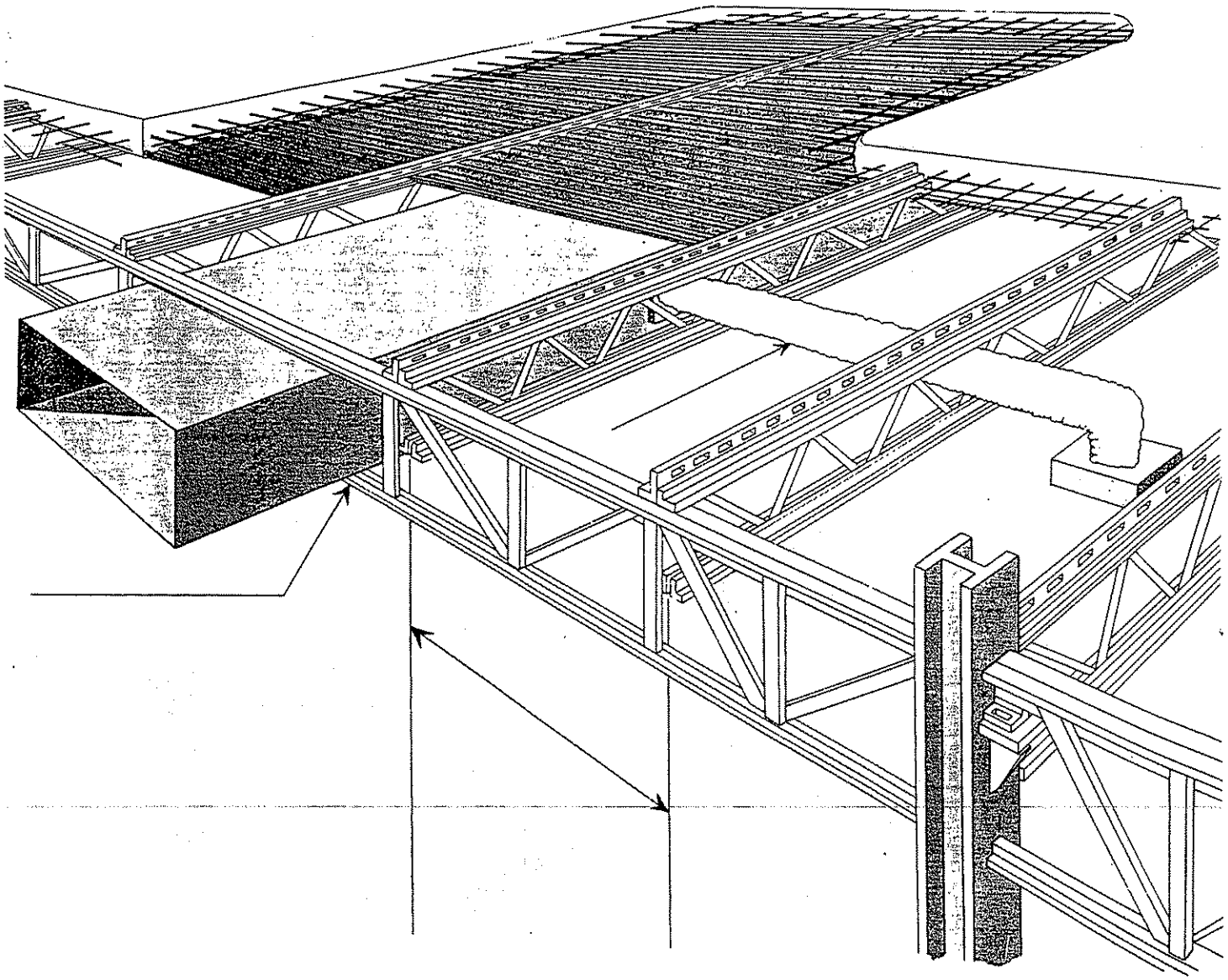
Source: Sebestyen, 1965

Univaz **System** (Hungary)



Source: Warszawski, 1990

Vescom System



Source: Vescom Structural Systems, Inc., 1992

Yuval Gad System

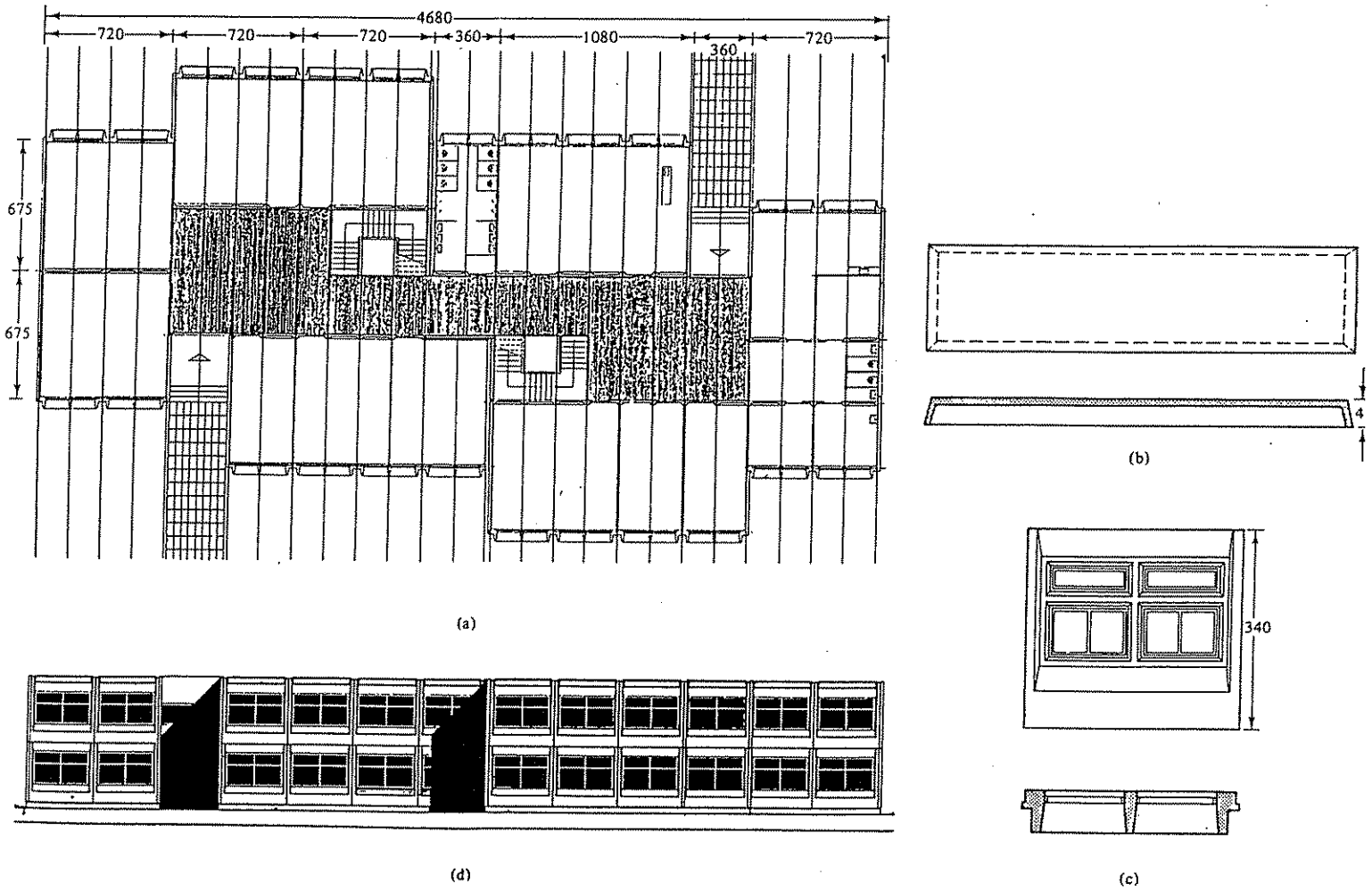


Figure 2.18 Yuval Gad school system (Israel): (a) general scheme, (b) casette floor element, (c) diamond-shaped exterior wall, and (d) picture.

Source: Warszawski, 1990

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