TYPICAL CONNECTION DETAILS

5.1 General

This chapter includes examples of connection details for structural as well as architectural precast, prestressed concrete products. The details included are neither exhaustive nor necessarily the best possible arrangements. The purpose in including these details is to present ideas and show some common schemes. The Connection Details Committee hopes that these ideas and schemes would lead to yet other ideas and schemes' to enhance the state-of-the-art of precast, prestressed concrete connection technology.

Selection of a connection detail for a particular situation requires consideration of strength requirements and load transfer paths. It should also include consideration of production, erection, serviceability and durability. Chapters 1, 2 and 3 of this Manual cover details related to these considerations. Common practice by precast, prestressed concrete manufacturers in a given area may also influence the final selection of details on a particular project.

Consistent with the purpose of this chapter, which is to present ideas and possibilities, detailed design information is not given on the sketches. Sizes of components such as, plates, bars, welds, and other details such as, joint spaces, bearing pad thicknesses have been purposely omitted.

5.2 Structural Precast Concrete Details

The following sections present several typical structural details. These particular details were selected by the PCI Committee on Connection Details from a large inventory on the basis of their more common use. A sufficient variety is included to illustrate the various concepts discussed in previous chapters.

The details are arranged in groups according to the products they are designed to connect. Within each category, the description of the details, including features and disadvantages, is given followed by sketches for the details. The details included cover the following categories:

- Column to Foundation. . . . . . CF
- Column to Column. CC
- Girder to Column . . . . GC
- Beam to Girder. . . . . BG
- Beam to Beam.. . . . . BB
- Slab to Beam.. . . . . SB
- Slab to Slab.. . . . . SS
- Slab to Wall.. . . . . SW
- Beam to Wall.. . . . . BW
- Wall to Wall . . . . WW
- Wall to Foundation . . . . WF
- Stairs to Landings. . . . . SL

[1] To facilitate recording of different ideas and details, a blank page is provided at the end of details shown within each category of connections.

5.2.1 Column to Foundation Connections (CF)

There are four basic types of column to foundation connections:

- Column Size Base Plates
- Oversize Base Plates
- Socket Base
- Grout-Sleeve Base

Typically, these connection details are concealed by placing them below the finished floor level. The selection of a particular connection detail for a given project usually depends upon whether the column is: (a) prestressed or non-prestressed; (b) cast individually or in a long-line form; and (c) pinned or restrained.

5.2.1.1 Column Size Base Plates (CF1, CF2 and CF3)

The column is cast with pockets and a base plate the same size or slightly smaller than the column. Pockets may be either in the corners (CF1), centered in the sides of the column (CF2), or on two sides (CF3). The column is erected over anchor bolts protruding from the foundation. The pockets and space between the column and foundation are filled with dry-pack or non-shrink grout. Temporary support and leveling are accomplished by tightening down on the nuts with the column resting on a center stack of shims or by a double nut arrangement as shown in the sketches.

Features:

1. Corner pockets allow easy wrench access.
2. Side pockets allow comer column bars to be welded to the base plate.
3. Holes in base plates are oversized to minimize tolerance problems.

4. Column size base plate does not require form penetration and permits use of thinner base plates.
5. Pocketed anchor bolts are concealed and protected from corrosion after grouting.
6. Bolting allows quick and easy erection in any weather.
7. Column can be prestressed with tendons passing through holes in the base plate.

Disadvantages:
1. Difficult to achieve moment resistance.
2. Corner pockets prevent attachment of column comer reinforcing bars to base plate.
3. Individual side pockets (CF2) restrict wrench movement and provide less effective placement of anchor bolts for moment resistance.
4. Projecting bolts are susceptible to damage.

5.2.1.2 Oversized Base Plates (CF4, CF5, CF6 and CF7)

The common characteristic of these column bases is the oversized plate which has at least one dimension larger than the corresponding column's dimension. The base plate may be cast with the column as one unit or the oversized plate may be attached by welding later. Typically, four anchor bolts are used to connect the column to the foundation and may be located in the corners or at the centers of the sides of the column. Column reinforcement is sometimes welded to the base plate, but it is more common to lap deformed bar anchors with the main column reinforcement.

Features:
1. Wrench movements are not restricted.
2. Column corner reinforcing bars can be welded to the base plate for anchorage.
3. The larger base plate increases effective bearing area and, with stiffeners on base plate, large moment resistance can be achieved.
4. Oversized holes in base plates help minimize tolerance problems.
5. Bolting allows quick easy erection in any weather.

Disadvantages:
1. Oversized base plates are usually thicker than column size base plates and thus are more expensive.
2. Connection may not be concealed or protected from corrosion.
3. When cast with concrete as one unit, the plate has to penetrate column form or project beyond end of form. Thus, the connection is rarely used when columns are prestressed or cast in long-line forms.
4. Stiffeners may have to be installed after casting.
5. Projecting bolts are susceptible to damage.

5.2.1.3 Socket Base (CF8)

The socket base connection involves setting a column into a relatively rigid base and filling spaces between the column and the base socket with structural grout. The socket may be formed above the foundation or into the foundation. Shims and wedges are typically used for temporary support and alignment. The connection is much stiffer than the steel base plate type connections and can be designed to provide substantial moment resistance at the column base.

Features:
1. Quick, easy erection in any weather, however follow-up grouting is weather sensitive.
2. Moment resistance at column base.
3. The socket connection results in simplified column casting with minimum tolerance problems.

Disadvantages:
1. The socket connection requires expensive foundation work.
2. It is difficult to ensure good grouting in the socket under the column.
3. It is difficult to achieve tension reinforcement continuity between the column and the foundation.

5.2.1.4 Grout-Sleeve Base (CF9, CF10, CF11 and CF12)

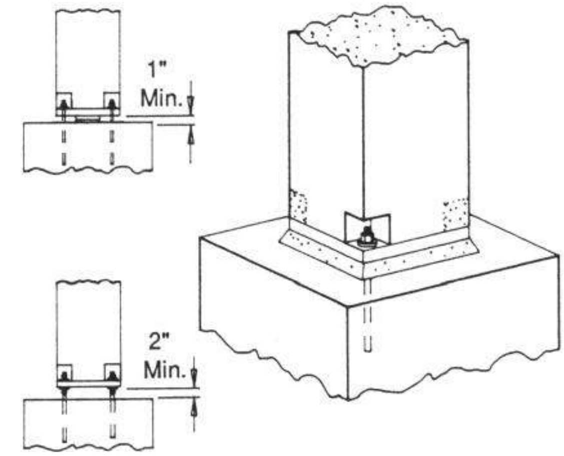
Grout-sleeve connections require special care during layout due to close tolerance requirements. Grout-sleeves can be cast into the column or the foundation. The sleeves fit over reinforcement projecting from the mating part. Sleeves are grouted and reinforcing bars are developed by bond strength. The gap under the column is filled with dry-pack or non-shrink grout.

Features:
1. Moment resistance at column base can be readily achieved.
2. Connection is concealed after grouting.
3. Can be used for architectural columns where base is exposed.

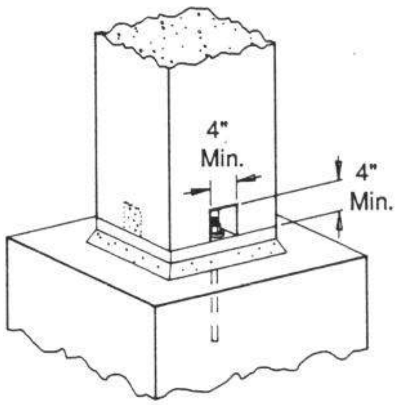
4. Difficulties due to close tolerance requirements are minimized by using larger sleeves.

Disadvantages:

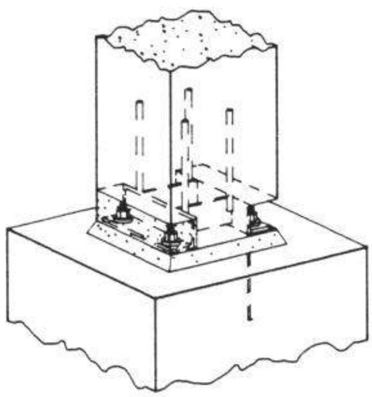
1. Sleeve length for larger bars can be quite long and special commercial high strength couplers (typically proprietary) might be necessary.
2. Requires temporary bracing during grout curing.
3. Protruding reinforcement, either in the column or the foundation, is susceptible to damage before column is placed or during erection.
4. Weather can affect grouting process.
5. Precautions must be taken to keep sleeves free of water and debris.



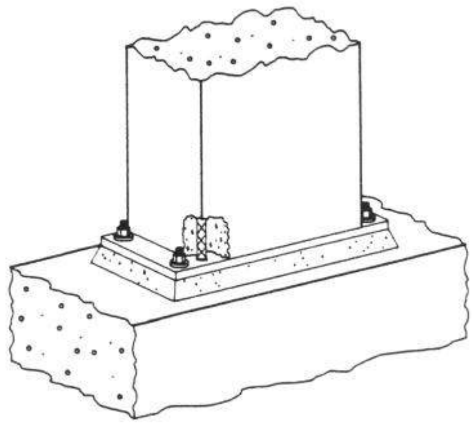
CF1



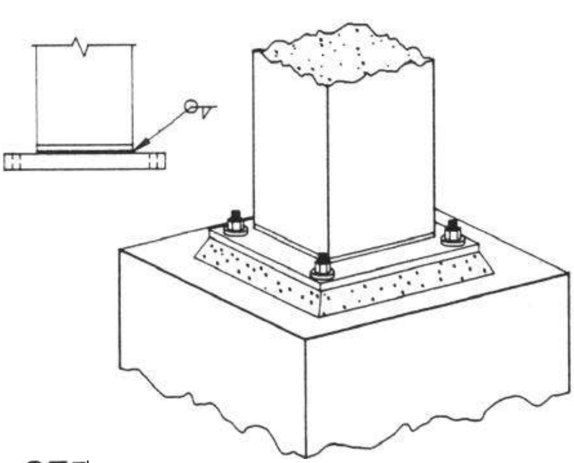
CF2



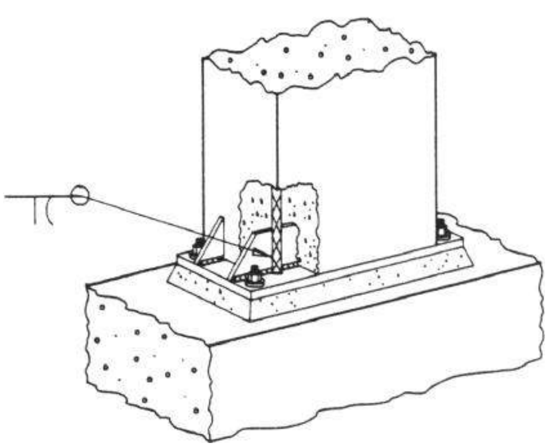
CF3



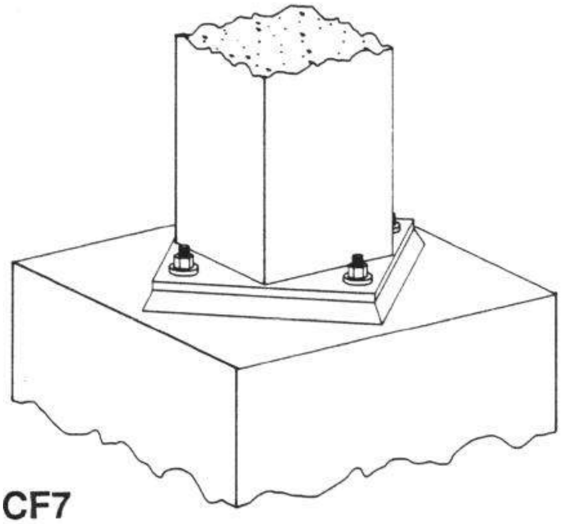
CF4



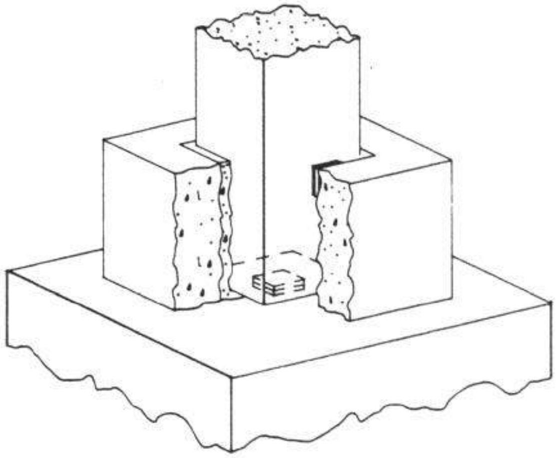
CF5



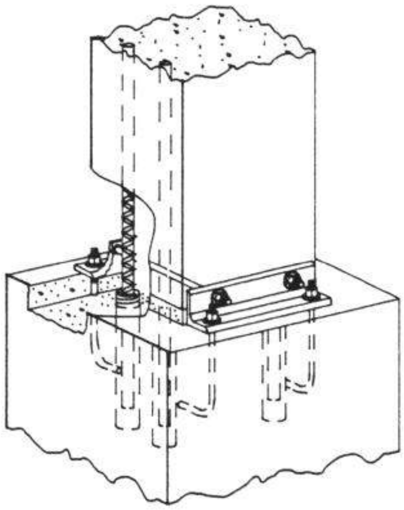
CF6



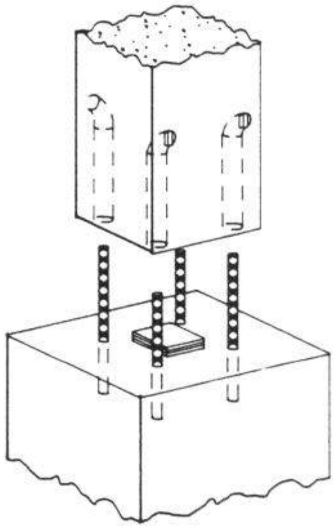
CF7



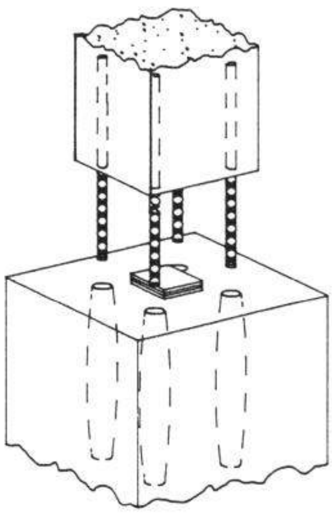
CF8



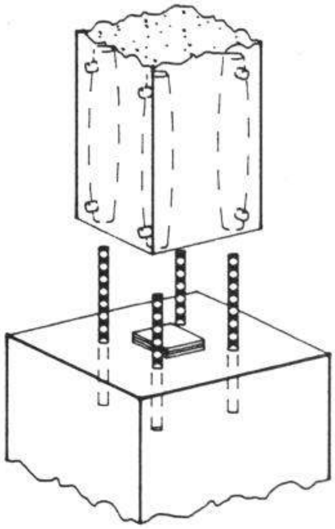
CF9



CF10



CF11



CF12

5.2.2 Column to Column Connections (CC)

Selection of the appropriate connection is based upon: (a) column reinforcement (prestressed or conventionally reinforced); (b) the degree of moment transfer required; (c) final exposure of connection; and (d) required erection sequence. The most common column to column connections are:

- Bolted
- Welded Plates
- Tube to Tube
- Grouted Sleeves
- Welded Lap Bars
- Tube Sleeves
- Post-Tensioned Splice

5.2.2.1 Bolted Connections (CC1, CC2 and CC3)

The column is cast in one of three ways: (a) flush, or slightly undersized base plate with four corner pockets; (b) flush, or slightly undersized base plate with four side pockets; (c) dapped sides with angles; the angles are anchored by welded bars.

The column is then set over anchorbolts protruding from the column below. The space between the columns is filled with dry-pack or non-shrink grout. Temporary support and leveling are accomplished by tightening the nuts with the column resting on a center stack of shims, or by use of double (leveling) nuts.

Features:

1. Oversized holes for bolts reduce tolerance problems.
2. Connection is concealed and protected from corrosion after the pockets are grouted.
3. Bolting allows quick, easy erection in any weather.

Disadvantages:

1. Due to limited moment capacity, the connection is suitable for locations near inflection points.
2. For the connection with angles (CC3), more grouting is required. Also, the axial tensile strength is limited by the thickness of the angle.
3. Projecting bolts are susceptible to damage.

5.2.2.2 Welded Plate Connections (CC4 and CC5)

Welded plate connections are commonly used when moment transfer is required. The columns are match cast with top and bottom plates which are welded during erection.

Features:

1. Moment resistance can be provided.
2. Field fitting problems are minimized if correctly match cast.
3. Immediate full bearing results, so erection can proceed to upper levels without delays for grouting.
4. The connection is protected from corrosion after concealment.

Disadvantages:

1. Match casting requires special care in the plant.
2. A significant amount of welding is required.
3. Crane must support column until welding is done.

5.2.2.3 Tube to Tube Connections (CC6)

Tube to tube connections minimize field adjustments and are suitable where limited moment transfer is required. The tubes, which may be round or square, are in a male-female arrangement with the smaller tube extending either from the bottom or the top column. The columns are match cast and the tubes may be grouted when erected.

Features:

1. Field fitting problems are minimized if correctly match cast.
2. The connection is concealed and protected from corrosion.

Disadvantages:

1. Tubes must be very accurately placed in the plant.
2. Correction of errors can be difficult.
3. Entire column must be stripped as a unit.

5.2.2.4 Grouted Sleeve Connections (CC7, CC8 and CC9)

Sleeves are placed in either upper or lower column to accept projecting reinforcement from the mating column. After alignment, the sleeves are grouted. The space between the column sections is filled with a non-shrink grout. Temporary support and leveling must be provided by guying or other means until the grout in the sleeves is cured.

Features:

1. Moment transfer can be achieved through the connection.
2. Concealed connection when grouted.
3. Tolerance parameters can be adjusted by changing sleeve size.

Disadvantages:

1. Sleeve length for large bars can be quite long.
2. Requires temporary bracing during grout curing.
3. Good weather or auxiliary heating is required for grouting.
4. Main reinforcement may require bending to accommodate sleeves.
5. Protruding bars are susceptible to damage during handling.
6. Sleeves must be kept free of water and debris.

Several proprietary devices for splicing bars are available in the market and have received increasing acceptance. Many of these devices include special features to aid in placement and erection (see CC9). Leveling is accomplished by shims or by use of a bolt in threaded insert.

With some systems the grout is pumped into the lower part of the sleeve until it comes out the top part. In others, the bars project from the upper column section and the grout is then placed in the sleeves and the shim space, prior to placing the top column.

Features:

1. Moment transfer capability is achieved.
2. Special installation devices reduce tolerance problems, and no post-erection grouting is required.

Disadvantages:

1. Additional means of bracing must be provided until grout in sleeves has set.
2. Proprietary devices may add to the cost.

5.2.2.5 Welded Lap Bar Connection (CC10)

This connection is only used when full moment transfer is desired in large, heavily reinforced columns. Both column sections are cast with reinforcement protruding from the ends. The reinforcement is welded together during erection. Temporary support and leveling are accomplished by resting the column on a center stack of shims and welding only selected bars. After proper alignment is achieved, the remaining bars are welded and the connection is grouted.

Features:

1. Moment resistance is developed at the connection with relatively short lap lengths.
2. The connection is concealed and protected from corrosion after grouting.

Disadvantages:

1. Reinforcement must be placed accurately to accomplish welding.
2. Reinforcement must be of a weldable grade steel.

5.2.2.6 Tube Sleeve for Composite Beam (CC1 1)

This connection may be used when fully continuous, composite ductile frames are required. It allows the placement of column ties for confinement. Beam reinforcement is placed through the joint and the assembly is completed with cast-in-place concrete.

If required, temporary support is provided by a sleeve-in-sleeve connection. A pipe or tube (structural) protruding from the upper section fits into a slightly larger pipe or tube in the lower section. A small weld holds the assembly in place. No weld is required if the fit is snug.

Features:

1. Moment transfer capability is achieved for both beam and column.
2. The connection has good ductility.
3. The connection is concealed.
4. With proper design, the next level can be erected before concrete is placed.

Disadvantages:

1. Sleeves must be accurately placed.
2. The connection is congested, so care is necessary to avoid honeycombing in cast-in-place concrete.
3. Requires much field labor.

5.2.2.7 Post-Tensioned Splice Connection (CC1 2)

This system uses post-tensioning bars for the column reinforcement and for splicing column sections. Post-tensioning ducts are cast in the columns at the plant. The tendons (usually bars) are attached to an anchor (at the bottom floor) or a coupler (at intermediate floors). The upper column is then threaded over the next lift of bars. The bars are tensioned and anchored, leaving enough projection to attach a coupler to receive the bars for another lift.

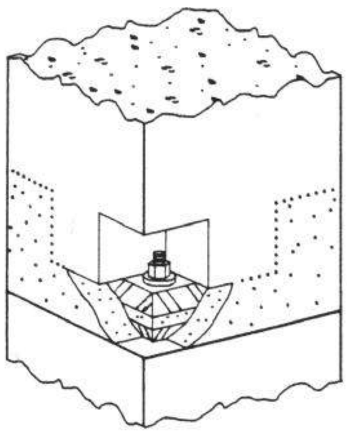
Features:

1. Provides a ductile, moment resisting connection.
2. Post-tensioning reduces drift in high-rise buildings.

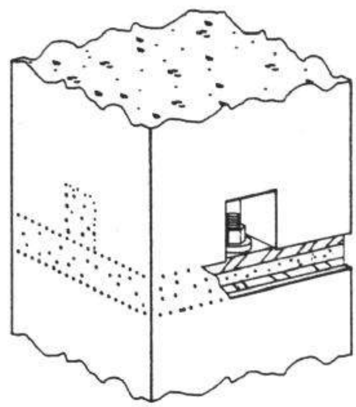
3. Good corrosion protection with dry-packed or grouted pockets.

Disadvantages:

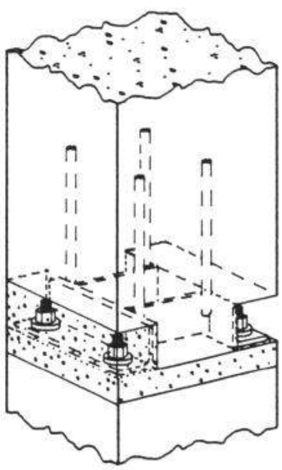
1. Erection procedure is more complex and requires special inspection.
2. Alignment of post-tensioning ducts is critical.
3. Requires supplemental reinforcement or pre-tensioning for handling.
4. Post-tensioning is an added operation.
5. Vertical post-tensioning ducts may be required to be grouted.



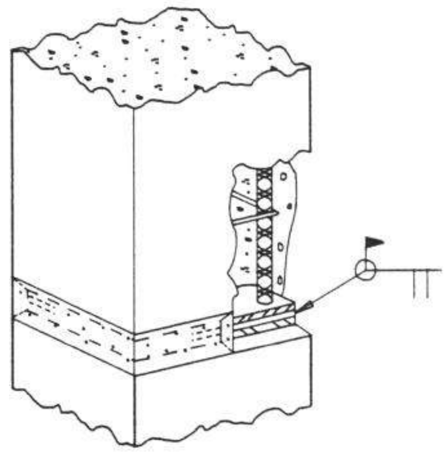
CC1



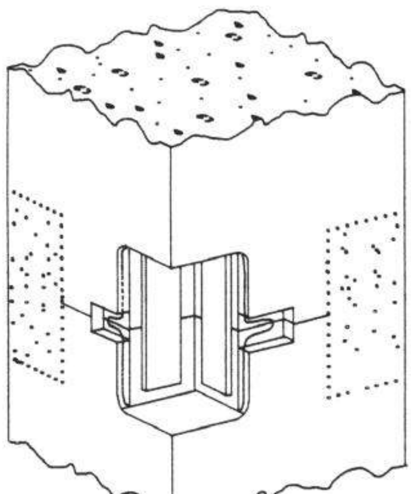
CC2



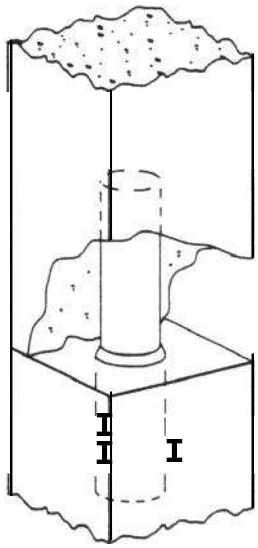
CC3



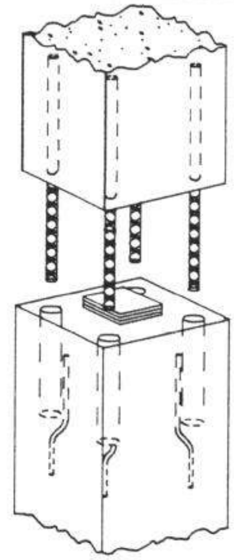
CC4



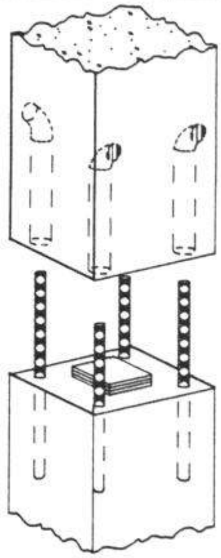
CC5



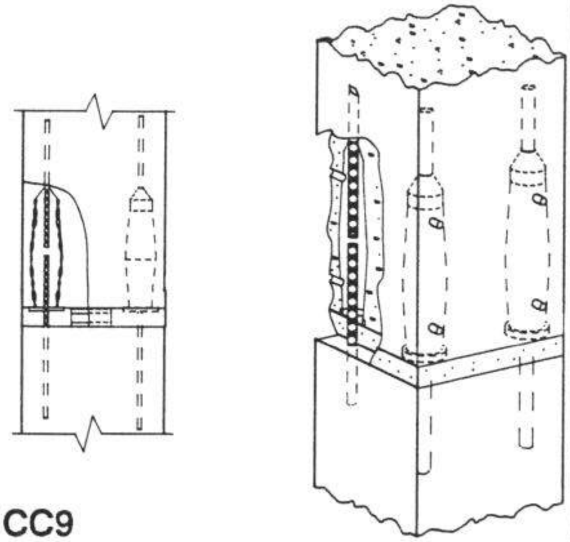
CC6



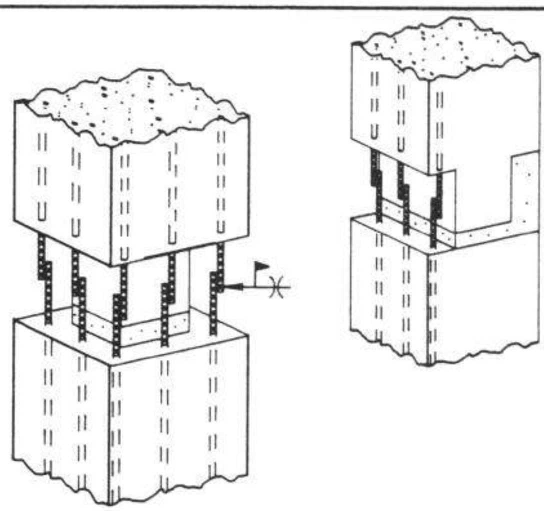
CC7



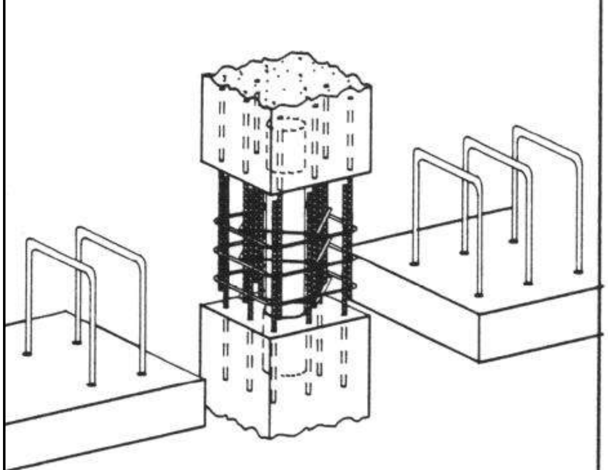
CC8



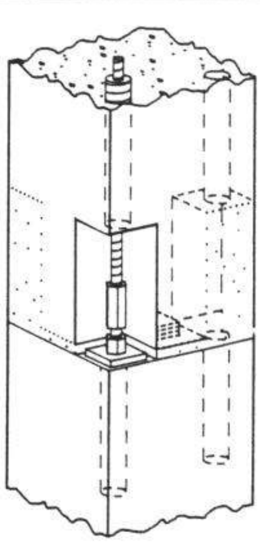
CC9



CC10



CC11



CC12

5.2.3 Girder to Column Connections (GC)

Since girder-column framing in precast concrete structures is very common, there are many and varied types of connections for joining these elements. The type of connection that is appropriate for a particular application depends primarily upon load and geometry conditions. Some other considerations are:

- Girder bearing condition: At roofs, girders may bear directly on column tops, or the column may extend to the top of the girder. In the latter case, and also at floors, the girders usually bear on corbels protruding from column faces.
- Floor and ceiling heights: Building height consideration may necessitate dapping of girder ends, use of knife or other hidden corbels, or use of hanger connections.
- Lateral force resistance: If the frame is to resist lateral loads, the connections must be capable of the required moment transfer. On the other hand, if a shear wall is incorporated in the structure as the primary lateral load resisting element, flexible connections may be used between girders and columns.
- Load type and magnitude: Corbel sizes and girder bearing plates depend on vertical and horizontal (e.g. volume change) forces. Eccentric loading may necessitate torsion restraint in the connection. Special situations, such as a cantilever girder, may require the girder to pass through the column thereby requiring special connections.

In addition to the above considerations, local plant preferences may dictate welding, bolting, doweling, grouting, or field concreting and post-tensioning.

5.2.3.1 Simple Welded, Bolted or Doweled Connections (GC1 - GC16)

The girder usually sits on a bearing pad which provides uniform bearing and permits small movements for accommodating the effects of shrinkage, creep and temperature changes. The top connection transfers horizontal forces between the girder and column, provides erection stability, and braces the column, but may not provide rotational restraint. Welding of girder bottom to the column requires utmost care. If the girder bottom is welded at both ends to the support, the forces resulting from restraint to volume changes can be quite large. Welding of girder bottom at one end only can also cause problems particularly where curvature caused by the thermal gradients is restrained. When welding is used, the top connection should allow some rotation to minimize negative moments at the girder ends. Thus, when the angle connection is used, only the toes are welded. A flat bar can be used if the joined plates in the column or girder are designed to flex, or the bar itself is sufficiently flexible. In order to prevent restraint when using the dowel-sleeve system, the bottom of the sleeve should be filled with compressible material such as sand, vermiculite, or asphalt. The remainder is then filled with grout. It should be noted that vermiculite could intermingle with very wet grout.

In the dowel-sleeve method, a sleeve in the end of the girderfits over a dowel which is threaded into either an insert in the support or a ferrule welded to the underside of the bearing plate. To prevent damage in handling, the dowel is inserted just prior to erection. The sleeve should be 3 or 4 times the size of the dowel to minimize field tolerance problems.

The schematics show several variations of connections which use structural steel members projecting from the column to support the girders. In general, steel corbels are smaller in size than concrete brackets which can be an important consideration when head room is critical. Fireproofing may be necessarywhen projecting steel shapes are used. Several methods of dapping and pocketing are shown to reduce depth of structure.

Features:

1. These connections allow quick, easy erection with few tolerance problems.
2. Volume change restraint is minimized.
3. Steelcorbelsprovide reducedstructuraldepth compared with concrete corbels.
4. Clean looking, concealed connections are possible.

Disadvantages:

1. Limited moment capacity and limited torsional restraint.
2. Dowel-sleeve connections provide no lateral restraint until sleeves are grouted. They can be weather sensitive and the sleeve can fill with water or debris during erection.
3. Many of the steel embedments in columns require form penetrations causing production problems in the plant. Alignment of hard-

ware during casting is critical.
4. Exposed steel may require encasement for fire and corrosion protection.
5. Some hidden connections require dapped girder designs. Pocketing can necessitate field grouting.

5.2.3.2 Hanger Connections (GC17 and GC18)

Two variations of hanger connections are shown in the schematics. Hanger connections are stable upon erection, although without a bottom stop, may "roll" when loaded eccentrically. Hanger connections are acceptable for special situations where head room is limited. They are not commonly used in typical precast construction.

Features:
1. They provide quick, easy erection with various degrees of erection stability.
2. Volume change restraint is minimized.
3. Connection is generally concealed and protected after topping is placed.

Disadvantages:
1. Connection hardware is expensive and more difficult to cast properly in the product.
2. Welding of reinforcement is critical.
3. Alignment of the embedded corbel is critical.
4. Girder rolling can occur without proper stops.

5.2.3.3 Composite Moment Connections (GC19 - GC20 also CC1 1)

Composite connections are most commonly used in moment resisting frames. In some versions, the girders bear on a hammerhead column. Other versions require the girders to be shored in place until field concreting is cured. Continuity of girder reinforcement is attained by lapping, welding, or hooking depending on dimensions available. The negative moment steel is often placed through sleeves in the column or adjacent to the column in composite topping. In soffit girder designs, it is sometimes possible to provide sufficient strength so that shoring is not required.

Features:
1. Full moment resistance at the connection can be achieved.
2. Field adjustments can be easily accommodated.
3. Good ductility and performance.
4. In some variations, multi-story columns can be used with economy. In these instances, the next floor can be erected before cast-in-place concrete work is completed.
5. Connections are concealed.

Disadvantages:
1. Temporary shoring may be required.
2. Routing negative reinforcement steel through the column can cause alignment problems.
3. During construction, connections may be weather sensitive.
4. Conflicts can arise between precaster and field concreting personnel. Who does and provides what?

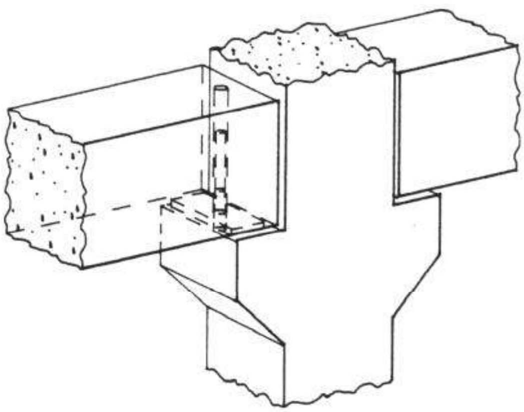
5.2.3.4 Special Applications (GC21 - GC24)

Post-tensioning can be used to provide negative moment resistance as shown in GC21 and GC22. A post- tensioning tendon is fed through a duct in the girder and an oversized sleeve in the column. An anchorage plate is attached in the pocket and the tendon is tensioned from the other end and anchored in the recessed pocket provided. The pockets should be sized to accomodate jacks. Prior to tensioning, the space between the girder and column is filled with dry-pack grout.

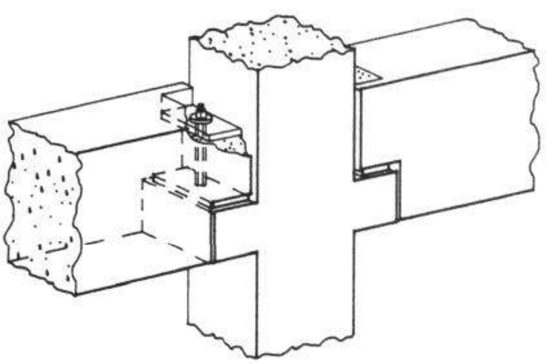
In other applications, post-tensioning strands or bars can be used to develop continuity of columns where the columns are interrupted to allow the girder to pass through (GC23 and GC24). The girder is erected over post-tensioning tendons which have been placed in conduits in the column and coupled to the tendons from the lower level in the pocket provided. The girder is set on shims and then grouted underneath. When the grout has set, the tendons are tensioned and anchored. The next column is then erected and grouted.

Features:
1. Moment resistance at connection is achieved for negative moment.
2. Girders or columns can pass through uninterrupted.
3. Connection is concealed and protected from corrosion after grouting.

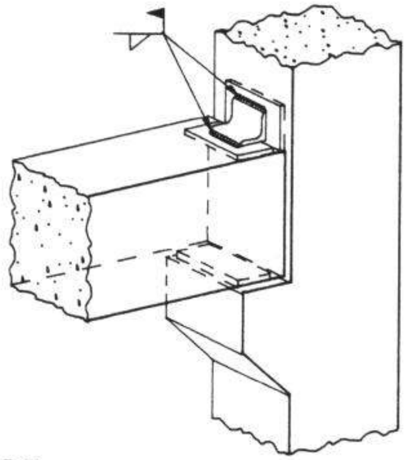
Disadvantages:
1. Anchorage bearing stresses must be considered in the girder and/or column design.
2. There is no erection connection until tendons are jacked. Other means of bracing may be necessary.
3. Post-tensioning requires special erection and inspection procedures.
4. Possible alignment problems can occur with conduits.



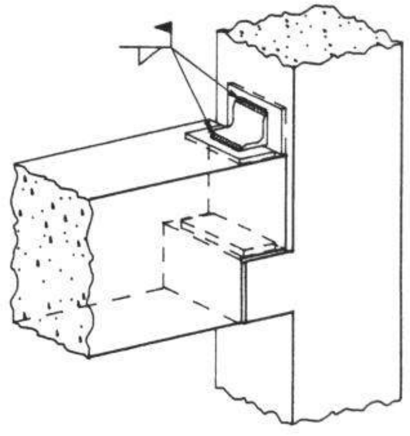
GC1



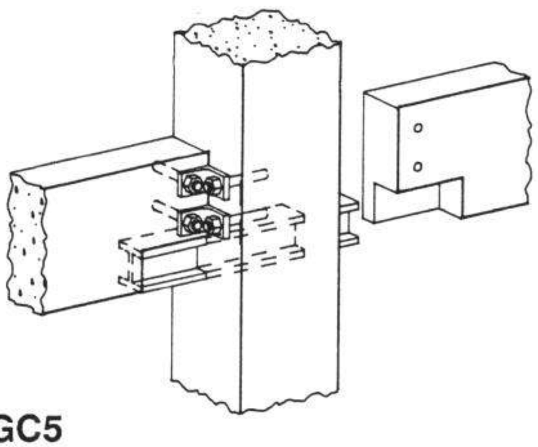
GC2



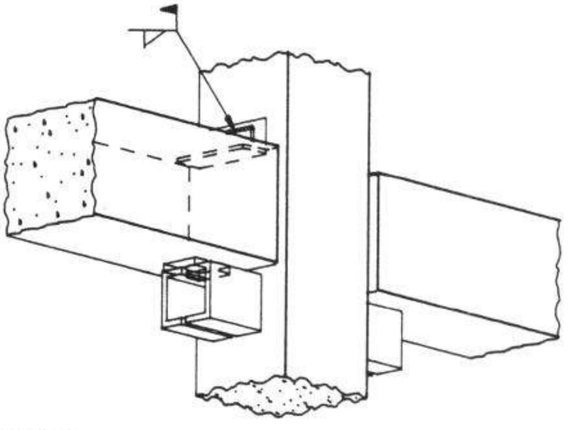
GC3



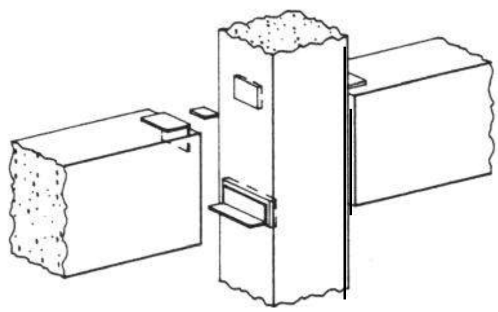
GC4



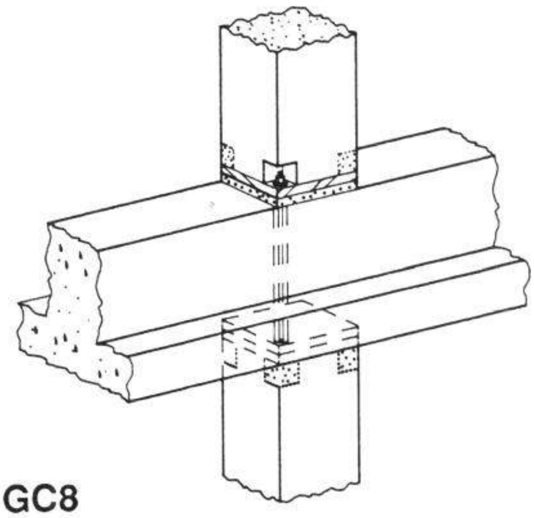
GC5



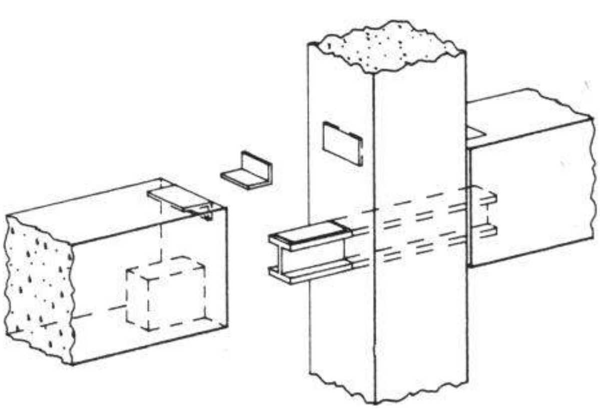
GC6



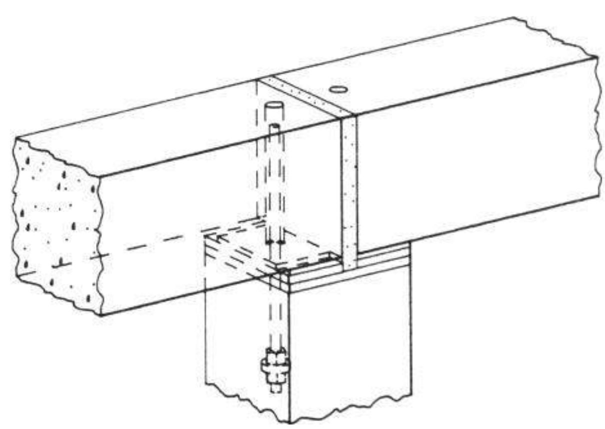
GC7



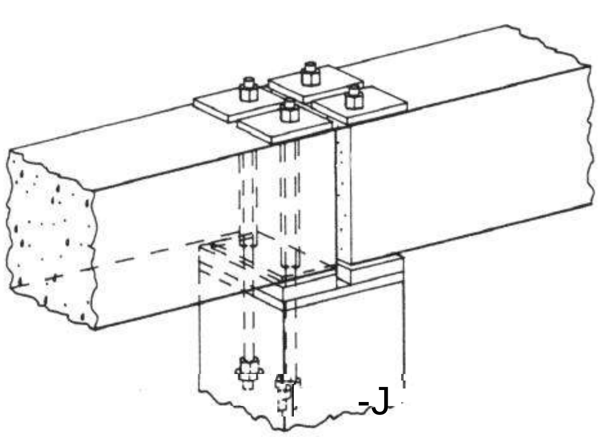
GC8



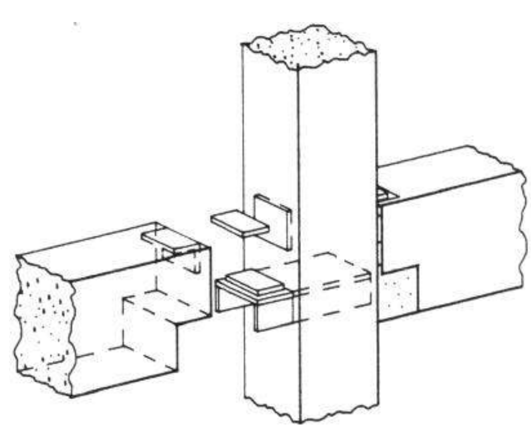
GC9



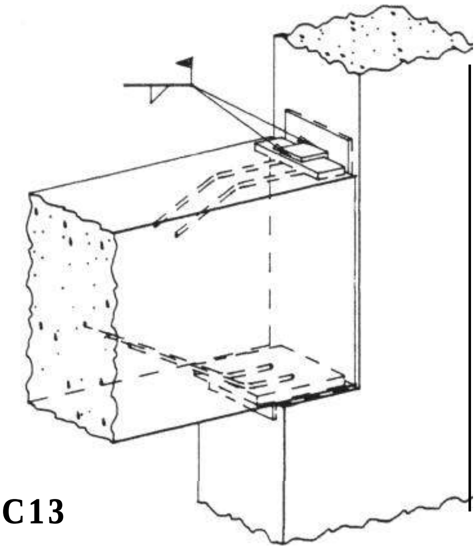
GC10



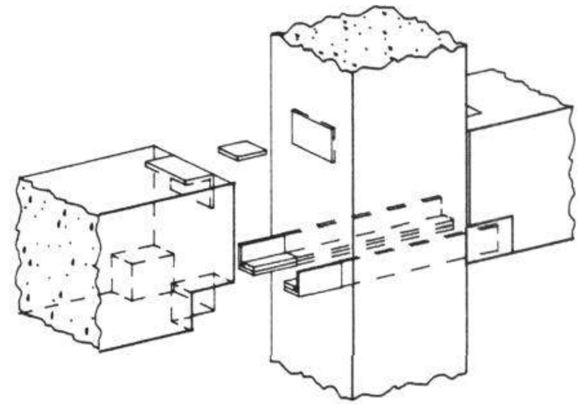
GC11



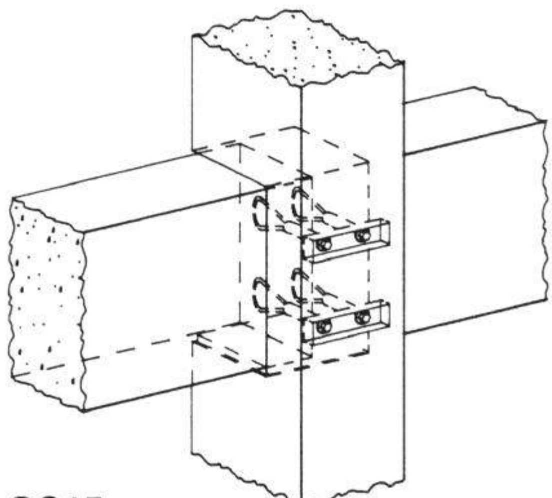
GC12



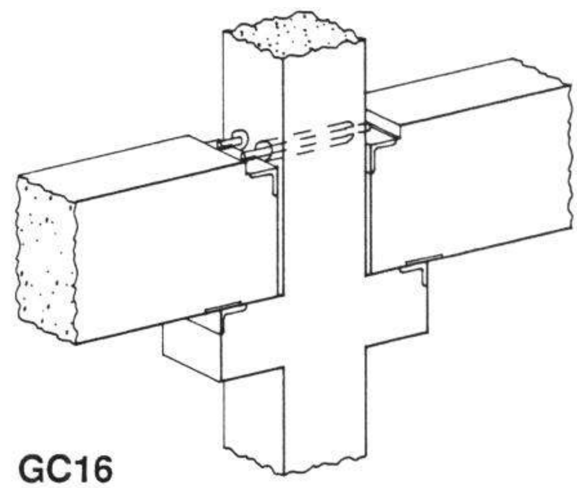
GC13



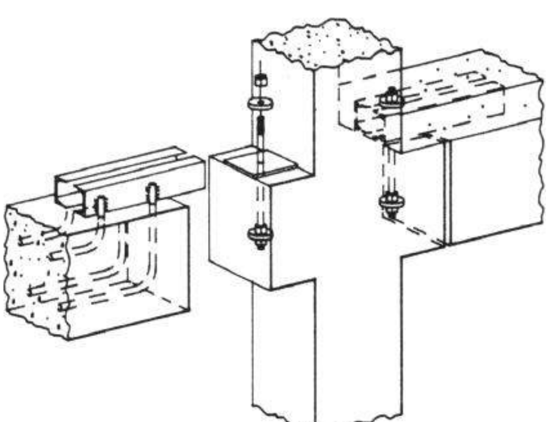
GC14



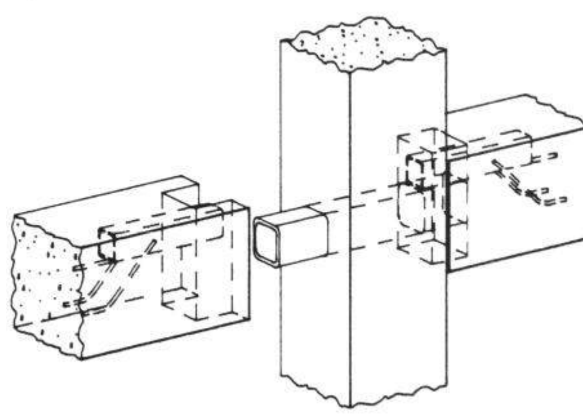
GC15



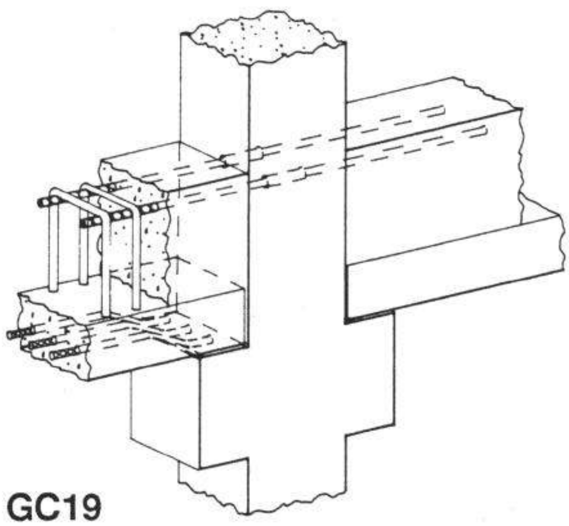
GC16



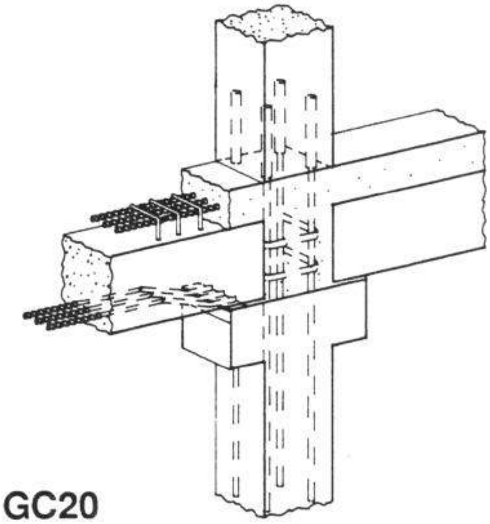
GC17



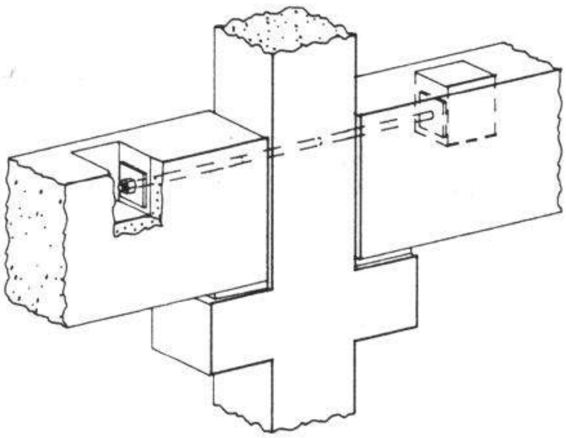
SC18



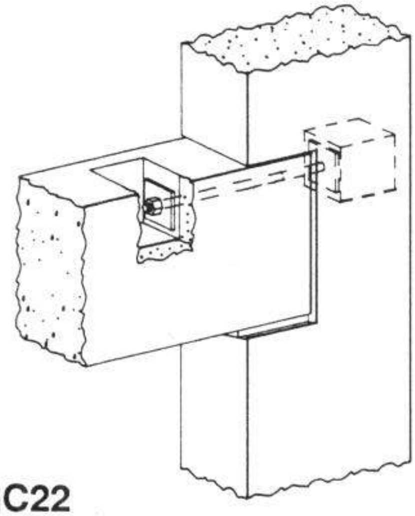
GC19



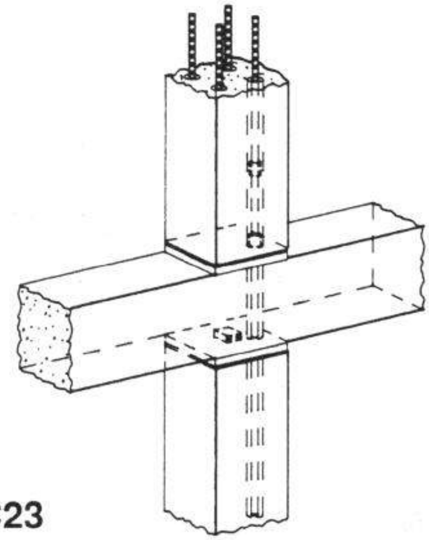
GC20



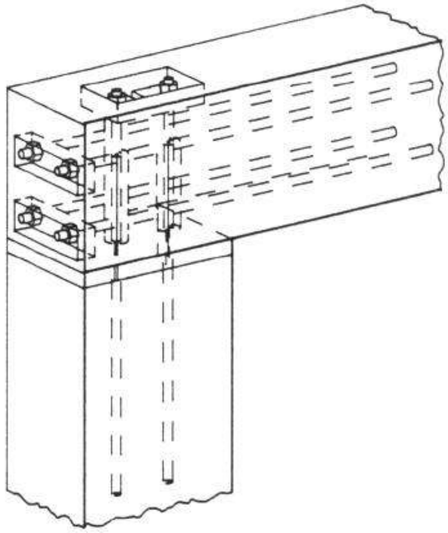
GC21



GC22



GC23



GC24

READER'S IDEAS

5.2.4 Beam to Girder Connections (BG)

These types of connections are required when precast beams are supported by girders. They may be used for framing openings and other special applications.

The first two (BG1 and BG2) depict cases where the beam sits on a bearing pad on a ledge in the lower portion of the girder. Depending upon the relative depths of the beam and girder, the beam may need to be dapped as well (See BG2). The beams and girders are often used in conjunction with a floor system having a composite topping. If there is no topping, a top connection may be required.

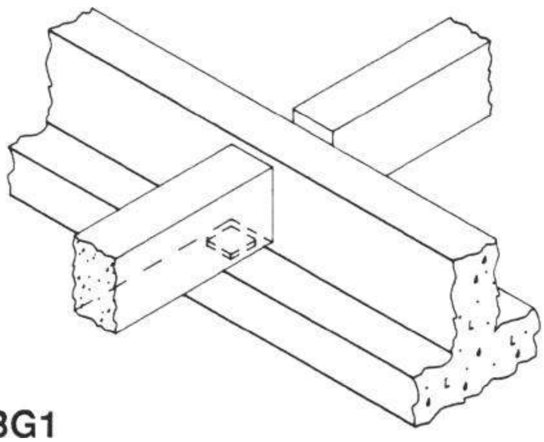
Connection BG3 shows a hanger connection concept similar to those shown in the beam to column connections. The dowel-sleeve joints (BG4) are also used when there is sufficient depth to allow placement of beams on top of the girders.

Features:

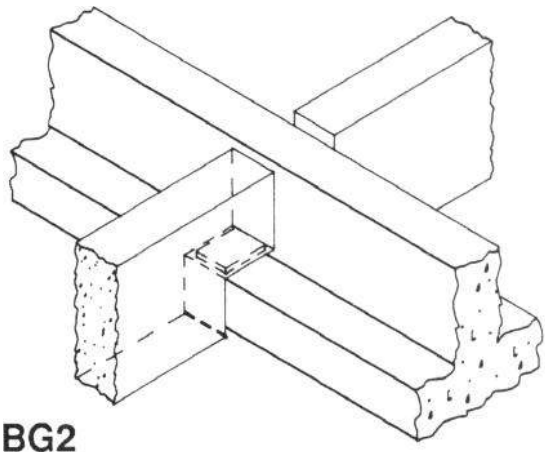
1. Girders with ledges to support beams allow quick, easy erection with a minimum of volume change restraint. Beams have immediate stability and crane time is short.
2. Grouted sleeves allow quick erection with a positive connection. When the beams are placed on top of girders the full section of the girder is effective.

Disadvantages:

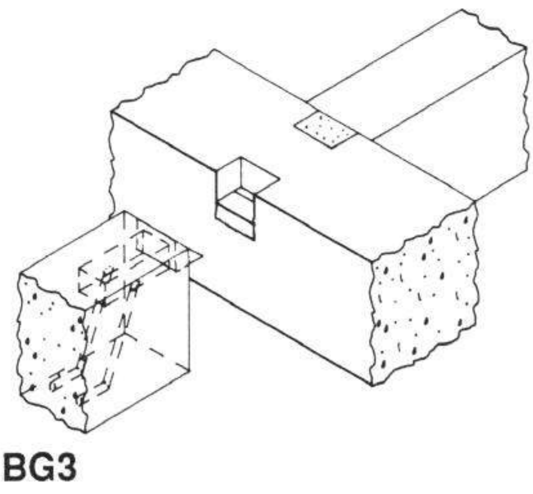
1. The dowel system, with beam placed on top of the girder, increases height of the building.
2. Dowel alignment is critical and sleeves must be protected from water and debris. Cold weather precautions are needed for grouting.
3. Dapped ends cause congestion of reinforcement and increase fabrication time. Only limited moment capacity is available in the connection.
4. Some of the connections are not easy to conceal and protect from corrosion or fire.



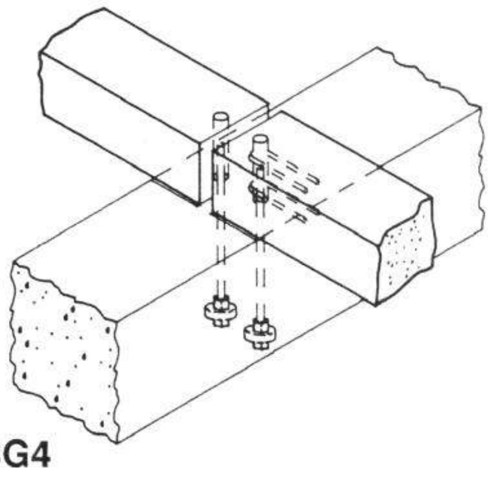
BG1



BG2



BG3



BG4

5.2.5 Beam to Beam Connections (BB)

These types of connections are used in special framing where it is desired to have the connection away from the column. Examples are tree columns with drop-in beams, cruciform beam-columns with connections at mid-span, or systems which use story-high columns and continuous beams.

The first illustration (BB1) requires dapping of ends on both beam segments. Modifications of hanger connections shown in the beam to column section can also be used. The top connection should be designed to allow longitudinal movement to prevent volume change force buildup.

The second example of beam to beam connections (BB2) utilizes embedded steel supports forming a cradle. Bearing pads and top connections are required and the hardware can be recessed and grouted if desired.

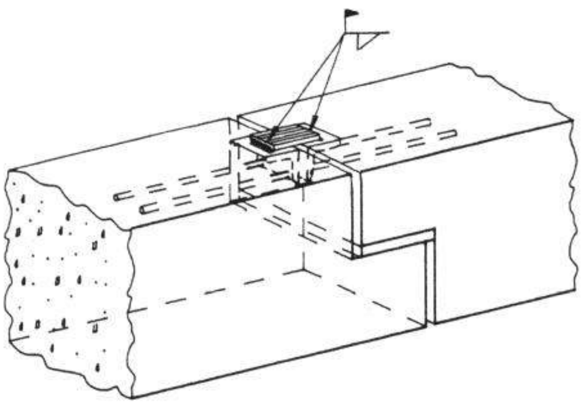
The connection BB3 shows the use of special splice sleeves to achieve beam connection. Continuity of reinforcement is achieved which facilitates moment transfer.

Features:

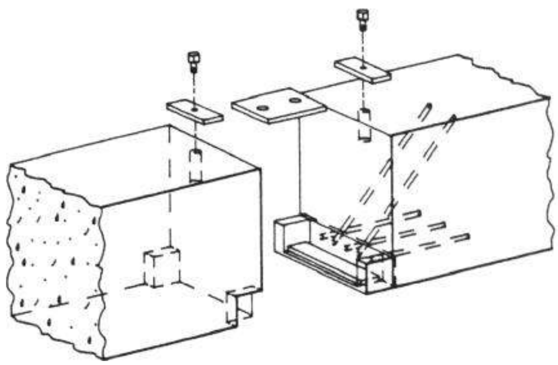
1. Longer clear spans can be achieved, allowing greater flexibility in framing.
2. Beam to beam connections allow quick, easy erection with minimum volume change restraint. Beams have immediate stability and crane time is short.

Disadvantages:

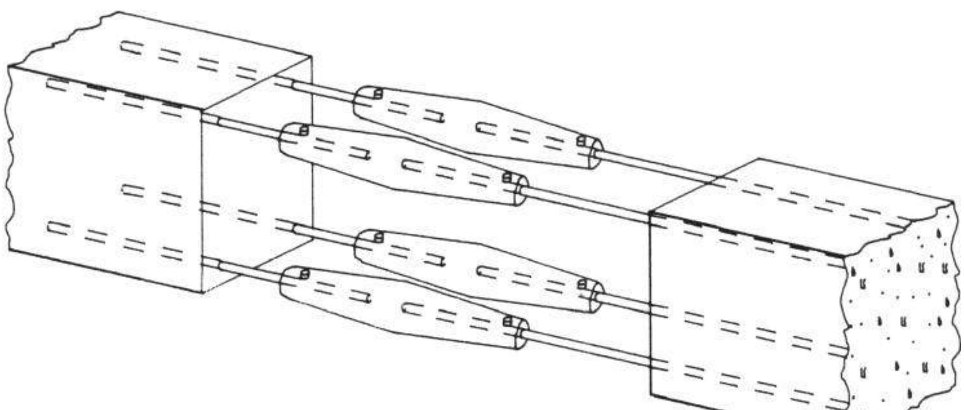
1. Dapped ends cause congestion of reinforcement and increase fabrication time.
2. Some of the connections are not easy to conceal and protect from corrosion or fire.



BB1



BB2



BB3

5.2.6 Slab to Beam Connections (SB)

These connections are most frequently made to join floor or roof members to precast concrete beams (inverted tee, ledger, rectangular), or steel beams. Often, the slab functions as diaphragm and the connections must transmit diaphragm shear and chord forces. In cases where cast-in-place topping is planned, it may be necessary to provide connections to ensure stability during erection.

5.2.6.1 Hollow-Core and Solid Slab Connections (SB1-SB6)

Precast slabs (voided or solid) bear on high density plastic, hardboard or neoprene bearing strips. Connection choice depends upon: (a) the magnitude of lateral forces in the diaphragm, and (b) whether or not the member has composite topping to transfer the forces. Some types of hollow-core are produced with extruding equipment that will not permit plates or other hardware to be cast integrally into the product. In these cases, the hardware must be installed subsequently.

Features:

1. When a mechanical tie from slab to support is not required:
   a. Quick easy erection is accomplished with adequate tolerances.
   b. Volume change restraint is minimized.
2. When a mechanical tie from slab to support is required:
   a. A positive connection to the beam is achieved for shear transfer or torsion restraint.
   b. When welding is used, cast-in-place concrete may not be required.

Disadvantages:

1. When a mechanical tie from slab to support is not required:
   a. Without topping, there is no positive tie to beam for shear transfer or torsion restraint.
2. When a mechanical tie from slab to support is required:
   a. When cast-in-place concrete is used to complete the connection, placement of longitudinal bars along top of beam requires threading through the beam stirrups. Also, there is no positive tie until joints are grouted and field concrete is cast and cured.
   b. When welding is used, accurate preplanned placement of beam hardware (embedded plates) is necessary.

5.2.6.2 Double Tee Connections (SB7-SB12)

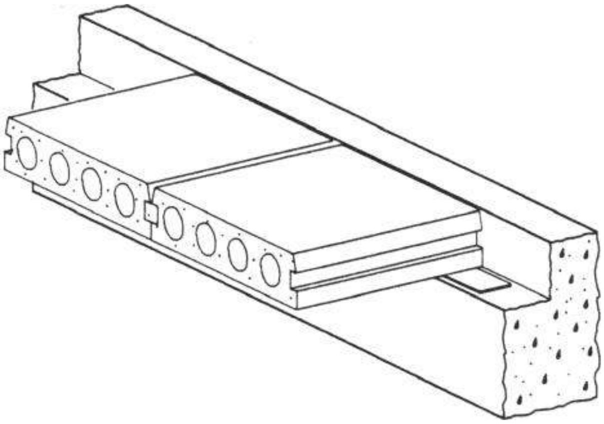
Tee stems are suspended (SB7) or sit on bearing pads and a top connection is made as shown. Although one top connection per double tee end will usually suffice for erection stability and diaphragm forces, two may be required in some situations. Experience has shown that in most stemmed members, a welded top connection will not cause volume change restraint problems if the bottom of the stem is not restrained. *It is recommended that the bottom of tee stems not be welded at the bearing to their supporting structure.*

Features:

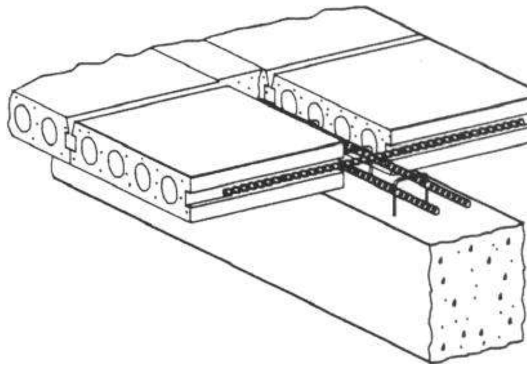
1. The connection provides erection stability and shear transfer capability.
2. Connections are simple and allow adequate tolerances.
3. Usually, there are no volume change restraint problems unless the stem bottom is welded at the bearing.
4. When hangers are used to minimize structural depth, there is no need for pockets or ledges on beams.

Disadvantages:

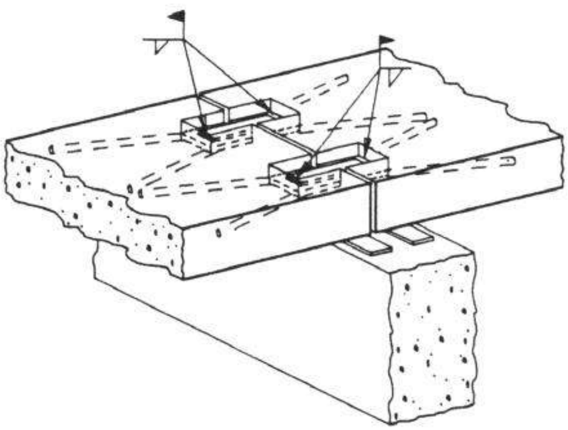
1. Embedded plate locations in beams require pre-planning and accuracy.
2. Hangers are limited in load capacity and hardware may be expensive and thus they should be used only when other solutions are not feasible.



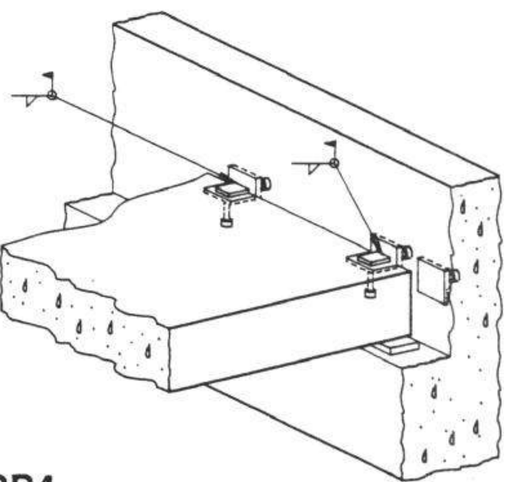
SB1



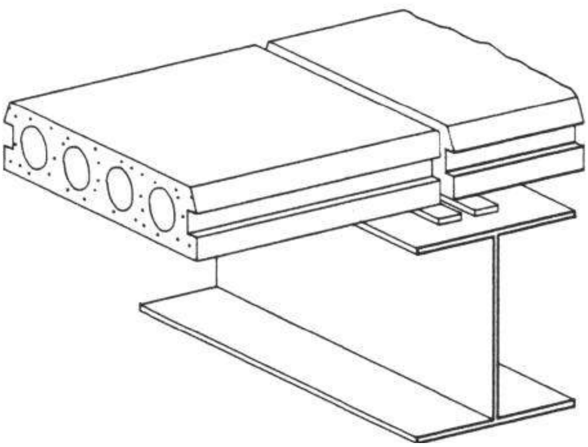
SB2



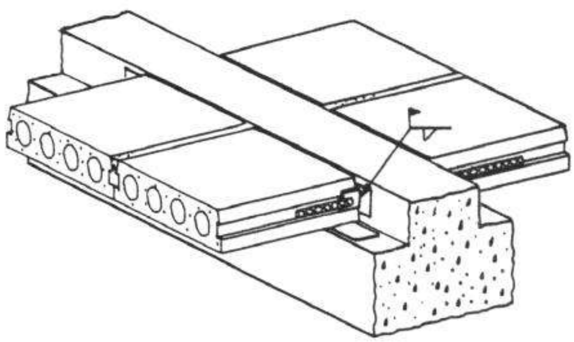
SB3



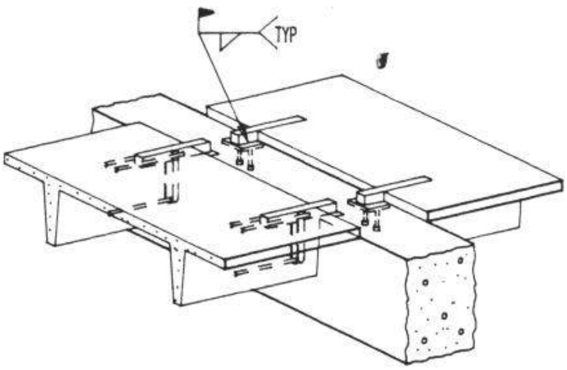
SB4



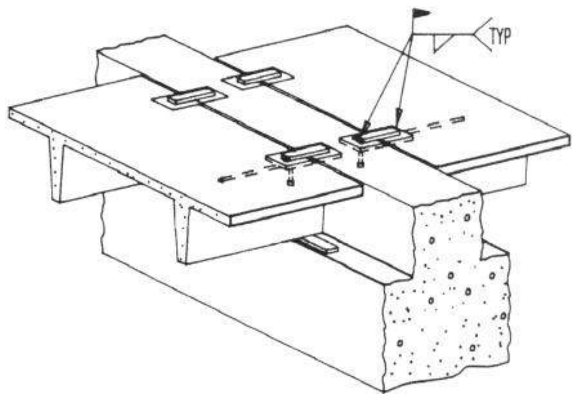
SB5



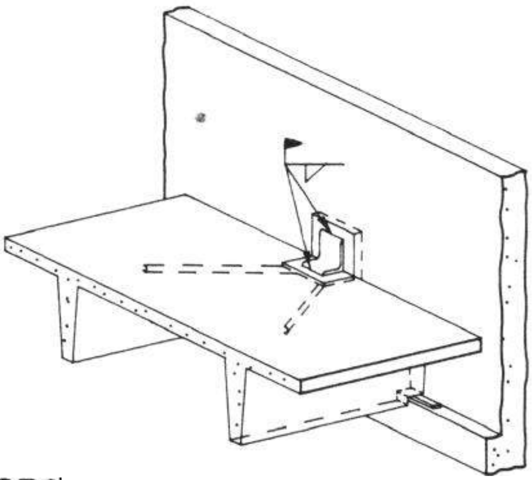
SB6



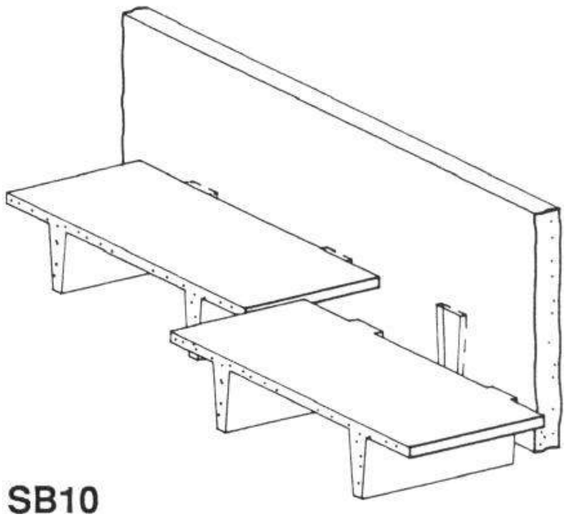
SB7



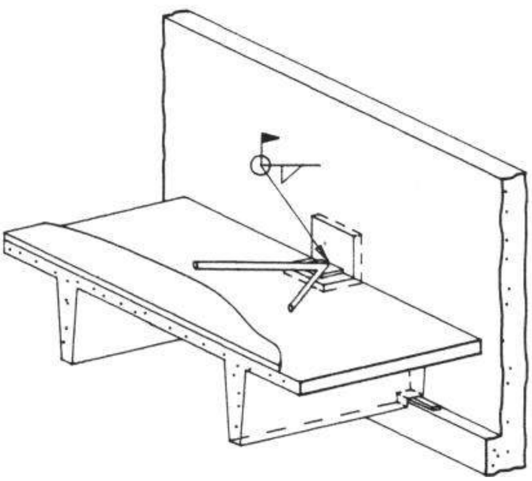
SB8



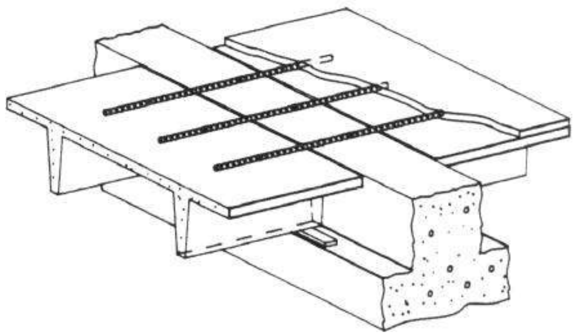
SB9



SB10



SB11



SB12

5.2.7 Slab to Slab Connections (SS)

Adjacent slabs are connected to transfer diaphragm shear loads, for vertical load distribution, and for alignment purposes. Slab thicknesses vary from 2 in. for double tee members to 12 in. and greater for hollow-core or solid slabs.

The standard connection used between the hollow-core slabs and the solid slabs is the grouted shear key (SS1). The size and shape of the key vary with the product type. The key is usually filled with a sand-cement grout. This connection distributes vertical loads and provides horizontal shear transfer for moderate loads for the deck to function as a diaphragm.

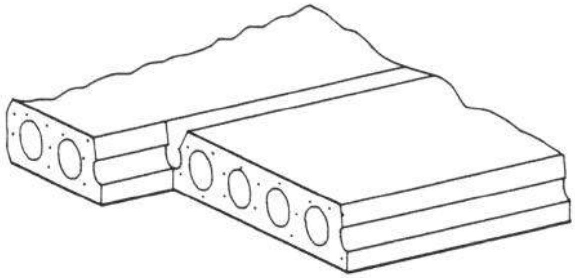
Mechanical connections use anglesorflat plates with deformed bar anchors and/or headed anchor studs embedded in the concrete (SS2 - SS6). These connections can be recessed if the slab is thick enough to accommodate the hardware. A plate or bar is welded to the embedded items to complete the connection. If topping is used in the floor or roof system, the connections are hidden and protected from corrosion.

Features:

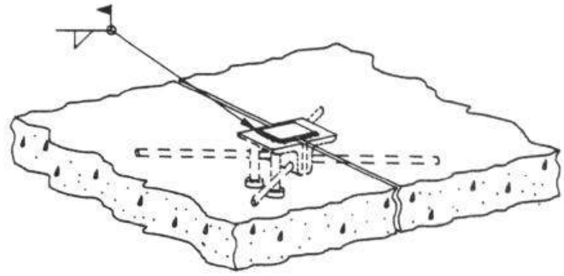
1. There are no embedded items required in the grout key, thus no corrosion.
2. Properly spaced connections distribute vertical loading and transfer diaphragm forces. The connections can help the erector even out differential camber.
3. All connections are simple and allow quick, easy erection.

Disadvantages:

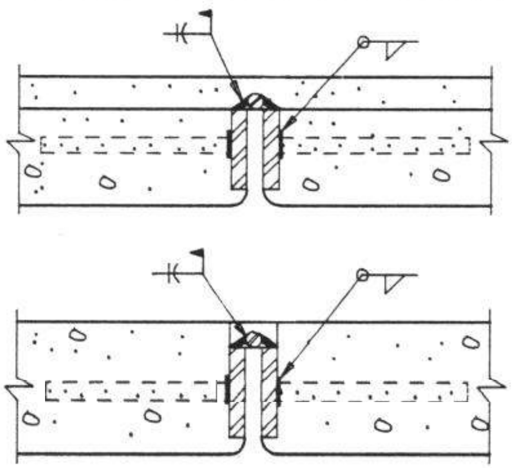
1. Grout keys are susceptible to damage from debris and freezing of water.
2. Mechanical connections must be carefully located during detailing.
3. If reinforcing bars are used, they must be weldable.
4. Connections in 2 in. double tee flanges have limited capacity to resist vertical forces. Their effectiveness in evening out differential camber between adjacent slabs is also limited.



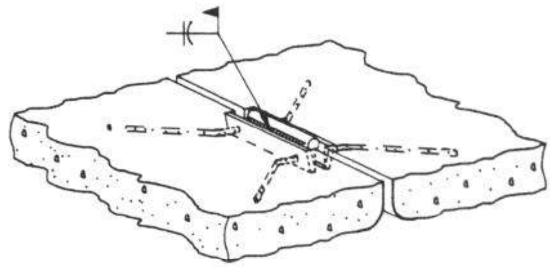
SS1



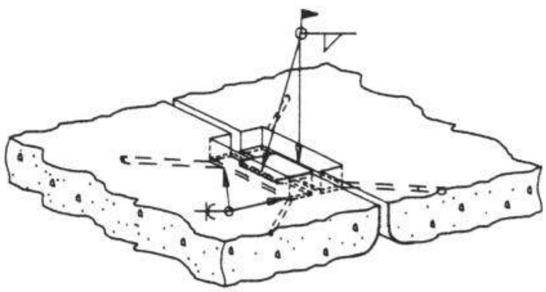
SS2



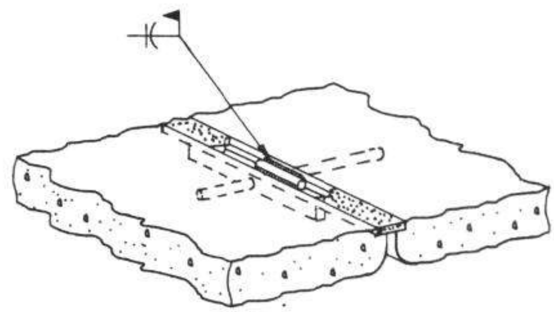
SS3



SS4



SS5



SS6

5.2.8 Slab to Wail Connections (SW)

Flat or stemmed slabs interface with several types of walls. Some walls can be hollow (masonry), others are solid (precast shear walls or cast-in-placefoundationwalls), andstillothersareribbed or stemmed (double tees). Connections joining the slabs and walls may require load transfer for bearing or diaphragm action, or they may require movement accommodation such as needed when long roof members are joined to non-load bearing walls.

5.2.8.1 Hollow-Core and Solid Slab Connections (SW1 - SW4)

Precast slabs are erected on high density plastic or hardboard bearing strips, leaving a 2 to 3 in. gap end to end. If the wall is concrete masonry, the cores are filled in the last 2 or 3 courses and vertical reinforcing bars are embedded at approximately 32 in. on center. Longitudinal reinforcement is added in the joint to tie the connection together. A composite topping, reinforced with welded wire fabric, is placed and the next level of wall is constructed. A regular masonry bond beam can be used in lieu of the filled courses. Bars or strands are located in grout-key spaces to satisfy minimum tie requirements. In end bearing conditions, the bars in the grout keys can be welded to plates in the exterior walls. Threaded inserts can also be used.

Features:

1. Tolerance problems are minor because of the wider grout joints inherent in hollow-core and solid slab construction.
2. Diaphragm forces can easily be accommodated and transferred to the walls.
3. Usually, there are no embedded items, thus eliminating corrosion problems.
4. Grouted shear key operations are not complicated and do not require extensive training.

Disadvantages:

1. Placement of concrete topping may delay wall construction and precast erection.
2. Dowels embedded in masonry must be aligned with notches or joints in slabs.
3. Coordination is required to clarify which trade is responsible for providing the hardware.
4. Often, multiple move-ins are necessary for the precast concrete supplier because of the slower masonry construction.

5.2.8.2 Stemmed Member Connections (SW5 - SW1 2)

Normally, double tee walls are arranged with their stems placed outward from the walls so that the flange provides a smooth wall inside the structure. Occasionally however the double tees will be placed with stems inside the building.

The wall panel has either a continuous reinforced concrete ledge or individual corbels. The roof or floor tee sits on a bearing pad and has a top connection which can take a variety of configurations. In roofs usually a top connection over each stem is used while in floors one top connection midway between stems is used. When roof slabs cantilever over the wall panels, the stem of the wall panel is blocked back and the flange notched so that the roof tee may pass through. The roof member bears on a pad on the top of the stems and cantilevers out. A plate cast in the bottom of the stem of the roof member is welded to an angle at the support. *Again, welding at bearing should be avoided,* unless relief of restraint is provided for by other means, such as in SW7 where the flexibility of the wall provides the relief.

in non-load bearing applications (SW8), a loose angle with avertical slot is bolted into an insert in the panel and welded to a plate in the slab. The slot allows for vertical movement, but enables transfer of diaphragm forces.

Features:

1. Quick, easy erection is accomplished, and the slabs brace the wall panels.
2. Connections are protected when roofing or topping is placed.
3. When slabs cantilever over wall panels, no haunch is required.
4. Adequate strength can be developed to resist diaphragm shear and chord forces.

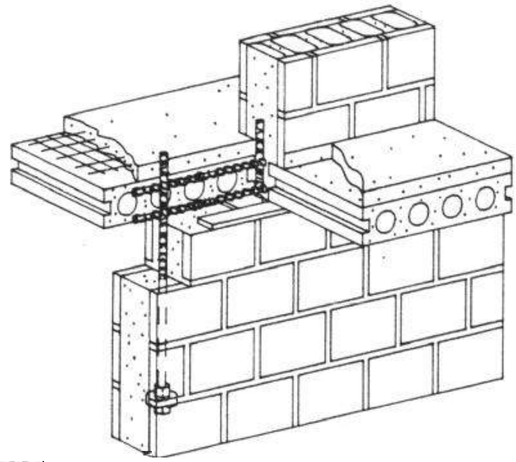
Disadvantages:

1. Special forming is required for a continuous ledge or corbel.
2. Wide tee slabs do not align with narrow panel tees which necessitates a continuous ledge. It is preferred that the roof tee width matches the wall panel width.
3. When wall panel stems are turned inside, detailing is more difficult and the quality of the exterior building finish is limited to as-cast top surface unless additional finishing is used. Also, the top connection is exposed and may require protection. Eccentricities are larger and extra reinforcement may be required.

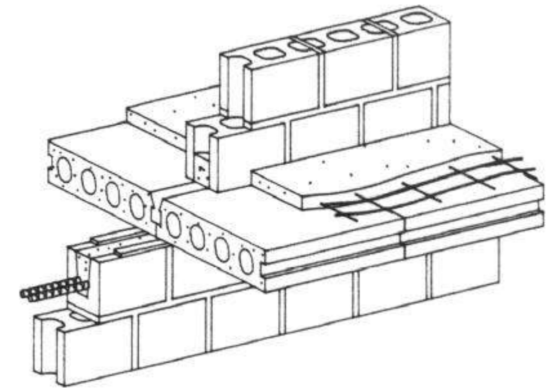
Finally, the narrowness of the wall panel stems may limit the types of connections that can be used.

4. Cantilevered roof panel connections may require overhead welding. Such connections are difficult and may require workers to operate on ladders which can be a safety hazard. Wall panel flanges require additional reinforcement when stems are blocked out.
5. The bolt sometimes hangs up in the slotted connection used in non-load bearing conditions. Also, flatness of embedded plates is critical to avoid binding of the bolted connections.

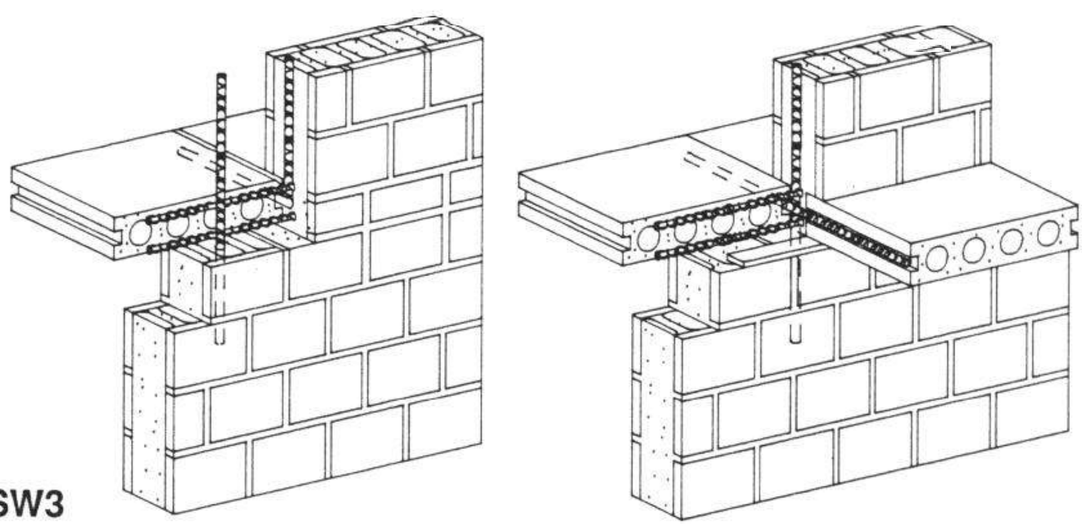
Stemmed roof and floor members also commonly bear on masonry or solid walls (SW9 - SW1 2). Precast tees are set on bearing pads with flanges blocked back when walls need to continue through. Either filled masonry cores or bond beams are necessary to resist member loadings. Care must be taken to avoid loading the face shell of bond beams as this will cause spalling or cracking of the block to occur. Longitudinal and vertical reinforcement in the wall is routine. Diaphragm forces are easily transferred to walls through dowelsorwelded top connections at tops of tee stems. Again, cafe is necessary when considering welding of tee stem *bottoms. In general, it should be avoided.*



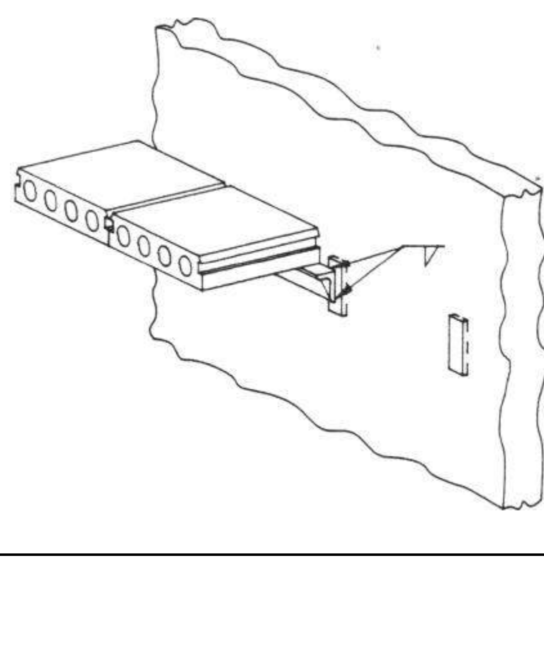
SW1



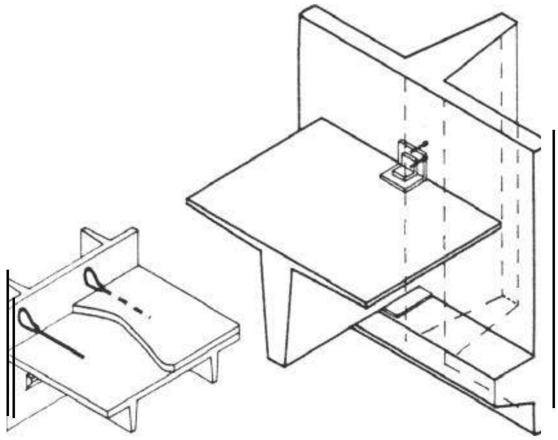
SW2



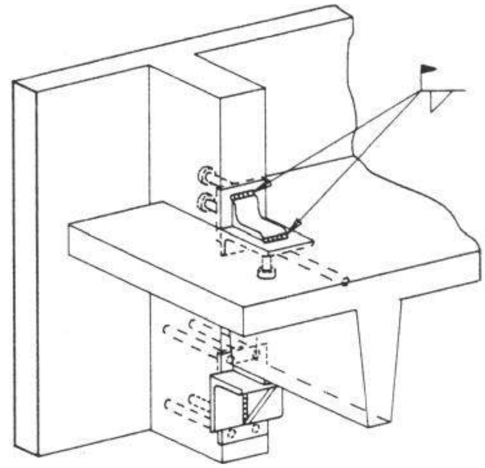
SW3



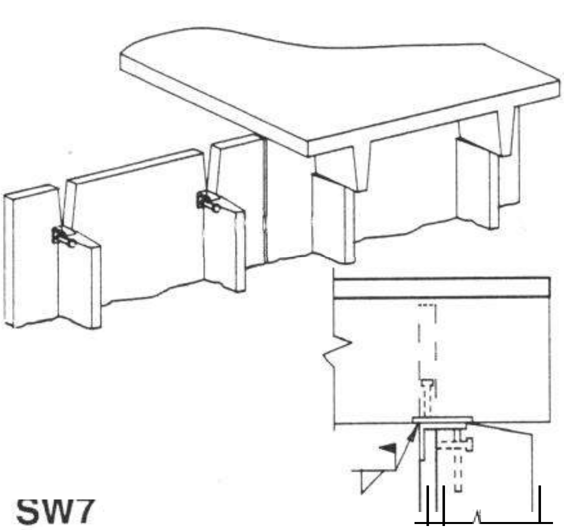
SW4



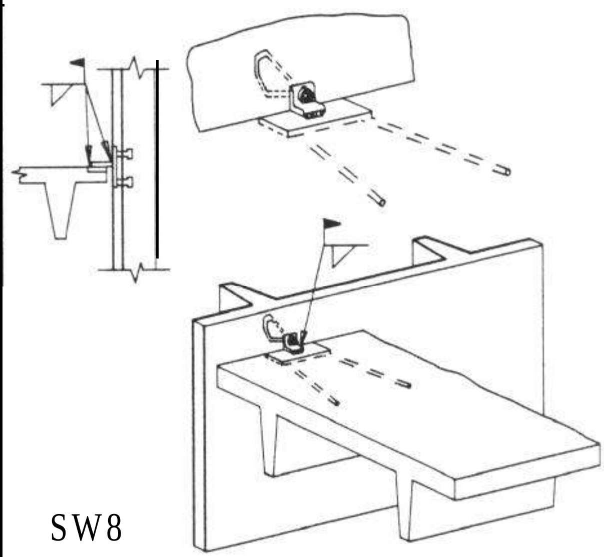
SW5



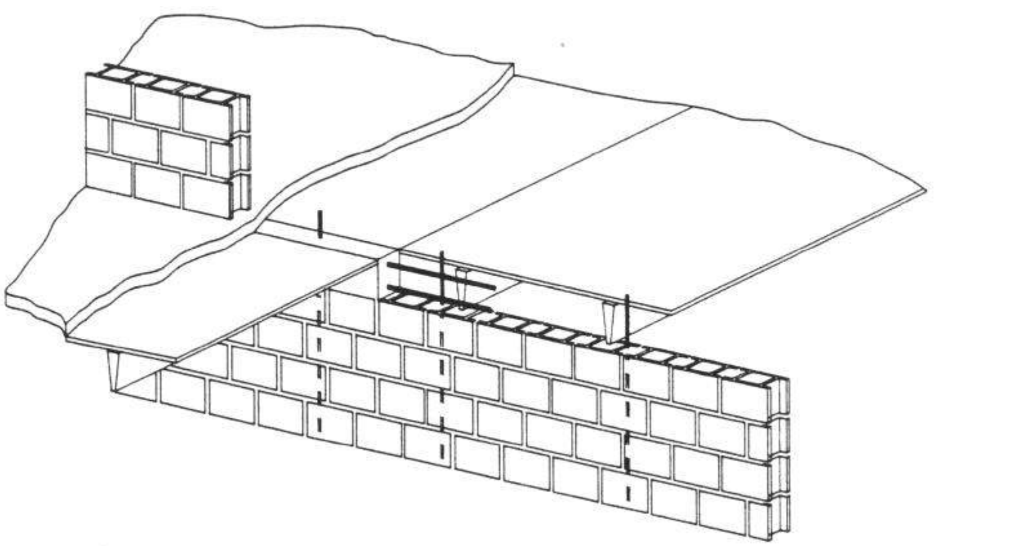
SW6



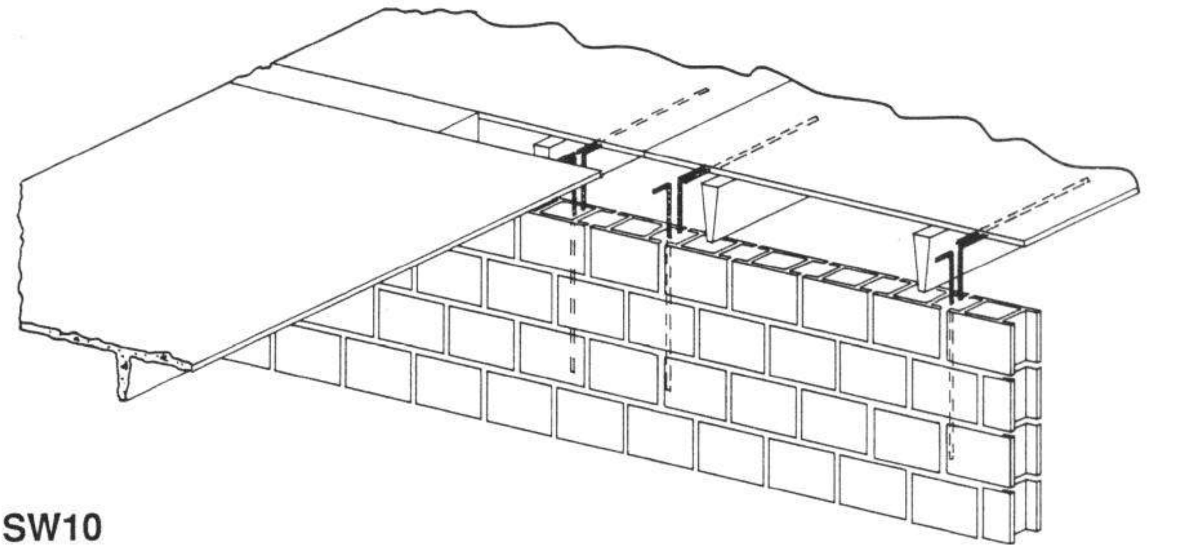
SW7



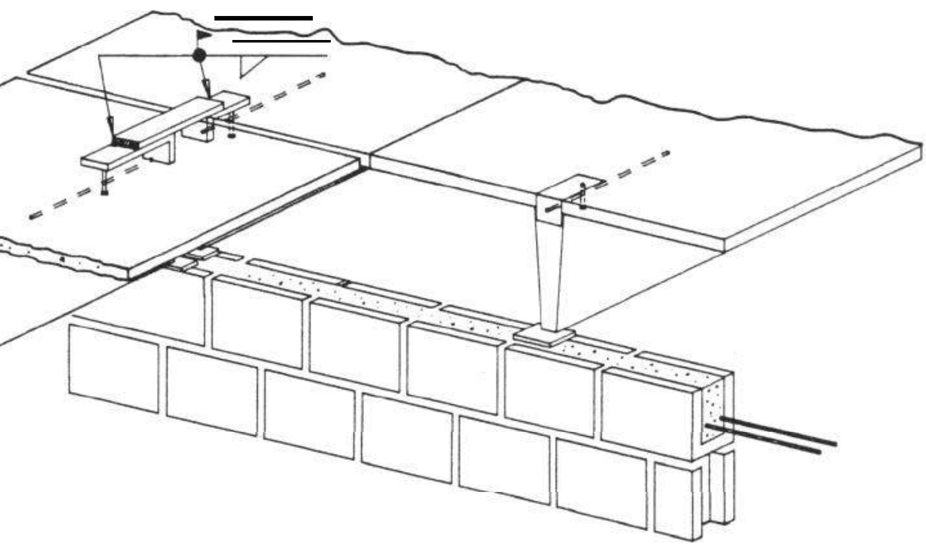
SW8



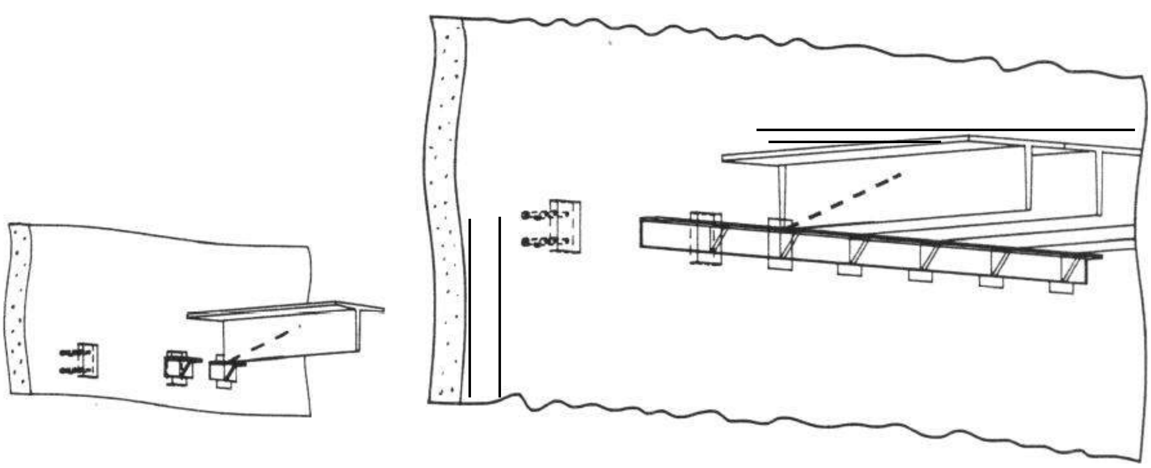
SW9



SW10



SW11



SW12

5.2.9 Beam to Wall Connections (BW)

Various types of beam to wall connections in common use are:

- On corbel with top connection
- In pocket
- With sleeve and dowel
- With bottom connection

All of the connections in this group are intended forvertical load transferonly and are not suitable for resisting moments. The beams shown are rectangular but the connections can be used with other shapes. Different wall construction, such as precast double tees, cast-in-place concrete and masonry are illustrated but, in some cases, the connections are interchangeable.

5.2.9.1 Beam to Wall Corbel Connection (BW1 and BW2)

The beam sits on a bearing pad supported by a concrete or steel corbel, projecting from the wall panel. The top connection transfers horizontal shear forces between the beam and panel, provides erection stability and braces the panel.

Features:

1. Quick, easy erection.
2. Few tolerance problems.
3. Braces the wall panel.

Disadvantages:

1. No moment capacity.
2. Special forming required for corbel.
3. Design of wall must consider eccentricity of the loads.

5.2.9.2 Beam to Wall Pocket Connection (BW3)

A pocket is cast into the wall to receive the beam. The beam sits on a bearing pad inside the pocket. A top connection may be used. Axial shortening of the beam due to volume change should be considered when designing depth of the recess. This connection is more commonly used with cast-in-pace walls, but can also be used with precast panels. Ample tolerances are required.

Features:

1. Minimum of embedded hardware for light loads.
2. Clean, concealed connections.

Disadvantages:

1. Pocket dimensions must be planned so that beam can "swing" into place. *It is recommended that this connection not be used at both ends of a beam.*

5.2.9.3 Sleeve and Dowel Beam to Wall Connection (BW4)

A sleeve in the end of the beam fits over a dowel protruding from the bearing, shown as a bond beam or grouted masonry core. The sleeve should be 3 or 4 times the size of the dowel to minimize field tolerance problems. In order to prevent restraint, the bottom few inches of the sleeve should be filled with a compressible material such as sand, vermiculite, or asphalt. The remainder is filled with grout.

Features:

1. Quick, easy erection.
2. Volume change restraint is minimized.
3. Provides shear resistance and some torsional restraint after grouting.

Disadvantages:

1. No lateral connection until sleeves are grouted.
2. No reliable moment capacity.
3. Sleeve can fill with water during erection and freeze and crack the beam, unless precautions are taken.

5.2.9.4 Beam Bottom lo Wall Connection (BW5 and BW6)

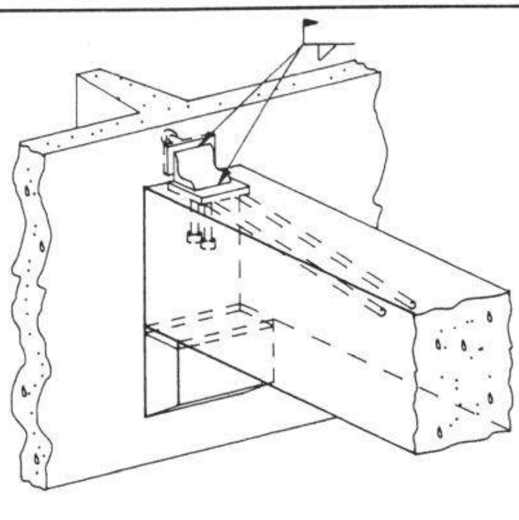
This connection is used primarily when the beam is required to provide lateral restraint to the wall. This detail requires bearing plates installed in the wall.

Features:

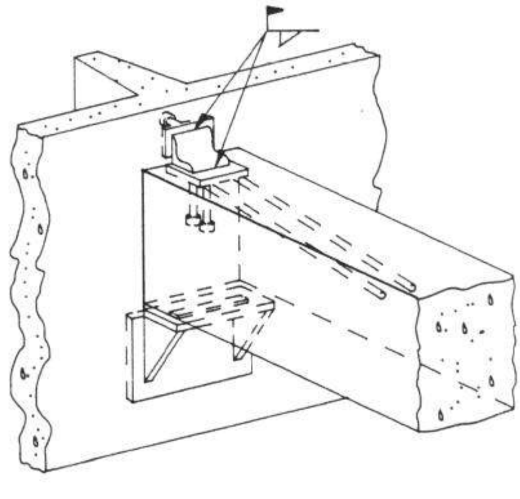
1. Positive tie to the wall.

Disadvantages:

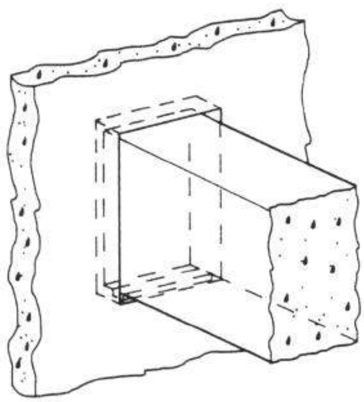
1. Requires close coordination with masonry trades.
2. Level placement of bearing plate difficult.
3. Volume change shortening of the beam must be considered in design of the wall.



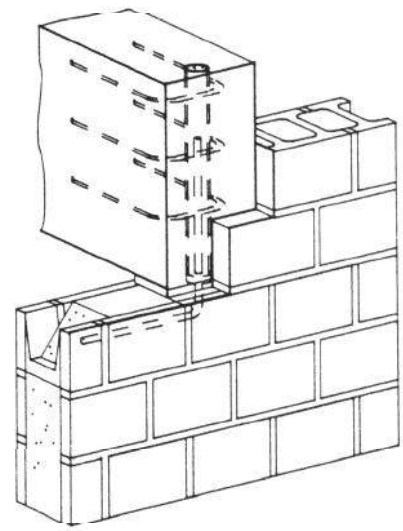
BW1



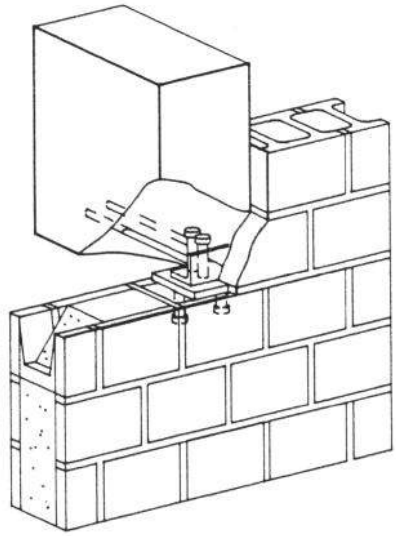
BW2



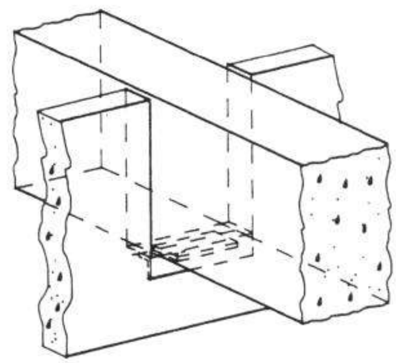
BW3



BW4



BW5



BW6

5.2.10 Wail to Wail Connections (WW)

There are two configurations of wall to wall connections: horizontal joints, usually in combina-tionwithfloorconstruction,andverticaljoints. These can be further identified as:

- Horizontal - bolted
- Horizontal - welded
- Horizontal - sleeve
- Horizontal - post-tensioned
- Vertical - bolted
- Vertical - welded

The connections from wall to wail are primarily intended to position and secure the walls although, with proper design and construction, they are capable of carrying loads from uplift, shear wall or frame action. Solid wall panels are shown but many of the connections could also be used with double tee or hollow-core wall panels.

5.2.10.1 Horizontal - Bolted Wall to Wail Connection (WW1)

A threaded bolt or continuous rod extends out of the top of the lower panel and bolts through a member cast in the bottom of the upper panel. The strength of the elements in the connection can be developed by bond and lap with panel reinforcement or by continuity through the panel. Proper vertical elevation is obtained with shims or leveling nuts. The joint is later dry-packed or filled with non-shrink grout.

Features:
1. No welding required.
2. Connection is concealed and protected after grouting.
3. Vertical uplift capacity can be developed.

Disadvantages:
1. Requires accurate placement of hardware. Cast-in connection should include oversized hole or slot.
2. if projecting bolts are used, they are susceptible to damage.

5.2.10.2 Horizontal - Welded Wail to Wail Connection (WW2 and WW3)

The upperwall is cast with an embedded plate in a recessed pocket. The lower wall is cast with an angle. A plate or round bar is then welded to the embedments in both the upper and lower walls. Alternately, the lower wall may also incorporate an embedded plate and the two wall panel plates are welded to shim inserted between the two plates. During erection, the panel is shimmed to the proper elevation and the joint dry-packed after the connection is completed.

Features:
1. Positive connection between walls.
2. Connection is concealed and protected after grouting.
3. Continuous vertical tie through connection.

Disadvantages:
1. Plate alignment in the walls is critical.

5.2.10.3 Horizontal - Sleeve Wail to Wail Connection (WW4)

The sleeve connectors shown receive reinforcing bars and are later filled with a non-shrink grout to achieve continuity. The sleeves are capable of developing full strength of the bars.

Features:
1. Continuity through the connections.
2. Connection is concealed and protected.

Disadvantages:
1. No connection between wails until splice sleeves or ducts are grouted.
2. Sleeve connections and sleeve grout may be proprietary.
3. Hardware placement is critical.

5.2.10.4 Horizontal - Post-Tensioned Wail to Wail Connection (WW5 and WW6)

Vertical post-tensioning bars are field installed in ductscast in the wall panels. The bars may be made continuouswith a couplerand post-tensioned (WW5) or they may be simply connected with a threaded coupler (WW6).

Features:
1. Vertical post-tensioning can be used to withstand uplift forces.
2. Connection is hidden and protected.
3. Welding is not required.

Disadvantages:
1. Duct and hardware placement in walls is critical.
2. Connection is not developed until tensioning is completed.

5.2.10.5 Vertical - Bolted Wall to Wall Connection (WW7 and WW8)

Inserts, or bolts welded to steel plates are cast into panels. The loose plate or angle has slots in opposite directions on each side to allow both vertical and horizontal adjustment. If properly placed, the bolts will allow some movement for volume changes. If a rigid connection is desired, the plates can be later welded.

Features:

1. Quick erection.
2. Volume change movement is accomodated.
3. When recessed, connectioncan beconcealed and protected.

Disadvantages:

1. Limited field adjustment.
2. Shear transfer between panels unreliable without welding.

5.2.10.6 Vertical - Welded Wall to Wall Connection (WW9 - WW12)

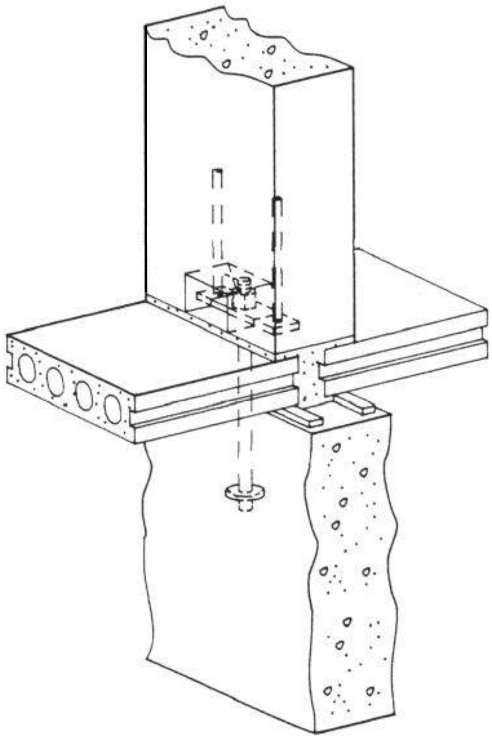
Plates or angles are cast in the wall panels and are anchored with studs and/or welded reinforcing bars. A loose plate, angle or bar is welded across the joint.

Features:

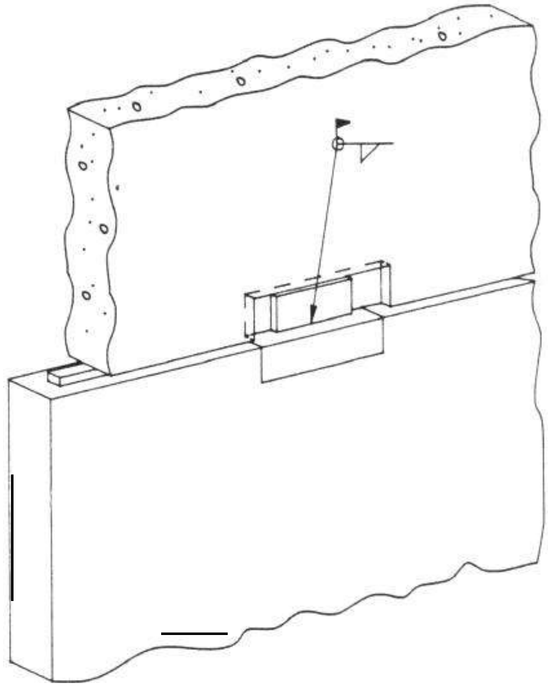
1. Ample adjustment allowance.
2. When recessed, connectioncan be concealed and protected.
3. Good shear transfer.

Disadvantages:

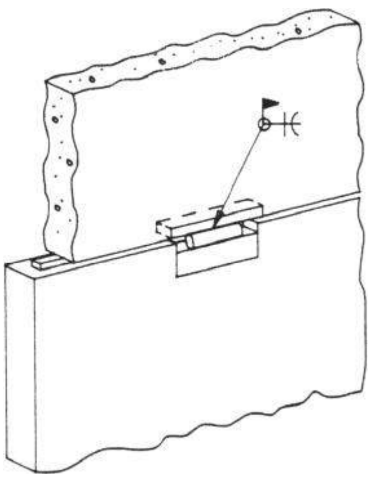
1. Rigid, unyielding connection.
2. Possible volume change problems except in WW12.



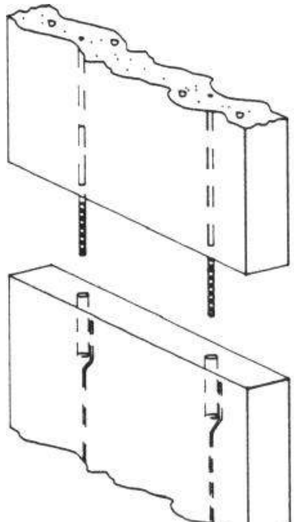
WW1



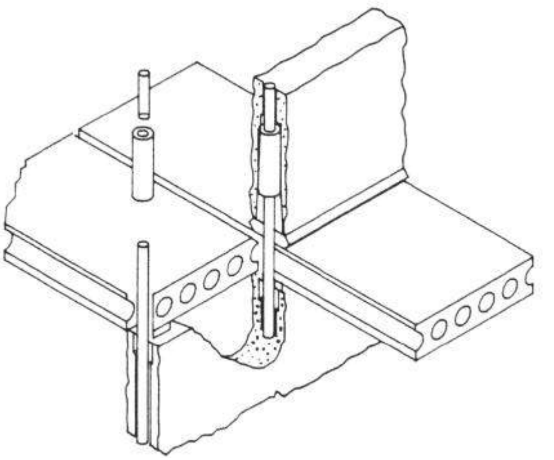
WW2



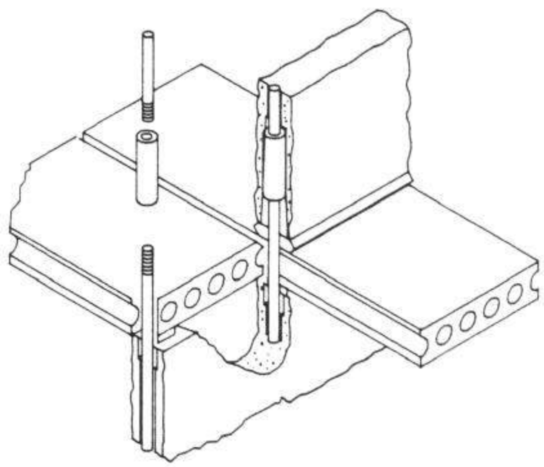
WW3



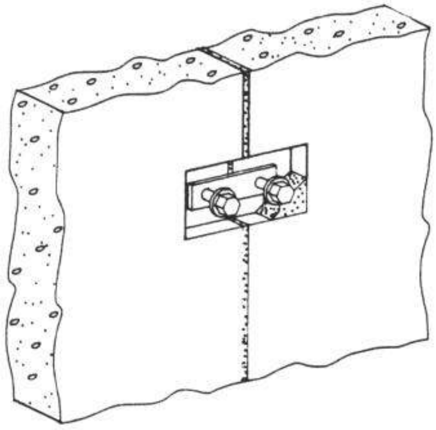
WW4



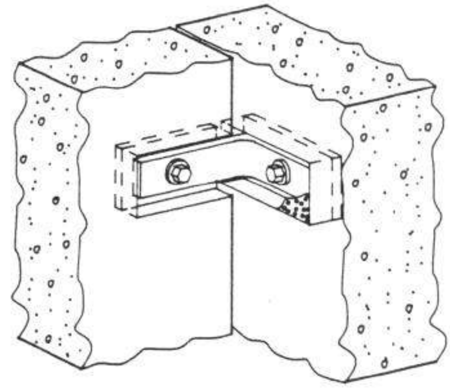
ww5



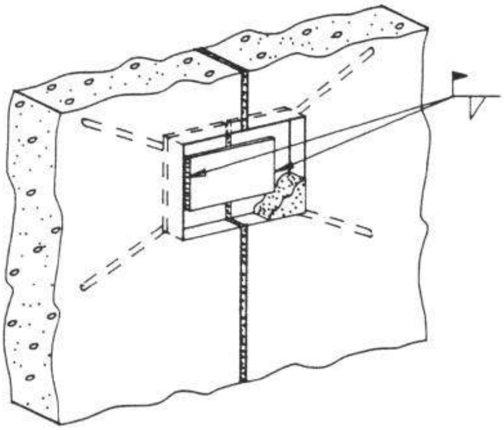
WW6



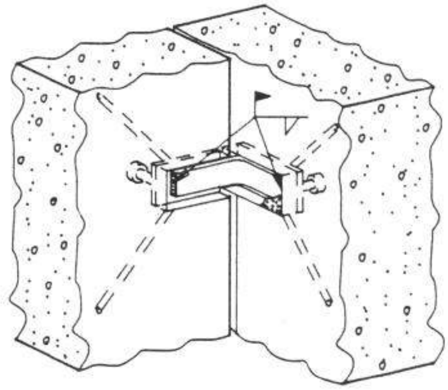
WW7



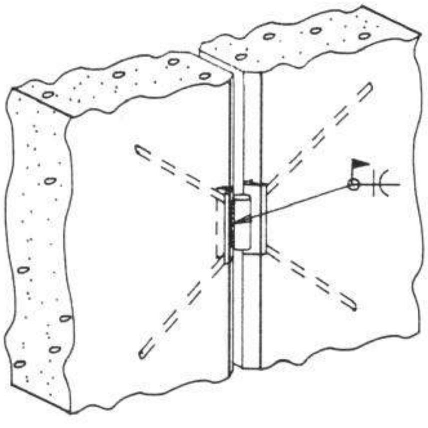
WW8



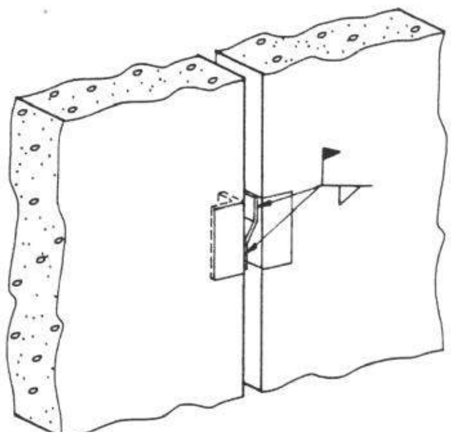
WW9



WW10



WW11



WW12

5.2.11 Wail to Foundation Connections (WF)

The types of wall to foundation connections commonly used are:

- Welded
- Bolted
- Grouted
- Moment Resistant
- Post-Tensioned

Ail of the types can be used with double tee wall panels, hollow-core wall panels or solid wall panels with the exception of vertical post-tensioning which is suitable for solid wails only. The wall panels may be load bearing or non-load bearing. Combination of welding, bolting, etc. is also used in some connections.

5.2.11.1 Welded Wail to Foundation Connection (WF1)

The wall panel and the foundation have weld plates cast into them. The wall panel is set on shims. Loose angles or plates are welded to the embedded plates. Generally, two connections per panel are provided. The space under the wall is usually filled with dry-pack or non-shrink grout.

Features:

1. Connection allows quick, easy erection.
2. There are few tolerance problems.
3. When the footing is not wide enough, the bottom leg of the angle can be turned under the panel.
4. When the face of the panel is in line with the face of the foundation, or grade wail, a plate can be welded between vertical plates in the wail and foundation.

Disadvantages:

1. When the connection is below grade, the welding may be difficult.
2. if the connection is on the exterior face of the panel, it is susceptible to corrosion unless protected with mastic or grout.

5.2.11.2 Bolted Wail to Foundation Connections (WF2 - WF4)

in WF2 and WF3, an angle or plate is attached to the wail panel and foundation wail. A cast-in insert is commonly used in the wall panel and a drilled-in expansion bolt may be used in the foundation. The wall panel is set on shims and two connections per panel are made. in place of shims, round head leveling bolts (WF4) can be used for panel alignment and the bolt heads welded to a plate cast in the foundation wall. The space under the panel is usually filled with dry-pack or non-shrink grout.

Features:

1. A commonly used variation of this type includes the connection angle or plate bolted to the foundation and welded to the wall panel.
2. Bolting allows quick easy erection in any weather.
3. Drilled-in expansion bolts eliminate the need for any hardware to be accurately located in the foundation.

Disadvantages:

1. Anchorage of the cast-in insert near the bottom of the wail panel may be difficult.
2. if not installed properly, drilled-in expansion bolts are not as reliable as cast-in inserts.

5.2.11.3 Moment Resistant Wall to Foundation Connections (WF5 and WF6)

These connections are used when cantilever moments must be developed. One type develops moment resistance at the base with a welded and/or bolted connection on each face of the wall panel. Another type includes a connection to the foundation and a connection to the interior floor slab. The floor slab connection can be made with coil rods threaded into inserts in the wall panel and cast into the floor slabs. An alternate uses the strand lifting loops in conjunction with bent reinforcing bars to accomplish the tie to the floor slab.

Features:

1. Moment resistance at the base is provided.

Disadvantages:

1. For base connection, anchorage within wall panel is critical.
2. For base connection, moment must be resisted by the foundation.
3. For slab connection, location of insert vertically is critical. Moment resistance is not developed until slab connection is complete.
4. For slab connection, slab construction requires care to ensure that the bars are properly embedded and that there is no slab settlement.

5.2.11.4 Grouted Wall to Foundation Connection (WF7)

The foundation is cast with corrugated steel sleeves to receive projecting reinforcing bars from the wall panel. The sleeves are filled with grout just prior to erection of the panels, which are shimmed to correct elevation and later dry-packed underneath.

Features:
1. Quick, easy erection.
2. No tolerance problems.
3. Shear resistance perpendicular to wall is achieved.

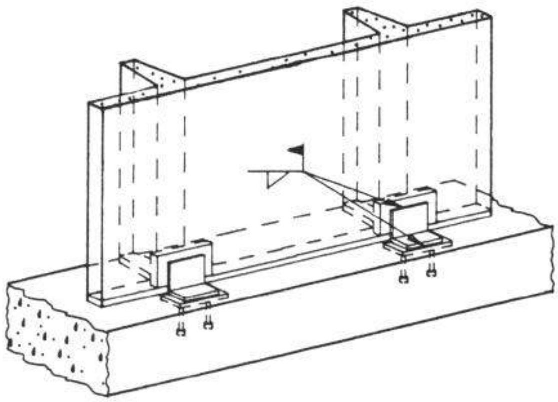
Disadvantages:
1. No connection for wall panel during erection.
2. Projecting dowels from wall panels can cause difficulties during fabrication.

5.2.11.5 Post-Tensioned Wall to Foundation Connection (WF8)

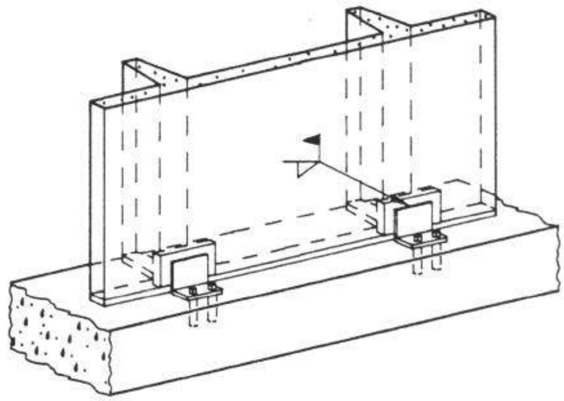
Vertical post-tensioning bars are installed in the foundation and continue through ducts in the wall panels. The bars may be coupled at the top of the foundation depending on erection considerations.

Features:
1. Vertical post-tensioning can be used to resist uplift forces.
2. Moment resistance is achieved.

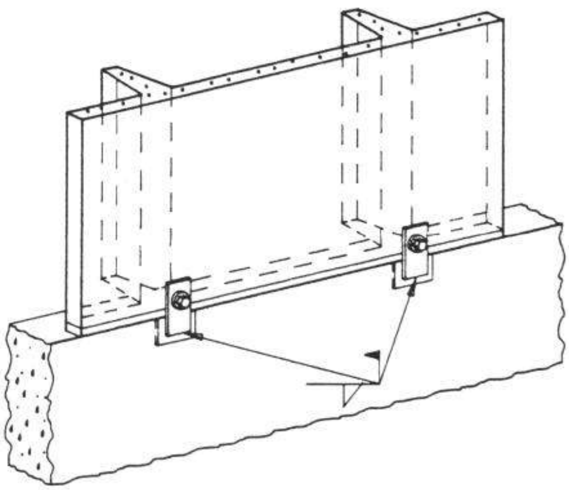
Disadvantages:
1. Bar, duct and hardware placement accuracy in foundation and wall panels is critical.
2. There is no positive connection until the bar is tensioned.



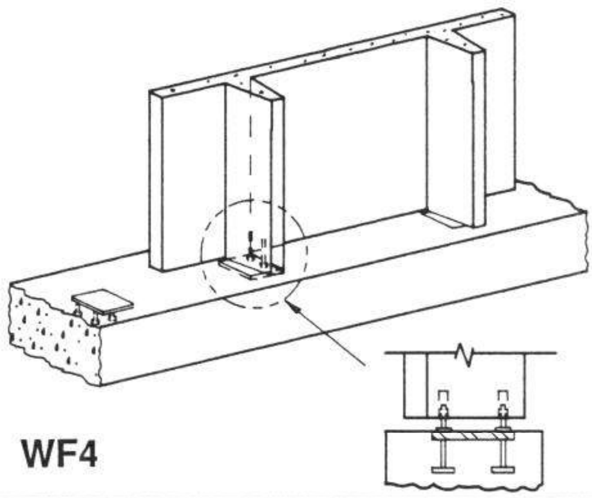
WF1



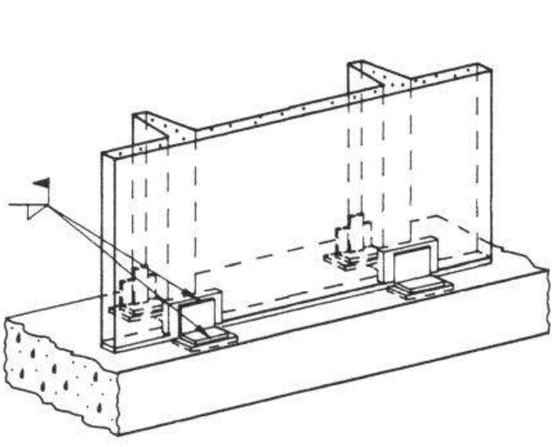
WF2



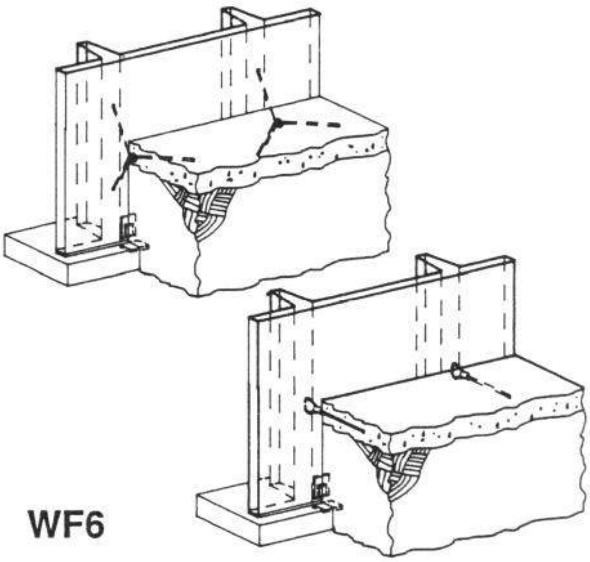
WF3



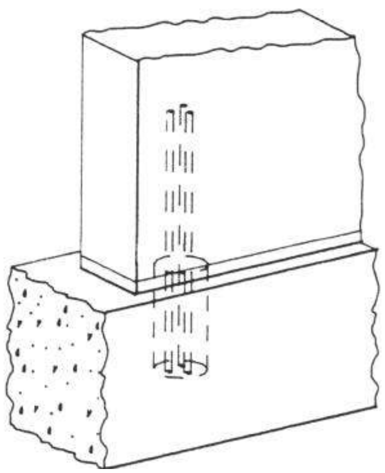
WF4



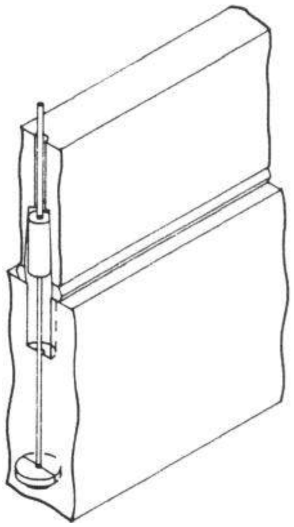
WF5



WF6



WF7



WF8

5.2.12 Stair to Landing Connections (SL)

Precast concrete stairs can be produced with integral landings or they may require separate landings. When landings are integral with the stairs, connections from the landing to supports are necessary. Generally, the support is a bearing wall, either precast or cast-in-place. Embedments or corbels are provided in the wall and attachment hardware is cast into the edge of the landing (SL1-SL2). Connections are designed to minimize crane setting time and are completed with field welding. A thin topping may be placed to obtain a good walking surface.

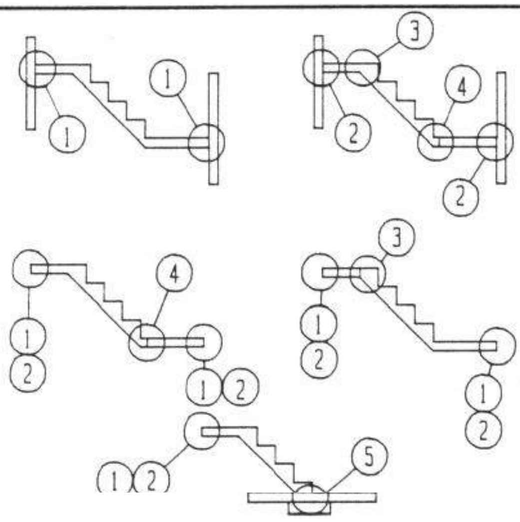
When landings are separate, they must be joined to the stair sections. The top stair may be recessed so that connections will be hidden when a topping slab is cast (SL3-SL4). The bottom stair usually rests on a footing so that the stair is simply set on shims with no welding required (SL5). When the lower floor slab is cast, the stair is securely positioned.

Features:

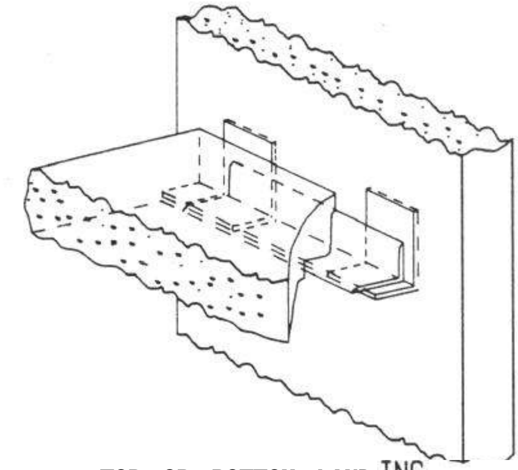
1. Quick, easy erection is attained, tolerances are adequate.
2. Joints can be located either at wall junctions or on continuous walls.

Disadvantages:

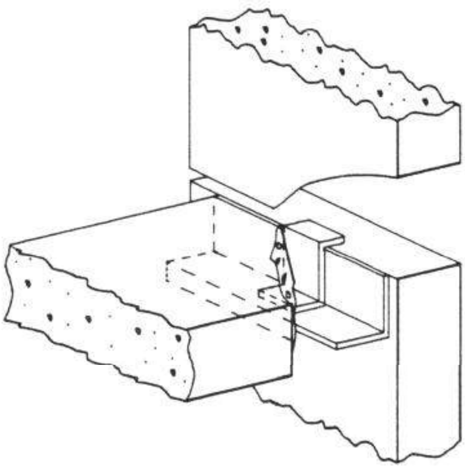
1. Connections are exposed to view from underneath unless special grouting is done. Fireproofing may be required.
2. Plate locations in supporting structure are critical.
3. A thin topping may be necessary.
4. Stairs with integral landings require special formwork.



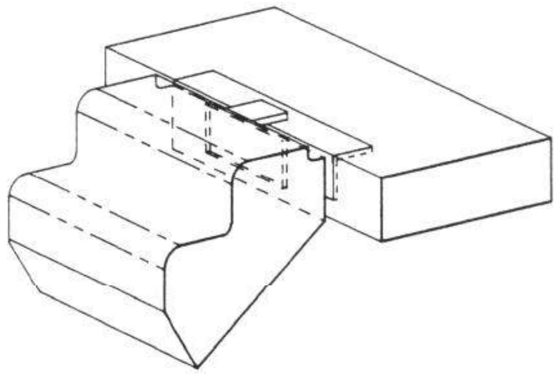
KEY TO DETAILS



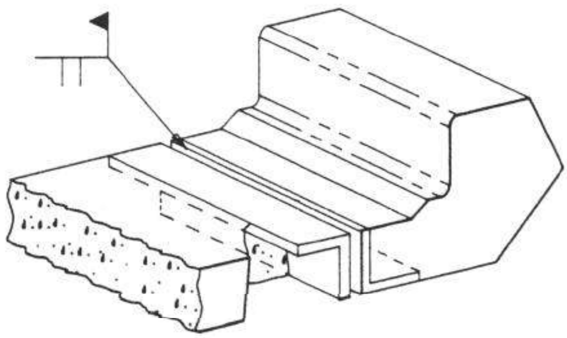
SL1 TOP OR BOTTOM LANDING AT CONTINUOUS WALL



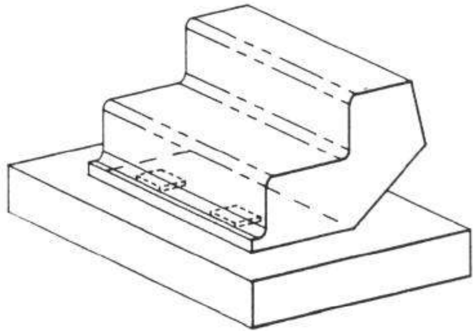
SL2 TOP OR BOTTOM LANDING AT WALL JOINT



SL3 TOP OF STAIR AT SEPARATE LANDING



SL4 BOTTOM OF STAIR AT SEPARATE LANDING



SL5 BOTTOM OF STAIR AT FOOTING OR LANDING

5.3 Architectural Precast Concrete Connections

The versatility of architectural precast concrete has led to its rapid growth, not only as an enclosure material (cladding) where shape and finish are of primary consideration, but also as a structural material where attractive appearance is combined with load bearing function. It has also been effectively used as shear walls for resisting lateral loads and as beam struts between lateral load resisting elements.

Regardless of whether an architectural precast element is used in a load bearing or a non-load bearing function, various forces must be considered in its design. In non-load bearing applications, a cladding panel must resist its self weight and all other appropriate forces, such as earthquake forces, forces due to restraint of volume changes and support system movement, as well as forces due to wind, snow and construction loads. If the panel is load bearing, then in addition to the above, it must also resist and transferdead and live loads imposed on it by the supported structural members. These forces are transferred by the architectural precast element through its connections to the supporting structure.

Once the loads are established and load transfer path identified, the design of the connections is based on concepts and design procedures given in earlier chapters of this Manual. However, there are several considerations which are unique to the design of architectural precast concrete connections. Thus, even though there is some duplication of previously covered material, a general discussion is given in the following paragraphs which attempts to bring together the various items pertinent to the architectural precast concrete connections. This general discussion is followed with typical details for various applications. These applications include the following broad categories:

- Bearing (Direct and Eccentric) — DB, EB
- Tie-Back (Bolted and Welded) — BT, WT
- Alignment (Bolted and Welded) — BA, WA
- Column and Beam Cover — CC, BC
- Soffit Hanger — SH
- Masonry Tie-Back — MT
- Seismic Shear Plate — SP
- Unique Conditions and Solutions — UCS

Some of the fundamental points that should be considered in the design of architectural precast concrete connections are:

(1) Provide for a simple and direct load transfer path with a minimum number of connections per panel, and a minimum number of load transfer mechanisms within a connection. A connection system which renders the panel to be statically determinate is preferable because the forces can be reliably calculated. It also facilitates accomodation of volume change movements. A discussion of load transfer mechanisms within a connection is given in Chapt. 2 (Sect. 2.2).

(2) Provide sufficient ductility in the connections to preclude brittle failures.

(3) Recognize the interdependency of behavior of panel connection and the supporting frame.

(4) Standardize connection details as much as possible. Standardization not only facilitates production and erection but also reduces the chance for error.

(5) Protect connections from corrosion and fire.

(6) Provide for adequate tolerances and clearances (see Sect. 1.5).

(7) Plan for the shortest possible crane hook-up time.

These design requirements pose aconsiderable challenge in that all of these must be considered separately as well as interactively to arrive at the best possible solution. It is not uncommon that a great deal of attention is paid to the consideration of loads while other factors, such as volume change, compatibility with frame movements, ductility and tolerances receive inadequate attention.

In high seismic areas, the most common application of architectural precast concrete is as cladding panels. The Uniform Building Code(17) requires that "Precast or prefabricated non-bearing, non-shearwallpanelsorsimilarelementswhichare attached to or enclose the exterior shall be designed to resist the forces and shall accommodate movements of the structure resulting from lateral forces or temperature changes."

For seismic forces, the Uniform Building Code requires that the body of the connector be designed for a force equal to 1.33 times the required panel force and that it be ductile. Furthermore, to ensure that failure would initiate in the body of the connector and thus be ductile, the Uniform Building Code requires that all fasteners of the connection system be designed for a force equal to four times the required panel force. Design for such elevated loads requires careful consideration of anchorage of the connectors to concrete to avoid premature and sudden failures. This generally leads many Designersto specify confining hoops (such as shown