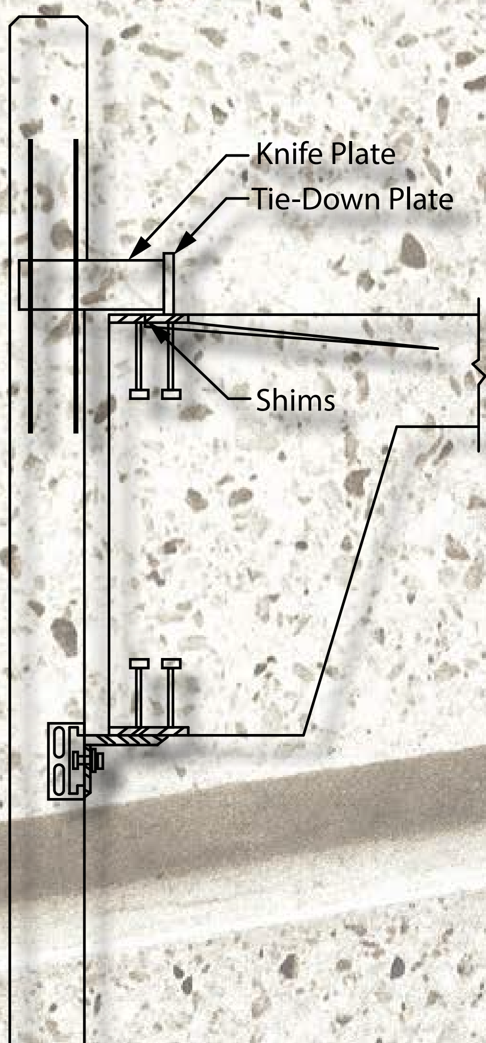
PCI Precast/Prestressed Concrete Institute

Connections for Architectural Precast Concrete



designer's notebook

CONNECTIONS FOR ARCHITECTURAL PRECAST CONCRETE

Connections are a significant design consideration that influences safety, performance, and economy of architectural precast concrete enclosure systems. Many different connection details may be required to accommodate the multitude of sizes and shapes of precast concrete units and varying support conditions.

The purpose of this article is to provide connection design concepts and other considerations to Architects. While connection design is normally delegated to the precast concrete supplier, design criteria and load paths must be specified by the Structural Engineer of Record (SER) and the Architect must be aware of the impact of connections on final detailing.

Whether an architectural precast concrete element is used in a loadbearing or a non-loadbearing application, various forces must be considered in connection design. In non-loadbearing applications, a cladding panel must resist its self weight and all other appropriate forces and loads, such as seismic, wind, snow, restraint of volume changes and effects of support system movement, construction loads, loads from adjacent materials, and any other specified loads. These loads and forces are transferred by the architectural precast concrete element through connections to supporting structure. If a panel is loadbearing, then in addition to the above, some connections must also resist and transfer dead and live loads imposed on it by floor and roof elements.

A major advantage of precast concrete construction is rapid installation. To fully realize this benefit and to maximize economy, field connections should be simple, repetitious, and easy to install. Precast concrete suppliers and erectors have developed preferred connections over the years that suit particular production and/or installation techniques.

Connections should comply with local building codes and satisfy functional and aesthetic requirements, such as recessing for flush floors and/or exposed ceilings. General concepts governing the design, performance, and material requirements of connections can be formulated. For the most effective design, along with efficient connection details, it is recommended that the designer coordinate connection concepts with a precast concrete manufacturer prior to finalizing the plans.

Terminology: The following describes terms common to the precast concrete industry. A precast concrete unit is used to generically represent a wall panel, window panel, spandrel, or column cover that is attached to the main building **structure**. A **connection** is the element that is used to make the attachment of the unit to the structure and will consist of parts embedded in concrete and parts that are field installed, each of which may be called a **connector**. The **body** is the main part of the connection that bridges between a unit and the structure. **Fasteners** are connectors such as bolts or welds used to attach the body to other portions of the connection. The **seat** or **haunch** is the projecting body of a connection from a precast concrete unit upon which the weight of the unit is supported. A **bracket** or **outrigger** is a concrete or steel element projecting from a column or edge beam that supports the seat or haunch from a precast concrete unit and transfers load to the structure. **Shear plates** are field welded connectors that primarily transfer in-plane or out-of-plane horizontal forces to the structure. **Tiebacks** are connections that resist out-of-plane forces due to wind, seismic, and the effect of eccentricity between vertical load and the point of support. **Anchors** are parts of a connection that are embedded in concrete, either in the precast concrete unit or main structure, to transmit forces into the concrete. Anchors typically are headed studs, bolts, or deformed bar anchors. **Post-installed anchors** include expansion or adhesive anchors. **Embedments** are items, usually steel fabrications with anchors, cast into concrete. **Inserts** are usually proprietary items cast into concrete provided in many configurations to serve many different functions. **Adjustable inserts** are proprietary assemblies that have internal adjustability.

Design Coordination

A successful project requires close cooperation and coordination between all participants. With current construction complexity, it is essential to have design input by the precast concrete supplier at an early stage. The supplier will be able to provide suggestions and designs that optimize panel size and joint locations for economy and efficiency.

In the most common contractual arrangement, final structural design of the precast concrete units and final design and detailing of connections of the units to the structure are performed by a Specialty Structural Engineer (SSE) either working for or contracted with the precast concrete supplier. It is imperative that design responsibility be clearly defined in the contract documents.

If the SSE is specified as responsible for the final precast concrete design, the applicable code, design loads, and performance criteria must be specified by the SER in the construction documents. For best coordination, the SER should describe intended load paths. This is best communicated by showing conceptual connections and connection points in the construction documents. For steel frame structures, the SER should determine how far in advance the final connections of the frame and/or floor slabs must be completed prior to precast concrete panel erection. For cast-in-place concrete structures, the SER should determine minimum concrete strength necessary prior to erecting precast concrete units.

The SER will have responsibility to design the supporting and bracing structure to adequately resist the connection forces generated in the precast concrete system. This should include both strength and stiffness. The strength requirement is obvious. In the erection of the precast concrete units, it is assumed that the units can be aligned in accordance with specified erection tolerances when the units are first set. Hence, adequate stiffness is defined by structure deformations that allow erection within tolerance. The best example is multiple panels supported by a beam in a single bay. Sufficient stiffness should be provided so the first panel set does not have to be realigned as subsequent panels are set.

Gravity supports for precast concrete panels ideally transmit vertical load directly to the building columns. However, it is common to locate gravity connections adjacent to columns due to geometric or detailing constraints. In this case, vertical load will be applied to the floor or roof deck structure. Two details are possible. If the gravity connections can be concealed in the interior finish, load will be applied to the edge of the floor slab or roof deck. This generally means that the deck must cantilever some distance over the edge beam. In the precast connection design, it is assumed that the deck cantilever has the strength and stiffness necessary to carry the vertical load and allow panel installation within specified erection tolerances. If the finish will not conceal the gravity connection, a penetration in the edge of the deck will be required and a bracket will have to be provided from the side of the edge beam to accept the gravity load. In this case, eccentric load will be applied to the edge beam and it is assumed that sufficient strength and both flexural and torsional stiffness is provided in the edge beam to carry the vertical load and allow panel installation within the specified erection tolerance. Supplemental framing may be required to accomplish this. The SSE will not evaluate the supporting structure to determine the need for such supplemental framing. This supplemental framing should be supplied and installed with the supporting structure so it is in place at the time of the precast concrete installation. It is generally not feasible to extend gravity connections to the centerline of the edge beam since interior finishes will not cover such a detail.

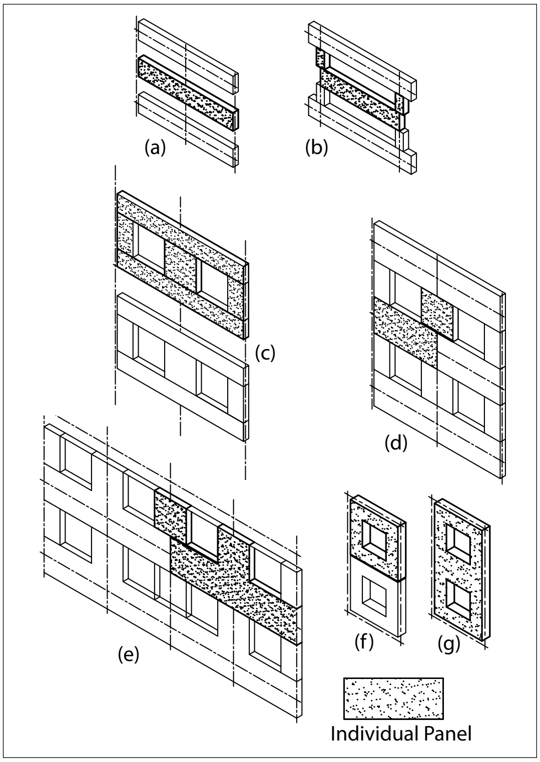


Figure 1 Typical arrangement of precast concrete panels.

Another important role of the SER is to review the precast concrete erection drawings and design work for compatibility with the original intent of the structural design. This is the final opportunity to verify that the SSE has properly interpreted the intent of the construction documents.

Connection Fundamentals

The first step in developing an architectural precast concrete project is establishing panel jointing to use economical panel sizes and coordinate with the floor and column locations in the structure. The second step is to develop the concepts of the connection system so the load points on the structure are coordinated and directions of connection rigidity versus directions of connection flexibility can be set. Beyond these two steps, the work is in the design and detailing.

Figure 1 shows a few of the many possible panel configurations for a wall. Figure 2 illustrates some common connection arrangements for different panel types. Figure 2(a) represents a typical floor-to-floor wall unit. Figures 2(b) and (c) show possible connection locations for a narrow unit, such as a column cover, and Fig. 2(d) shows a wide unit, such as a spandrel. As shown in Fig. 2, panel connections generally consist of two bearing connections and a minimum of four tieback connections. Bearing connections and tieback connections are sometimes combined. Figure 2(d) also shows optional intermediate tieback connections. The primary purpose of intermediate tiebacks is to control concrete tensile stresses due to out-of-plane bending of a panel. These connections may also be used to resist in-plane seismic forces because the connections can be rigid in the direction parallel to the length of the panel without restraining panel shortening due to temperature or shrinkage.

The connection system should not include more than two bearing connections for each panel. Precast concrete panels are very rigid and will not allow a reliable distribution of gravity loads to more than two bearing points. The bearing connections for a given panel should also be located at the same elevation so deflections of supporting frame members do not cause distribution of gravity load different than planned.

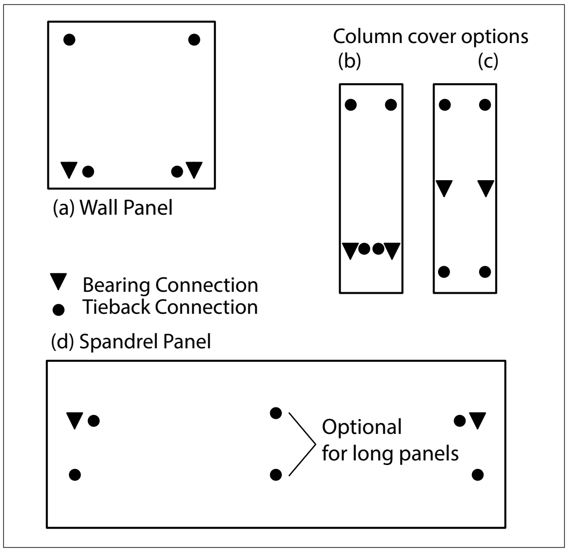


Figure 2 Typical cladding panel connector locations.

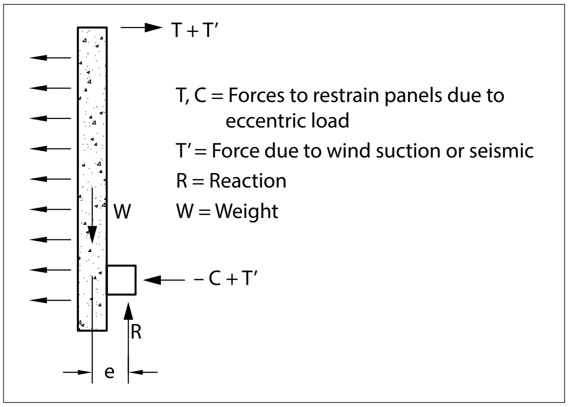


Figure 3 Forces on a panel subjected to wind suction or seismic and eccentric loading.

A panel may be subjected to gravity loads, lateral loads normal to the plane of the panel, and lateral loads in the plane of the panel. For vertical load and out-of-plane load, Fig. 3 illustrates how forces are resolved in gravity and tieback connections to resist the effects of the loads. Note that the tieback connections get components of force directly from the out-of-plane loads plus stabilize the panel when the vertical load is eccentric from the point of vertical support.

As will be discussed in more detail later in the article, panels and structural systems will move due to time dependent changes in the materials, environmental effects, or loads. While connections must have strength and stiffness in the directions that forces are applied, common connection detailing will allow movements in other directions to avoid generating large forces if those movements were restrained. Allowance for movement in connections requires consideration of in-plane movements both horizontally and vertically. Generally, movements out-of-plane are not considered because forces will have to be resisted in the out-of-plane direction. Movement can be allowed by sliding, for example bearings sliding on shim stacks or bolts sliding in slotted holes, or by flexing where a ductile steel element is allowed to bend.

A series of typical connection details with an explanation of the connection function are presented at the end of this article.

Connection Hardware and Materials

Hardware in connections will generally consist of an embedment in the precast concrete unit, an embedment in the supporting structure, a connector element to bridge between the precast concrete unit and the supporting structure, and fastening devices. Anchors into concrete usually consist of reinforcing bars, deformed bar anchors, and headed stud anchors. These anchors are welded to steel shapes such as plates, angles, channels, hollow structural sections, or fabricated steel assemblies to make up an embedment to be cast into concrete. Embedments into the concrete might also include proprietary threaded or weldable inserts.

The connector elements that bridge between the precast concrete unit and the supporting structure are usually flat plates, angles, special steel fabrications, or threaded rods. In welded connections, these elements may be plain pieces. In bolted connections, slotted or oversize holes are generally provided to accommodate field tolerances or provide sliding elements to accommodate movements.

Fastening devices in connections primarily consist of welds or bolts. However, post-installed anchors or grout are occasionally used. Shims are not considered fasteners, but do serve as load transfer devices.

Welded connections are structurally efficient and easily adapted to varying field conditions. Welded connections can be completed only after final alignment.

Hoisting and setting time is critical for economical erection. Welding that must be executed prior to the release of the unit from hoisting equipment should be minimized.

Welding should be performed in accordance with the erection drawings by personnel that have been certified for the welding procedures specified. The type, size, length and location of welds, and any critical sequences should be clearly defined on the erection drawings. All welding, including tack welds, should be made in accordance with the applicable provisions of the American Welding Society (AWS).

Welding on galvanized hardware requires proper procedures to avoid contamination of the weld metal. Cold galvanizing or zinc-rich paint should be applied over welded areas to replace removed galvanizing.

When welding is performed on embedments in concrete, thermal expansion and distortion of the steel may induce cracking or spalling in the surrounding concrete. The extent of cracking and distortion of the metal is dependent on the amount of heat generated during welding and the stiffness of the steel element. Using thicker steel sections can minimize distortion. A minimum of 1/4 in. (6 mm) is recommended for plates. Heat may be reduced by:

1. Use of low-heat welding rods of small diameter.

2. Use of intermittent, rather than continuous, welds.

3. Use of smaller welds and multiple passes.

Some designers specify use of stainless steel connections in highly corrosive environments to prevent long-term corrosion. Welding of stainless steel produces more heat than conventional welding. The increased heat input, plus a higher coefficient of thermal expansion, will create greater cracking potential in the concrete adjacent to embedments. A good detailing solution is to keep embedment edges isolated from adjacent concrete to allow expansion during welding without spalling the concrete. Sealants, sealing foams, clay, or other materials placed around plate edges prior to casting concrete can be used to create this isolation.

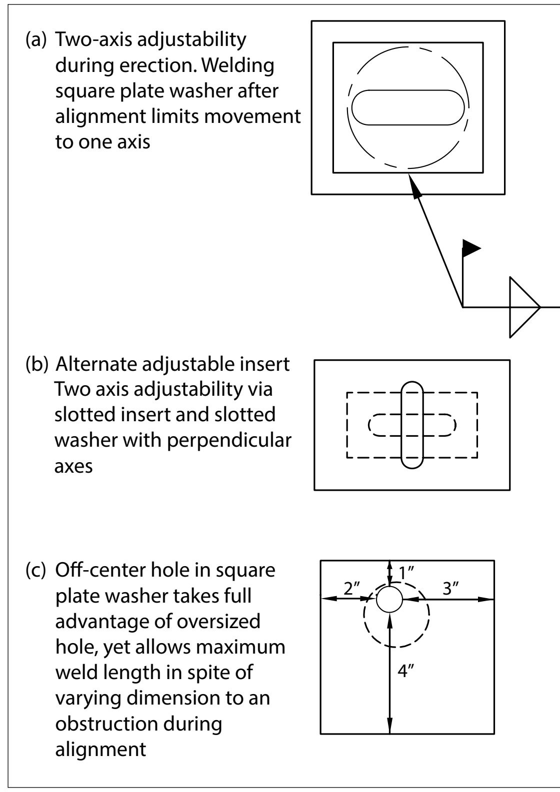


Figure 4 Slotted or oversized holes.

Bolted connections often simplify and speed up erection operations because the connections can resist force immediately upon bolt installation allowing a crane to be released more quickly. When considered in the connection detailing, final alignment and adjustment of the panel can be made at a later time.

Standard bolt sizes used in the industry are 3/4, 1, or 11/4 in. (19, 25, or 32 mm) diameter. High strength bolts are not commonly used. Coil thread stock or coil bolts, which have a coarse thread, are also used. The coarse thread allows quicker installation and is less prone to damage.

Bolted connections must allow for construction tolerances. Slotted or oversized holes accommodate variation and tolerance. (Fig. 4). When slotted holes are also intended to allow structure movements by bolt sliding, the slots must be long enough to account for tolerances plus the amount of planned movement. Plate washers with off-center holes allow maximum flexibility without requiring separate size parts (Fig. 4[c]). For sliding connections, the bolts should be snug, but not so tight to restrict movement within a slot. Low friction washers (Teflon or nylon) may be used to improve movement capability. Roughness at sheared or flame-cut edges should be removed. Bolts should be properly secured, with lock washers, liquid thread locker, or other means to prevent tightening or loosening.

Post-installed anchors, including expansion anchors and adhesive anchors, are often used as connections at foundations or for corrective measures when cast-in inserts are mislocated or omitted. Design provisions are provided in ACI 318, *Building Code Requirements for Structural Concrete*, and may be used if post-installed anchors are qualified in accordance with ACI 355.2 or ACI 355.4. Installation must be in strict conformance with the manufacturer's printed installation instructions.

Expansion anchors are inserted into drilled holes in hardened concrete. Performance of these anchors is dependent on the quality of field workmanship. Strength is obtained by tightening the bolt or nut, thus expanding parts of the anchor, which exert lateral pressure on the concrete. Performance of expansion anchors when subjected to stress reversals, vibrations, or earthquake loading is such that the designer should carefully consider their use for these load conditions.

Adhesive anchors depend on bond of the adhesive to the anchor and bond of the adhesive to the concrete for force transfer. The adhesive may exhibit reduced bond strength at temperatures in the 140 to 150°F (60 to 66°C) range. Such temperatures may be experienced in warm climates, particularly in façade panels with dark aggregates. Similarly, adhesive anchors may not be allowed in fire-rated connection assemblies.

Grouting or drypacking of connections is not widely used, apart from base plates or loadbearing units. The difficulty in maintaining exact elevations and the inability to allow movements and still maintain weather tightness must also be considered. Grouting should be used carefully when installed during temperatures below or near freezing. Units with joints that are to be drypacked are usually supported with shims or leveling bolts until drypack has achieved adequate strength. Shims used for this purpose should be subsequently removed to prevent them from permanently carrying the load or to facilitate joint sealant installation. A dry-packed joint requires a joint wider than 1 in. (25 mm) for best results.

Grouted dowel/anchor bolt connections depend on their diameter, embedded length, and bond developed. Placement of grout during erection usually slows down the erection process. Any necessary adjustment or movement that is made after initial set of the grout may destroy bond and reduce strength. It may be better to provide supplemental bolted connections to expedite erection.

Erection drawings should show the required grout strength:

1. Before erection can continue.

2. Before bracing can be removed.

3. At 28 days.

About AIA Learning Units

Please visit www.pci.org/elearning to read the complete article, as well as to take the test to qualify for 1.0 HSW Learning Unit.

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If you are new to the Registered Continuing Education Provider system, www.rcep.net will email you a welcome email when PCI uploads your data. That email will contain your account password. Your login name at www.rcep.net will be your email address, so you must include it when submitting your completed quiz.

Instructions

Review the learning objectives below.

Read the AIA Learning Units article. Note: The complete article is avaliable at www.pci.org/elearning.

Complete the online test. You will need to answer at least 80% of the questions correctly to receive the 1.0 HSW Learning Units associated with this educational program.

Learning Objectives:

1. Discuss the various types of precast concrete connections.
2. Understand the design considerations for precast concrete connections.
3. Explain the precast panel-connection-structure interaction.
4. Describe the necessary tolerances and product interfacing.
5. List the broad categories of connection details.

Questions: contact Education Dept. - Alex Morales, (312) 786-0300; Email amorales@pci.org