temperatures. Welded connections are also difficult to make where corrosion resistant connections are required.

FLEXIBILITY OF CONNECTIONS FOR ERECTION AND INSTALLATION

Architects and engineers do not always realize the problems experienced in the field in erecting precast wall units with anchors and connecting materials cast to close tolerance in the precast concrete panel that must mate with inserts and anchors cast to a more liberal tolerance in the building frame in the field.

Panel connections should be designed not only to have sufficient tolerance in vertical and lateral adjustment, but also to make proper allowances for field erection tolerances and for the resulting forces and movements due to eccentric loading that should be anticipated and designed for in the connection anchors and inserts. In many cases, the panel connection must also be designed to allow for differential movement between wall panel and building frame to minimize the transfer of building loads to the wall panels.

Wherever possible, good practice of connection design should provide a positive seating or shelf to support the panel dead weight in place and to allow for proper bolting with the panel supported or seated instead of hung from connection angles and clamps. Clip angles and clamps should be used to primarily resist the lateral loads and forces, and not for supporting vertical loads of the panels. Several examples of panel connection details indicating seating methods for vertical loads and clip angles for lateral loads are shown in Figs. 8-4, 8-5, and 8-6.

CORROSION RESISTANCE OF CONNECTING MATERIALS

Corrosion is also an important factor in connection design and the selection of material for precast wall panels connection assemblies is of prime importance.

It is becoming more apparent that connecting materials that support precast wall units are vulnerable to long term corrosion even in those areas where the connections are not exposed to atmospheric conditions, but are enclosed in the building skin with such backup materials as brick, block, or plaster.

Generally the wall panel unit and the load carried by wall panel connections is much greater than those anchors and connections used for brick, block, marble or stone facings. Therefore, the possibility of connection failure due to corrosion of panel connections in a nonexposed area can be considered vulnerable over a long period. Corrosion can occur in enclosed areas where moisture or condensation is possible, ventilation is at a minimum and periodic inspection of panel connections is impossible.

The use of stainless steel connections or corrosion resistant coatings, such as galvinizing or cadmium plating is considered good practice and is finding prominence to prevent insert or connection failure in later years.

Protective coatings used on panel connections should be done in such a manner to prevent embrittlement or loss of strength of connection. Mating components of connections should also be plated or selected from materials that will prevent corrosion induced by electrolytic action.

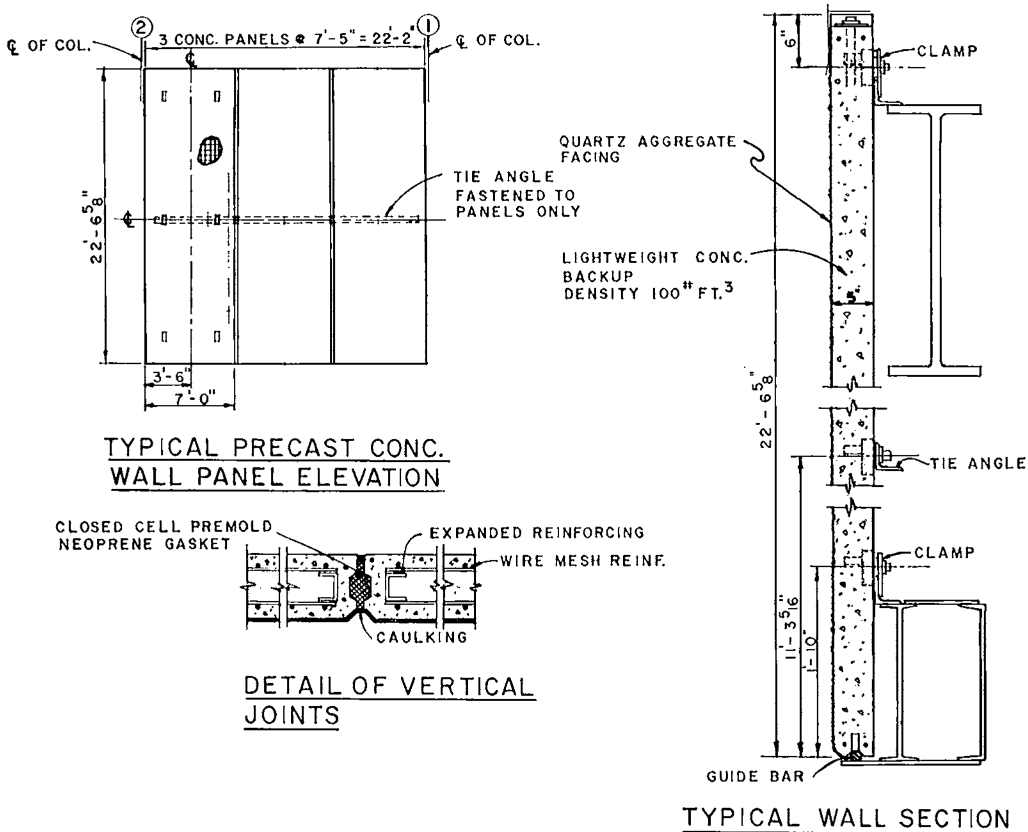

Fig. 8-6—Panel support details for precast concrete panels supported by steel frame. Note adjustable clamps and clip angles to hold panels laterally and positive support seat panel vertical loads

SUGGESTED STANDARDS AND GOOD PRACTICE FOR DESIGN OF PRECAST CONCRETE WALL PANEL CONNECTIONS AND INSERTS

1. Panel connections should be designed to positively seat the panel and never to hang the panel from insert anchors or connections, except for small panels. Clips, clamps, or brackets should be used for lateral forces or loads.

2. Panel connections should be designed to allow for panel movement after erection due to concrete shrinkage, temperature, and moisture differential as well as differential movement or drift between building frame and precast wall unit.

3. In earthquake or seismic zones, panel connections assemblies should be designed for horizontal, lateral, and vertical load of panel and the connections should allow for frame movement and story drift. Inserts and anchors should be fastened or welded to panel reinforcement.

4. Panel inserts and connections should be designed to have an ultimate strength such that when panels are installed under the most unfavorable permissible conditions of construction tolerance, the connection assembly will support at least twice the ultimate design panel loads.

5. Inserts and anchors used for handling and erection of precast concrete panels should be designed for at least 100 percent impact.

6. Inserts, anchors, and connection should be made from materials that are permanently ductile. Brittle materials, such as grey iron castings, should be avoided in inserts, anchors, and connections.

7. Design the panel connections to have vertical, horizontal, and lateral adjustments if proper connection of precast panels to supporting frame is to be properly made in the field. Allow at least 1 in. clearance between precast wall panel and the structural supporting frame for erection and alignment of wall units.

8. Panel anchors, inserts, and connections should be made from noncorrosive materials or the materials should be galvanized or cadmium plated to resist corrosion even for connections that are not exposed to the atmosphere.

9. Panel connections should be fireproofed as required by local codes or to a minimum fire resistance rating equivalent to that of the precast wall panel.

RESEARCH AND TESTING OF CONNECTIONS AND INSERTS

To date, most research and testing of concrete inserts and connections has been limited to efforts of individual wall panel fabricators or concrete insert or accessories manufacturers. Many types of concrete anchors on the market today lack even simple test data to substantiate the claims of the manufacturer. In most cases, the research and methods of testing have not been standardized and follows no set pattern of test procedure.

Based on experience and available test data, the modes of failure of concrete inserts and panel connections are many and vary considerably. These modes of failure take the form of concrete failure in shear bearing or bond, or the insert or anchor fails in tension, shear, bending, or a combination of these modes in which connection assembly fails as a unit.

In many cases, failure of panel connections have been attributed to concrete strength or embedment or the type of material used for the connection.

ACI Committee 533, Precast Concrete Wall Panels, recently instituted an investigation on the feasibility of a research and testing program. The results would be used as a basis for standardizing the method of testing and recommendation for concrete, anchor, insert, and connection assembly design for precast concrete wall panels.

It is hoped that this research program will develop and be used for the, "Design Recommendations of Precast Concrete Wall Panels," to be submitted by ACI Committee 533, to the industry.

PAPER SP 22-9

The Structural Anchorage of Precast Prestressed Concrete

By THOMAS A. HANSON

The major types of connections for precast-prestressed concrete are described briefly. These include gravity connections, welded connections, bolted connections, post-tensioned connections, cast-in-place connections, and dowelled connections. The connection examples include connecting column bases, connecting beams to columns, connecting beams to girders, and bearing wall connections. Areas needing further research to develop better connection design procedures are listed.

Keywords: anchorage; beams (structural); bearing walls; bolted connections; bolts; cast-in-place connections; columns (structural); connections; dowels; girders; post-tensioning; precast concrete; prestressed concrete; structural design; welded connections.

■ THE ADVENT OF PRESTRESSING in the United States was accompanied by many public displays of the strength and elasticity of the new kind of concrete. The first bridges and buildings utilized simple spans, in which the prestressed members merely rested on supports, with provisions for rotation, expansion, and contraction. Before long, however, more sophisticated structures were being designed, in which complete frames were composed of precast-prestressed concrete members. As such structures became taller and more complex, there developed a need for further knowledge in methods of anchoring members to foundations and walls, and to other members. Recognizing this need, the Prestressed Concrete Institute organized a committee, with the writer as chairman, to survey the details in use, and to compile a series of connections recommended for various conditions.

Major factors affecting anchorage

The following factors were considered when selecting the details surveyed:

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1. Structural Adequacy
2. Fabrication and erection cost
3. Tolerances for casting and erection
4. Low maintenance
5. Fire rating

Functions of connectors

The connections were first organized according to function, and then by actual methods and devices used to make the connection. Four distinct functions were chosen as follows:

1. Column base
2. Beam-to-column
3. Beam-to-girder
4. Bearing wall

Methods represented

Numerous connection methods were represented, including:

1. Gravity
2. Welding
3. Bolting
4. Post-tensioning
5. Cast-in-place
6. Dowelling

In 1963, the Prestressed Concrete Institute published a connections booklet which contains a wide variety of details for many applications. However, because of the special loadings and conditions of each project, the details were presented in schematic form, to be finally designed and drawn by the structural engineer. The following are pertinent examples of connections of various types which appear in the PCI booklet:

GRAVITY CONNECTIONS

Gravity connections are those in which a member merely bears on its support with little or no physical attachment, as shown in Fig. 9-1. Flexible bearing pads are normally used to provide an even load distribution, and to allow some rotation without damaging the members. A gravity-type connection is often best since it allows small movements due to temperature, shrinkage and creep. Because of its simplicity, the gravity connection is inexpensive to fabricate and erect.

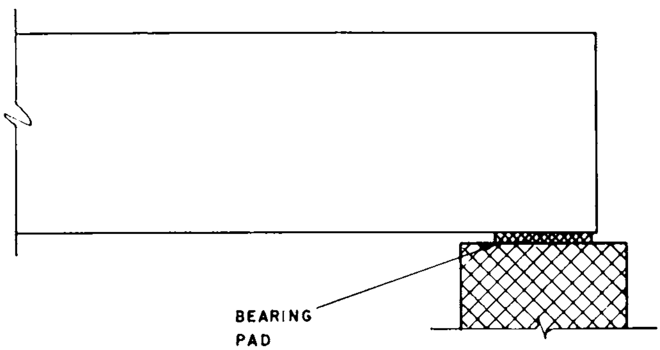

Fig. 9-1—Typical gravity connection detail

When using gravity connections, the designer must be careful to assure stability for wind, seismic, or construction loads. To obtain this stability, other connection types may have to be used at appropriate locations, or horizontal floor or roof diaphragms may transfer lateral loads to shear walls.

Stadium seating slabs can be fastened to the supporting beams with gravity connections. Along the sides of the cast-in-place beams, ledges can be provided to support the slabs. After the slabs are set, the ends are grouted to fill the tolerance gap and to prevent future movements.

Radial beams bearing on a round core wall can be fixed with gravity connections. In this case, the closed ring of the roof slabs maintains the shape of the roof diaphragm, and masonry to be placed between the beam ends transfers lateral loads into the circular shear wall.

Fig. 9-2—Gravity Connection: A-frames bearing on precast trusses

Gravity connections were also used where the A-frames bear on the precast-prestressed trusses, as shown in Fig. 9-2. It was anticipated that the roof members on this project would creep downward over a period of years, with a corresponding outward movement at the bearing point. By using lubricated gravity connections, the trusses were not subjected to this lateral thrust. Bolts in slotted holes were used for erection stability, and lateral roof loads were transferred to the end walls by a roof diaphragm.

WELDED CONNECTIONS

Depending on weld locations, welded connections can provide pinned ends, partial restraint, or full continuity.

In Fig. 9-3, for example, welds are made at the bottom of the beams to permit rotation of the beam ends. Here it is particularly important that axial tension in the beams (due to shrinkage and creep) is properly transmitted horizontally through the connection to the adjacent span. Inadequate horizontal ties on the beam weld plates can cause vertical cracks near the ends of the beam, resulting in a shear failure. Similarly, insufficient horizontal steel across the top of the column can cause vertical splitting of the column.

It is usually best to make welds at the top of roof members. Such a connection as shown in Fig. 9-4. By placing the members on flexible bear-

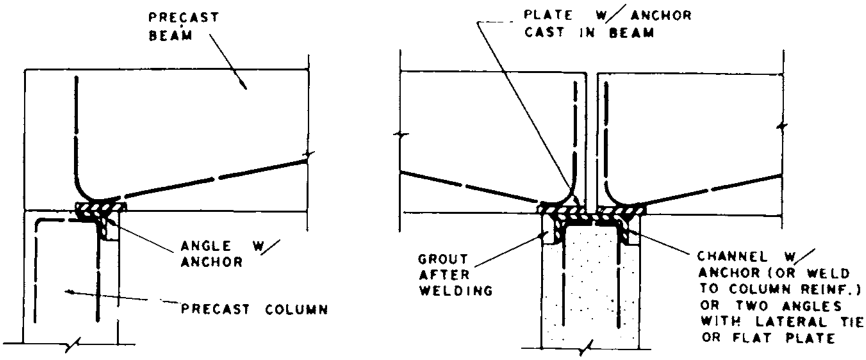

Fig. 9-3—Welded connection detail for simple spans

ing pads and omitting grout between the ends, the members are essentially free to rotate by pivoting about the top, causing no harm to the roof membrane.

Full continuity can be achieved by a combination of top welds and grout between the beam ends, as shown in Fig. 9-5. A similar connection can be made when a column extends through the joint. The shear is then transferred to the column through steel or concrete haunches on the column, or hangers embedded in the beam.

Beam continuity can also be achieved by allowing the beams to bypass the columns. A plate is cast into the beam face, an angle is cast into the column corner, and a shear weld is made between the two. Each component of the connection must be designed for the beam shear plus the stresses due to eccentricity of the loads.

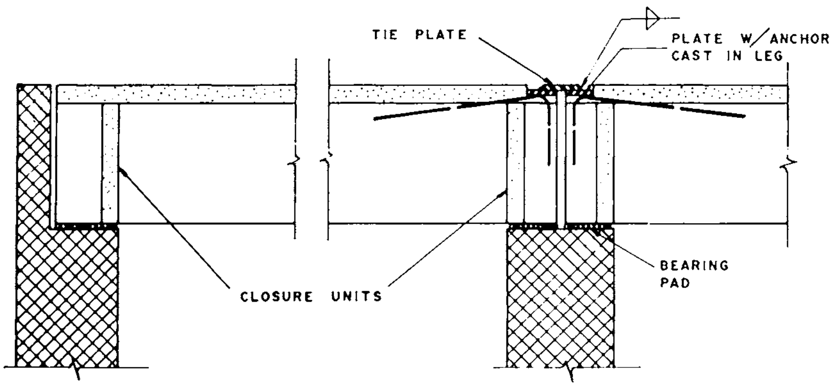

Fig. 9-4—Welded connection detail for roof members

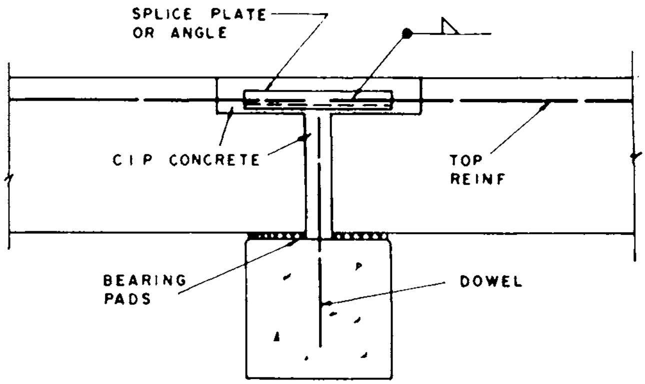

Fig. 9-5—Welded connection detail for continuous members

BOLTED CONNECTIONS

A main advantage of bolted connections is that the erection and attachment of members can be done quickly, resulting in reduced erection costs. The proper fitting of bolted connections, however, requires close casting tolerances. Bolts are used in shear or in tension, as illustrated in the following applications.

The connection in Fig. 9-6 utilizes bolts in shear. If top beam reinforcing is welded, the beams can be continuous, but this joint is more commonly used to connect lightly loaded precast struts. Horizontal slots should be used to allow greater casting tolerances. Also, after erection it is wise to weld the steel plates or the bolts.

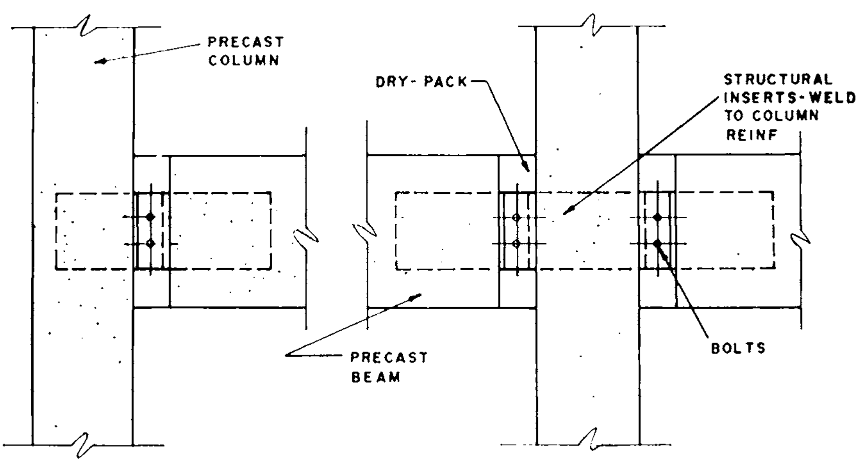

Fig. 9-6—Bolted connection with shear plates