

# Loadbearing Architectural Precast Concrete Wall Panels



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*Architectural precast concrete wall panels that act as loadbearing elements in a building are both a structurally efficient and economical means of transferring floor and roof loads through the structure and into the foundation. In many cases, this integration can also simplify construction and reduce costs. This article presents the many benefits that can be derived from using loadbearing architectural precast concrete walls in buildings. Discussed herein are the various shapes and sizes of wall panels, major design considerations, and when loadbearing or shear wall units should be the first design choice. The role of connections, shear walls, and the use of precast concrete as forms for cast-in-place concrete is explained. In general, the design methods and techniques presented in this article apply to buildings in both seismic and non-seismic areas. The latter part of this article shows how these design principles can be applied in practice in a variety of buildings. These examples illustrate the use of window wall panels, spandrels, and solid or sandwich wall panels as the loadbearing wall members. When all the advantages of using architectural precast concrete as loadbearing walls are added up, it makes good sense to use this structural form in building applications.*

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**L**oadbearing facades have both an aesthetic and structural function. In building practice, the most economical application of architectural precast concrete is as loadbearing structural elements. Loadbearing units become an integral part of the structure, taking the vertical and horizontal floor and roof loads, and/or transferring horizontal loads into shear walls or service cores. Such an arrangement

can be economical, not only from a structural design standpoint, but also from the viewpoint of overall construction. In some cases, the loadbearing elements also can contribute to the horizontal stability of the building.

Architectural precast concrete cladding is noted for its diversity of expression, as well as its desirable thermal, acoustic and fire-resistant properties. Commonly overlooked is

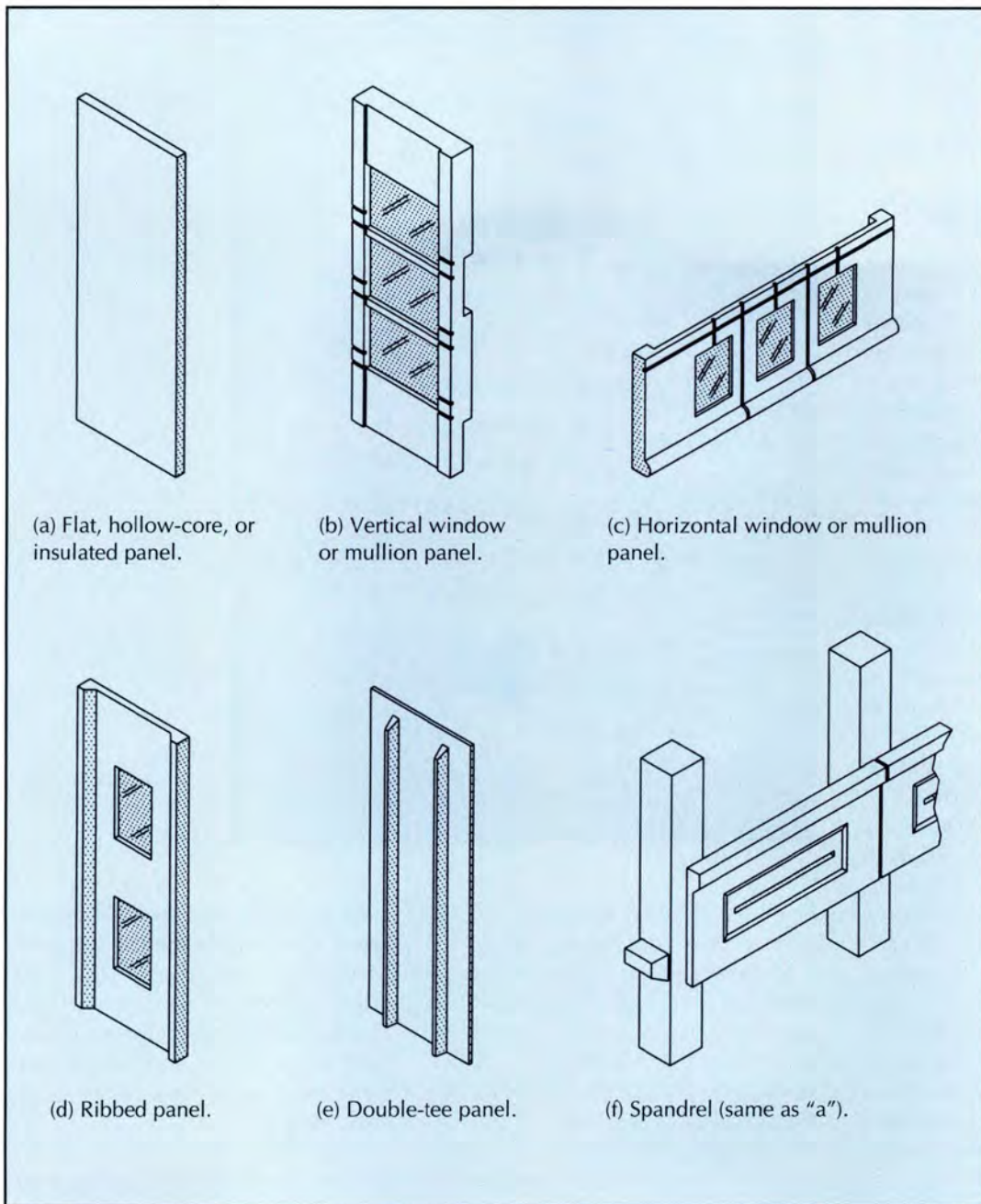


Fig. 1.  
Various types of architectural loadbearing wall panels.

the fact that concrete elements normally used for cladding applications, such as solid wall panels, window wall or spandrel panels, have considerable inherent structural capability.

In the case of low- or mid-rise structures, the amount of reinforcement required to handle and erect a precast component is often more than necessary for carrying imposed loads. Thus, with relatively few modifications, many cladding panels can function as loadbearing members. For taller buildings, additional reinforcement may be necessary for the lower level panels.

The slight increases in loadbearing wall panel cost (due to reinforcement

and connection requirements) can usually be more than offset by the elimination of a separate perimeter structural frame. Depending upon the application, the loadbearing panels also may reduce or eliminate a structural core or interior shear walls, particularly in buildings with a large ratio of wall-to-floor area. The increase in interior floor space gained by eliminating columns can be substantial and, depending on the floor plan, partition layout flexibility can be enhanced.

To take maximum advantage of loadbearing units, decisions as to their functions should be made before structural

design has progressed to a stage where revisions become costly. Cost savings tend to be greatest in low- to mid-rise structures of three to ten stories. As with all precast concrete applications, further economies can be realized if the panels are repetitive. Besides minimizing the number of casting forms necessary, repetitive panel designs enable repetitive connections.

Architectural loadbearing panels can be used effectively to renovate and rehabilitate old deteriorated structures. These panels can be used not only in all-precast structures but also in structural steel framed structures and cast-in-place concrete structures.

Guidance for using loadbearing architectural precast concrete wall panels can be found in Refs. 1 and 2. Other pertinent information on this subject can be found in the list of references.

## SHAPES AND SIZES

Architectural load carrying components can be provided in a variety of custom designed or standard section shapes. A wall system can be comprised of flat or curved panels (solid, hollow-core, or insulated) (see Figs. 1a and f), window or mullion panels (see Figs. 1b and c), ribbed panels (Fig. 1d), or a double-tee (see Fig. 1e). Each type of panel will readily accommodate openings for doors and windows. Fig. 1b, c, d and e illustrate various types of ribbed panels. The panel shown in Fig. 1c is a horizontal Vierendeel truss window mullion panel, while the other panels are vertical window mullion panels. Fig. 1f shows an exterior horizontal spandrel as part of a column-wall system.\*

In the interest of both economy and function, precast panels should be as large as practical, while considering production efficiency and transportation and erection limitations. By making panels as large as possible, numerous economies are realized — the number of panels needed is reduced, fewer joints (waterproofing requirements), lower erection cost, and fewer connections are required. Panels may be designed for use in either vertical or horizontal positions.

For low-rise buildings, by spanning loadbearing panels vertically through several stories, complex connection details can be minimized, and consequently the economic advantages of loadbearing wall panels are increased.

For high-rise buildings, it is normally more practical to work with single-story horizontal panels connected at each floor level. The elements can be more slender, simplifying the erection.

Ref. 3 discusses the use of horizontal panels on the 16-story United Bank Tower in Colorado Springs, Colorado (see Fig. 2). The single-story panels are typically 14 ft 6 in. x 16 ft x 8 in. (4.42 x 4.88 m x 203 mm) thick with 13 x 30



Fig. 2. United Bank Tower, Colorado Springs, Colorado.

in. (330 x 762 mm) monolithically cast pilasters at the ends (see Fig. 3).

Multistory panels usually do not exceed 45 ft (13.7 m) in height — the maximum transportable length in many states (see Fig. 4). Panels should be designed in specific widths to suit the building's modular planning. When such a building is designed properly, the economic advantages of loadbearing wall panels are significantly increased.

Panel dimensions generally are governed by architectural requirements. Most shapes, textures, and surface finishes commonly associated with cladding are possible, provided structural integrity and other technical requirements can be satisfied at the same time.

Load uniformity is one of the important advantages for high-rise, loadbearing panel structures where the bearing walls also serve as shear



Fig. 3. Single-story wall panels.

\*In most cases, when the term "panel" is used in the text, it refers to all panels shown in Fig. 1.

walls. It produces even loads on the perimeter foundations and reduces the tendency for differential settlement. The jointed nature of the facade also makes it more tolerant of any differential settlement.

Curves are easily handled by precast concrete. On curved panels, a continuous supporting ledge cast on the inside face is preferred to provide bearing for floor/roof members and to stiffen the panels to minimize warpage. The Police Administration Building in Philadelphia, Pennsylvania, made history as one of the first major buildings to utilize the inherent structural characteristics of architectural precast concrete (see Fig. 5). The building is unusual in its plan configuration, consisting of two round structures connected by a curving central section, demonstrating the versatility of precast concrete for unusual plan forms. The 5 ft (1.52 m) wide, 35 ft (10.7 m) high (three-story) exterior panels carry the two upper floors and roof (see Fig. 6).

Wall panel size and shape can be affected by the details and locations of the vertical and horizontal panel-to-panel connections. Both gravity load transfer between panels and gravity and axial load combinations caused by lateral loadings or size of window openings can become the major factors influencing panel structural dimensions and connection design. Although, for most precast exterior bearing wall structures, it will be found that the gravity dead and live load condition will control structural dimensions.

When stemmed floor members, such as double tees, are used, the width of loadbearing walls or spandrels should module with the double-tee width. For example, for 12 ft (3.66 m) double tees, walls should be 12, 24, or 36 ft (3.66, 7.32, or 10.97 m) wide. Local precast concrete producers should be contacted for their particular module.

Inverted tee beams typically are used on interior spans. To minimize floor-to-floor dimensions, double tees are frequently dapped at interior beam lines and at exterior spandrels. Dapping is generally not necessary on vertical wall panels.



Fig. 4. The brick-faced precast panels on the Barker Substation, Denver, Colorado are 36 ft (11 m) tall.



Fig. 5. The Police Administration Building at Philadelphia, Pennsylvania.



Fig. 6. Three-story panels supporting double tees.

## DESIGN CONSIDERATIONS

In recent years, tremendous advances have been made in precast concrete structural engineering technology. Greater knowledge regarding connections and wall panel design has made it possible to use architectural loadbearing precast wall panels more cost effectively. Solid panels, or panels with small openings, constitute "true" bearing walls as their major stress is in compression. Uniaxial bending from gravity loads is normally only minor and incidental. With solid flat panels, load path locations can be determined easily.

As openings in the wall become larger, loadbearing concrete panels may approach frames in appearance and the concentration of load in the narrower vertical sections increases. In multistory structures this load accumulates, generally requiring reinforcement of the wall section as a column (at panel ends and at mullions between windows) designed for biaxial bending due to load eccentricities.

Loadbearing panels and shear walls, generally, will be supported continuously along their lower surface. They may be supported by continuous footings, isolated piers and grade beams or transfer girders. The bearing wall units can start at an upper floor level with the lower floors framed of beams and columns allowing a more open space on the lower levels.

When this is done, careful attention must be paid to the effective transfer of the lateral forces to the foundation. As with a vertical irregularity in any building in a seismic zone, the structural engineer should make a careful assessment of the behavior and detailing. In multistory bearing walls, design forces are transmitted through high quality grout in horizontal joints.

As in all precast construction, the transfer of vertical load from element to element is a major consideration. Differences in section, shape, architectural features and unit stress result in a variety of solutions and types of connections.

Depending on wall section and foundation conditions, a loadbearing wall panel can be fixed at the base (shear walls for lateral forces) with the roof elements freely supported on the

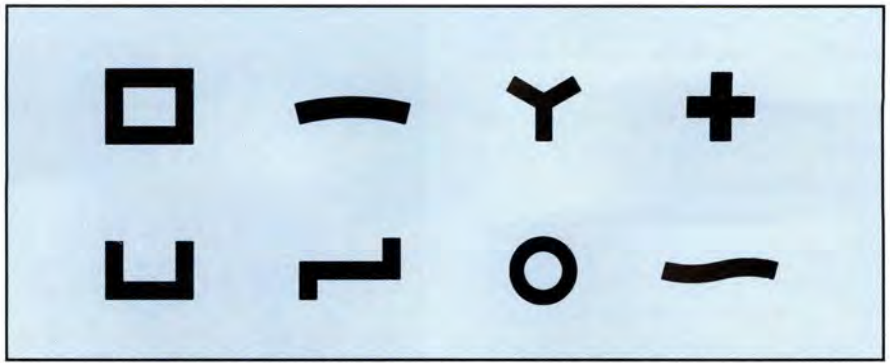


Fig. 7. Building layouts in which loadbearing panels can be used advantageously. (Note: Caution must be used with irregular plans in regions of moderate or high seismic risk.)

panel. Alternately, depending on the shape of the building, wall element flexural stresses can be reduced by pin connecting them at the foundation and providing shear wall bracings at the

ends or across the building to ensure lateral stability.

The design and structural behavior of exterior architectural precast concrete bearing walls depends on the

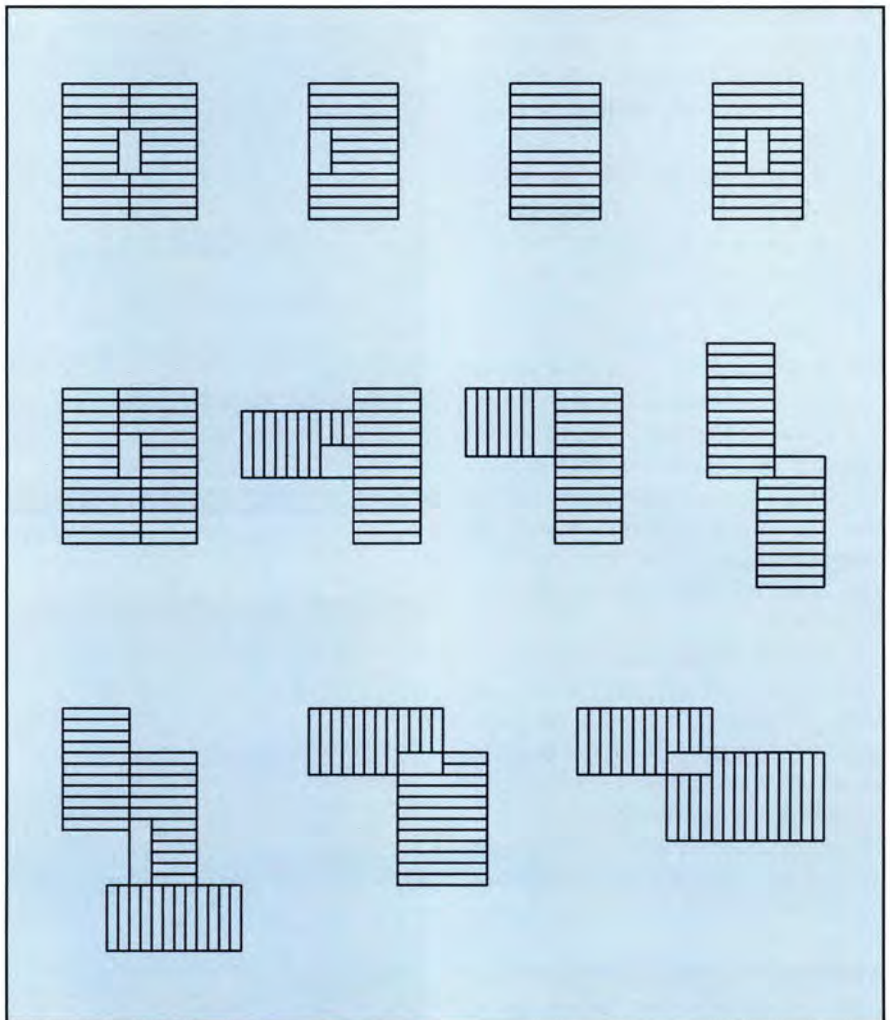


Fig. 8. Plan view of possible locations of vertical cores with respect to loadbearing walls. (Note: Although the building core is an important element of the lateral force resisting system, it may be insufficient to handle the torsional effects of eccentrically applied loads in some of these plans. Also some plans have re-entrant corners that create plan irregularities.)

panel shape and configuration. The designer should consider the following:

- Gravity loads and the transfer of these loads to the foundation — Vertical (gravity) loads are parallel to the plane of the wall, at an eccentricity influenced by the geometry of the wall, location of load, manufacturing and erection tolerances.
- Magnitude and distribution of lateral loads and the means for resisting these loads using shear walls and floor diaphragms — Loads in the horizontal direction may be both parallel to and perpendicular to the plane of the wall.
- Location of joints to control volume change deformations due to concrete creep, shrinkage and temperature movements; influence upon design for gravity and lateral loads, and effect upon non-structural components. Volume change effects can be evaluated using methods reviewed in Chapter 3 of the PCI Design Handbook.<sup>1</sup> Particular caution must be exercised at load path transitions, such as at the corners of a building where loadbearing and non-loadbearing panels meet or at re-entrant corners.
- Connection concepts and types required to resist the various applied loads.
- Tolerances required for the structure being designed with regard to production and erection for both precast concrete units and connections, including tolerances for interfacing different materials.
- Specific requirements during the construction stage which may control designs, such as site accessibility.

Loadbearing or shear wall units should be the primary design consideration if one or more of the following three conditions exist:

1. There is inherent structural capability of the units due to either their configuration or to sufficient panel thickness. The sculptural configuration of units often enables them to carry vertical loads with only a slight increase in reinforcement. For example, the precast concrete units may have ribs or projections that enable them to function as column elements for the structure. Ribs may be part of the architectural expression, or where

flat exposed surfaces are required, ribs may be added to the back of panels for additional stiffness. Projections do not have to be continuous or straight, as long as no weak point is created within the units. Generally, there is little cost premium for sculptured panels when there is adequate repetition. Similarly, some flat panels (including sandwich wall panels) may be sufficiently thick to carry loads with only minor increases in reinforcement. Structural design of panels with insulation placed between layers of concrete (sandwich panels) usually ignores the loadbearing capacity of the non-bearing wythe.<sup>4</sup> If possible, the structural wythe of a sandwich wall panel should be kept on the temperature stabilized side of the building to reduce thermal stresses due to temperature variation.

2. A uniform structural layout of the building facilitates distribution of lateral forces from wind or earthquake loads. Plus, this uniformity lends itself to repetitive, economic castings (see Fig. 7). This concept is difficult to employ if the load paths are continually changing. Cast-in-place topping on precast concrete floor units enable the floors to act as diaphragms, distributing lateral forces, reducing both individual wall unit loads and connections.

3. The building has a central core or bay designed to absorb lateral forces

and transfer them to the foundation (see Fig. 8). When the core creates a torsional irregularity, it should be supplemented by designing the perimeter panels as part of the lateral force resisting system. Plan irregularities created by the extended wings of the C and Z shapes in Fig. 7 are particularly problematic in moderate or high seismic risk areas. Because the core or bay provides the structural rigidity, panel-to-floor connections can remain relatively simple. A typical building core may contain an elevator lobby, elevators, stairways, mechanical and electrical equipment, and space for air ducts. While the core is being erected or cast, the precaster can proceed with the fabrication of the exterior wall units and install them as the shear wall or core is being constructed, often resulting in saving construction time.

Loadbearing wall panels used to construct the core are connected after erection to form composite T, L, U or box-shaped sections in plan. The main advantages of precast cores versus cast-in-place cores are surface finish quality, faster construction, and greater flexibility of the precast concrete erection sequencing.

The three conditions do not preclude other situations where loadbearing panels or shear walls may be used.

Architectural precast panel design does not differ from two-dimensional frame design, once the panel is iso-

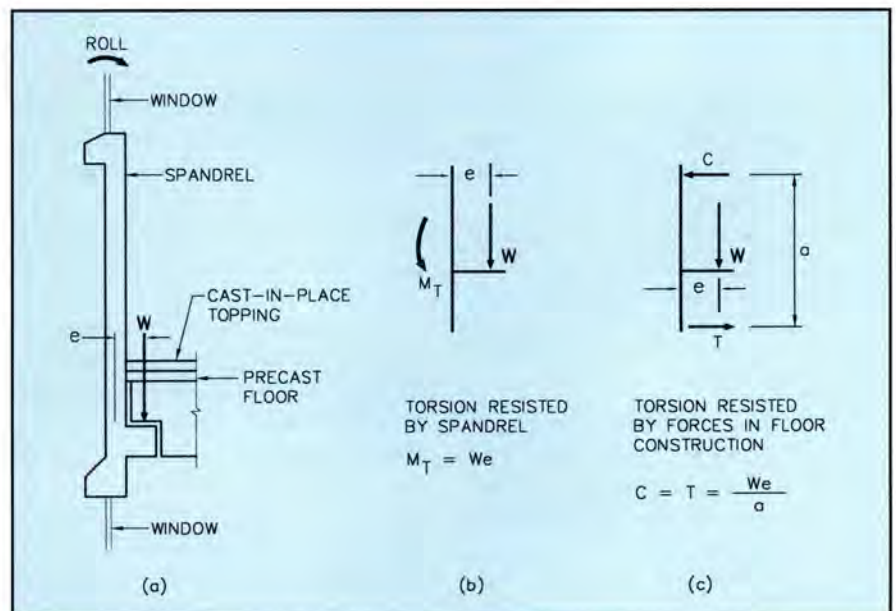
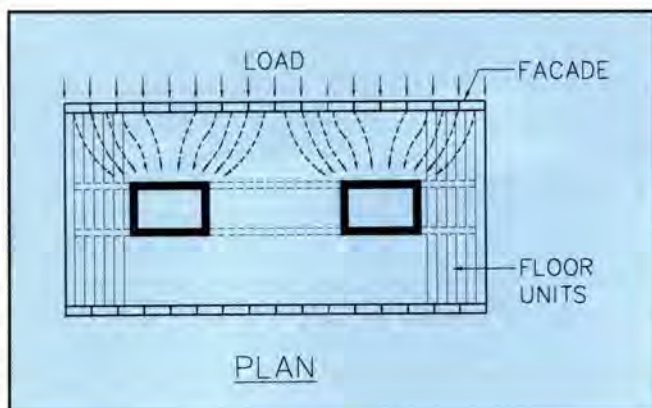


Fig. 9. Loadbearing spandrel.

Fig. 10.  
Principle of  
diaphragm action in  
precast floors and  
roofs.



lated and taken as a free body. Accepted design procedures and code requirements apply. Perhaps the only design consideration difference is recognizing the role precast concrete panel production and erection play in the overall design process. Similarly, usual accepted procedures and code requirements apply to the design of an individual precast concrete panel and its components.

When spanning horizontally, panels are designed as beams; or, if they have frequent, regularly spaced window openings as shown in Fig. 1c, they are designed as Vierendeel trusses. A horizontal Vierendeel truss type panel lends itself to simple handling since it is shipped in its erected position, requires vertical load transfer connections at each story level, and requires only minimum erection handling and erection bracing.

A two-story vertical panel requires additional erection handling because it needs to be rotated during erection, and because it demands more sophisticated erection bracing. When the panels are placed vertically, they usually are designed as columns, and slenderness should be considered (see Sections 3.5 and 4.9 of the PCI Design Handbook, Fifth Edition<sup>1</sup>). If a large portion of the panel is a window opening, as shown in Fig. 1b, it may be necessary to analyze the member as a rigid frame.

Loadbearing spandrel panels are essentially perimeter beams, that may extend both above and below the floor surface, and transfer vertical loads from the floor or roof to the columns. Except for the magnitude and location of these additional vertical loads, the design is the same as for a non-load-

bearing spandrel. Loadbearing spandrels are either ledged, pocketed, or have individual or button haunches (also known as spot corbels) to support floor/roof members. Steel shapes and plates may be cast in to reduce haunch height and, therefore, floor-to-floor height. Non-loadbearing (closure) spandrel panels may have much the same cross section as loadbearing spandrels without ledges, pockets, or haunches.

Loadbearing members loaded non-symmetrically may be subject to both internal and external torsion. If the resulting applied load is not coincident with the member's shear center, torsion will exist along the span of the member. A typical arrangement of spandrel and supported floor is shown in Fig. 9.

Torsion due to eccentricity must be resisted by the spandrel. When torsion is resisted in this manner in the completed structure, twisting of the spandrel during erection must be considered. Spandrels that are pocketed to receive stems of the double-tee floor or roof slabs decrease torsion stresses greatly, as well as minimize twist and eccentricity during erection. If torsion cannot be removed by floor connections, the spandrel panel should be designed for induced stresses.

Non-prestressed reinforced concrete members subject to torsion should be designed in accordance with the applicable provisions of the ACI Building Code, Chapter 11.<sup>5</sup> Prestressed members subject to torsion should be designed in accordance with the applicable provisions of the PCI Design Handbook, Chapter 4,<sup>1</sup> Design of Spandrel Beams,<sup>6</sup> and the ACI Building Code.

Precast building elements are commonly reinforced with welded wire fabric, mild reinforcing steel or prestressing steel. Unless analysis or experience indicates otherwise, both loadbearing and non-loadbearing panels should be reinforced with an amount of mild reinforcing steel, as specified in the appropriate building code, and be at least equal to  $\rho = 0.001$ .

Lateral loads applied normal to the wall are the result of wind or seismic forces, and are usually transmitted to vertical stiffening cores, shear walls, structural frames, or other stabilizing components by roof and floor members acting as horizontal diaphragms. This reduces the load on individual wall units and their connections (see Fig. 10). The connections between façade elements and floor members are normally designed as hinges in the direction perpendicular to their plane.

Vertical continuity is achieved by providing connections at horizontal joints of vertical members. Columns should be braced at each level through a continuous load path to the diaphragm.

## SHEAR WALLS

In many structures, it is economical to take advantage of the inherent strength and in-plane rigidity of exterior wall panels by designing them to serve as the part of the lateral load resisting system. Walls taking horizontal loads from the effects of wind or earthquakes are referred to as shear walls. Shear walls are used as the most common and economical lateral force resisting system and have been utilized widely in buildings up to 30 stories.

A shear wall system's effectiveness is dependent largely upon panel-to-panel connection design. A significant advantage of jointed construction is in the inherent ease of defining load paths through connections. As such, it is relatively easy to separate a precast concrete lateral force resisting system's performance from that of the vertical loadbearing frame.

Shear walls are vertical members, which transfer lateral forces, in or parallel to the plane of the wall, from superstructure to foundation. Thus, shear

walls act as vertical cantilever beams. Shear walls are placed at appropriate locations within and around the building perimeter according to the architectural and functional design requirements.<sup>7</sup> The 1 ft (0.305 m) thick panels on the Sarasota County Judicial Center located in Sarasota, Florida, measure 21 x 15 ft (6.40 x 4.57 m). They serve as shear walls at the corners of the building (see Fig. 11). Continuous steel plate connections were cast into the corner panels to permit a welded connection at the vertical corner joint.

Typically, a structure incorporates numerous walls, which can be used to resist lateral forces in both principal axes of the building. The portion of the total lateral force which each wall resists depends upon the wall's bending and shear resistance capacity, the participation of the floor, and the characteristics of the foundation.

It is common practice to assume that floors act as rigid elements for loads in the plane of the floor, and that the deformations of the footings and soil can be neglected. Thus, for most structures, lateral load distribution is only based on the properties of the walls. Shear wall building design is performed in accordance with Sections 3.7 and 3.10 of the PCI Design Handbook, Fifth Edition.<sup>1</sup>

The importance of earthquake loads varies according to a project's geographic location. Many areas of the United States require structural analysis for potential earthquake forces in varying degrees of intensity. Concrete panels have the inherent strength to perform as shear walls with little or no additional reinforcement. It is important, however, that the connections be designed to transfer lateral forces, and also accommodate thermal movements and differential deflections (or camber). The ability to transfer lateral forces may be a panel's only structural purpose. But, it is more often combined with loadbearing capabilities.

Shear walls are economical because walls already required by the building layout [such as exterior walls, interior walls (see Fig. 12)<sup>8,9</sup> or walls of the elevator, stairway, mechanical shafts or cores] can become structural shear walls. Load transfer from horizontal



Fig. 11. Shear wall at the corners of the Sarasota County Judicial Center, Sarasota, Florida.

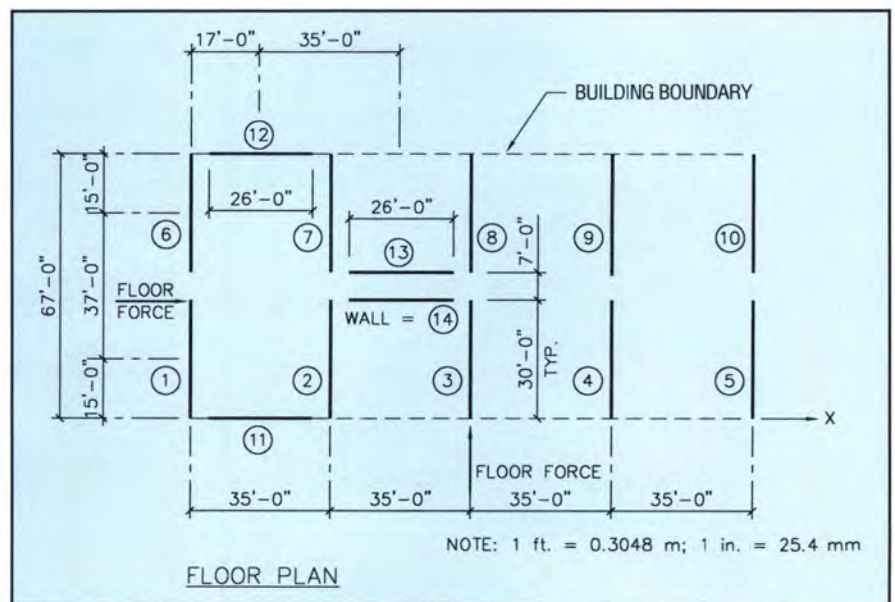


Fig. 12. Building layout showing shear walls for a symmetrical condominium building plan (Ref. 8).



diaphragm to shear walls, or to elevator walls, stairway cores or mechanical shafts, can be accomplished either via connections or by direct bearing. Whenever possible, it is desirable to design shear walls as loadbearing panels. The increased dead load acting on the panel is an inherent advantage because it increases the panel's resistance to uplift and overturning forces created by lateral forces.

The effect of cumulative loads on connections between panels must be considered, since these loads become a significant factor in determining minimum panel dimensions. Shear

walls in precast concrete buildings can be individual wall panels or wall panels which are connected together to function as a single unit. Connected panels greatly increase shear resistance capacity.

Connecting long lengths of wall panels together, however, can result in an undesirable build-up of volume change forces. Hence, it is preferable to connect only as many units as necessary to resist in-plane shear forces and the overturning moment. Connecting as few units as necessary near the mid-length of the wall will minimize the volume change restraint forces.

In some structures, it may be desirable to provide shear connections between non-loadbearing and loadbearing shear walls in order to increase the dead load resistance to moments caused by lateral loads. However, in most cases, an exterior shear wall (or perimeter frame) system provides more efficient and flexible floor plans than does an interior shear wall system because it eliminates the need for a structural core (see Fig. 13).

Furthermore, exterior shear walls do not affect the interior traffic flow or sight lines. The exterior walls provide the vertical strength and horizontal

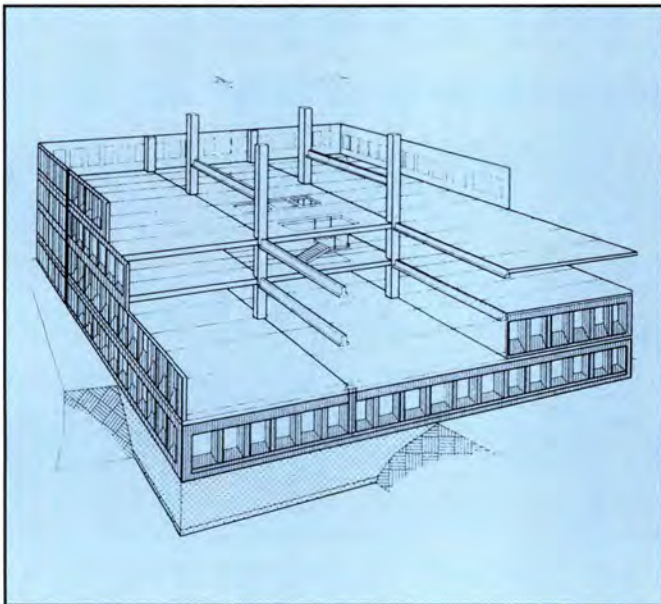


Fig. 13. Exterior shear wall system (or perimeter frame).

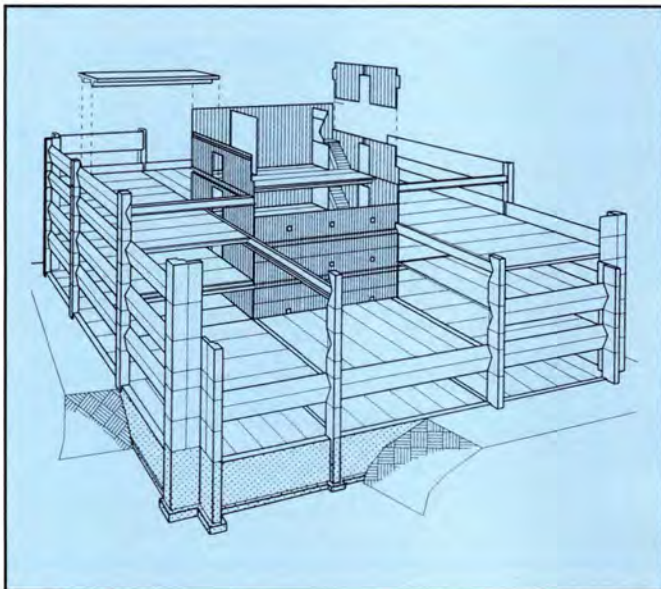


Fig. 14. Interior shear wall system.

**Design**

- slabs and wall panels should be shaped to create self-forming elements and require a minimum of temporary support and bracing
- crack control is critical to avoid leakage and damage to outside surface of precast concrete panel
- if precast shell and cast-in-place concrete are to act compositely bond ties should be considered — but must be positioned so that reinforcement can be placed
- develops lateral load resisting wall and column sections
- reinforcement that passes across the interface should be adequate to support required forces using shear friction
- must be reinforced to transfer horizontal and vertical shear forces without undue deformations

**Production**

- placement of panel reinforcing steel must be held to close tolerances to minimize cracking
- good system but precast concrete difficult to cast

**Erection**

- temporary shoring is often required

**Variations**

- provide inserts in panel to facilitate forming for cast-in-place concrete

(a) VERTICAL SECTION

(a) HORIZONTAL SECTION

VARIATIONS

(b) PRECAST PERMANENT FORMWORK (ONE-PIECE SPANDRELS MAY REQUIRE SUPPORT AND RESTRICT PLACEMENT OF CONCRETE)

TEMPORARY FORMWORK

BOND TIES SCREWED INTO CAST-IN INSERTS

(c) SEPARATE PRECAST SILL UNIT

TEMPORARY FORMWORK

BOND TIES

Fig. 15. Precast concrete units serving as forms for cast-in-place concrete to tie walls, beams, and floor together.

connections to allow the entire wall to function as a single unit to mobilize dead load overturning resistance. In addition, they eliminate the need for exterior columns and beams.

In an interior shear wall system, the lateral forces are not transferred directly to the foundation. Instead, the wall panels distribute the lateral forces to floor diaphragms, which, in turn, transfer them to a structural core or to the interior shear walls (see Fig. 14). Frequently, the shear wall panels are connected vertically and at the corners to form a structural tube that cantilevers from the foundation, creating a stronger element than its individual parts.

### PRECAST CONCRETE AS FORMS FOR CIP CONCRETE

Architectural precast concrete units also may serve as forms for cast-in-place concrete. This application is especially suitable for combining architectural (surface aesthetics) and structural functions in loadbearing façades, or for improving ductility in locations of high seismic risk by using wet cast connections with high levels of reinforcement at the joints. Continuity and ductility are achieved by casting in place the beams and columns using precast concrete loadbearing panels as the exterior formwork.

The ductility of walls depends partially upon reinforcement locations. Ductile behavior is improved significantly if the reinforcement is located at the ends of the walls. This way, structurally inactive cladding can become a major lateral load (seismic and wind) resisting element. Seismic loads are resisted primarily by the building's central core and partly by the ductile concrete exterior frame. Basically, floor slabs act as diaphragms. Fig. 15 illustrates the use of cast-in-place concrete to tie the walls, beams, and floor together. This can be an efficient system for providing lateral resistance in precast concrete buildings.

The four-tiered colonnade wrapping Liberty Square in Vancouver, British Columbia, is constructed of precast panels that double as formwork for cast-in-place concrete (see Figs. 16 and 17). The loadbearing capacity of

the integrated precast and cast-in-place frame resulted in a substantially stronger wall — one that is structurally independent of the central core.

The Marathon Plaza, San Francisco, California, consists of two terraced

towers, nine and ten stories high (see Fig. 18). Precast wall panels were designed with their edges serving as forms for columns and spandrel beams, thus integrating the panels into a tube to resist lateral forces (see Fig. 19).



Fig. 16. Liberty Square, Vancouver, British Columbia.



Fig. 17. Panels serve as forms for cast-in-place concrete.



Fig. 18. Construction of Marathon Plaza, San Francisco, California.



Fig. 19. Close-up of edges of panel.

The cast-in-place concrete structure of the 13-story Simmons Biomedical Research Building, Dallas, Texas (see Fig. 20), was cast into forms consisting of precast concrete column and spandrel beam covers (see Fig. 21).

## CONNECTIONS

Connections for loadbearing wall panels are an essential part of the structural support system. The stability of the structure depends upon them. Loadbearing panel connections should be designed and detailed in the same

manner as connections for other precast structural members. It is desirable to design loadbearing precast concrete structures with connections which allow lateral movement and rotation, and to design the structure to achieve lateral stability through the use of floor and roof diaphragms and shear walls.

Connection methods include bolting, welding, post-tensioning, grouting, or a combination of these techniques. The floor system may or may not have a structural topping. Designers are referred to an extensive treatment of design methods in Refs. 1 and

2. Often, loadbearing walls have horizontal and/or vertical joints across which forces must be transferred.

Connections must comply with local codes whose provisions generally vary across North America. Connections may be subject to functional requirements such as recessing for flush floors and/or exposed ceilings. Individual manufacturers have developed specific connections over the years because they suit their particular production and/or erection techniques. However, some basic connection concepts governing design, performance and material requirements can be formulated. No attempt has been made to size or detail individual pieces, welding or anchorages of the connections shown in this discussion. Instead, this



Fig. 20. Simmons Biomedical Research Building, Dallas, Texas.



Fig. 21. Panels serve double duty as formwork for columns and perimeter beams.

is an engineering task required for each individual project.

Horizontal joints in loadbearing wall construction usually occur at floor levels and at the transition to foundation or transfer beams. These joints may connect floors and walls or wall units only. The principal forces to be transferred are vertical and horizontal loads from panels above and from the diaphragm action of floor slabs.

Horizontal joint and connection details of exterior bearing walls are especially critical, because the floor elements usually are connected at this elevation, and since a waterproofing detail must be incorporated. Vertical joints may be designed so that the adjacent wall panels form one structural unit (coupled), or act independently. In addition to the vertical shear force transfer due to lateral loads, vertical joints also may be subject to shear

forces induced by differential loads upon adjacent panels.

The stability of the structure during construction must be considered when planning erection procedures. Therefore, temporary guying and/or bracing must be provided until final structural stability is achieved in the completed structure. This bracing design is the responsibility of the precast concrete erector and should be shown on a bracing plan prepared by the erector. Sometimes, the bracing plan requires review by the engineer of record and building officials.

Connections that transfer vertical or lateral loads from panel to panel may differ according to the particular building. Gravity load transfer often can be achieved with simple weld plate connections because of concrete's inherent strength in compression. Mechanical reinforcement splice connections may be required to pro-

vide uniform load paths for tensile forces. Lateral connections can allow rotation (pin connections) or be rigid (moment connections), depending upon the structural system selected.

### Wall-to-Foundation Connections

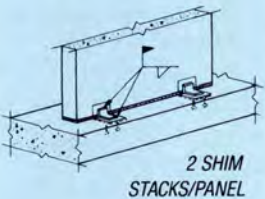
Wall-to-foundation connections are used to tie loadbearing walls to the foundation (see Figs. 22 to 26). Any connection joining a wall panel to a foundation wall or a continuous footing should provide a means of leveling and aligning the panel. The attachment method also should be capable of accepting the base shear in any direction. In cases where an interior core carries lateral loads, this may be accomplished with a simple welded connection.

### Slab-to-Wall Connections

Slab-to-wall connections are made to join precast or cast-in-place concrete

**Design**

- if connection is on exterior face of panel, it is susceptible to corrosion unless protected with mastic or grout
- hardware layout drwg. required for G.C.
- can be designed for horizontal shear and uplift; flexure in angle limits uplift capacity



**Production**

- simple
- embedded plates in wall may need to be jiggged level if cast top-in-form to avoid tilting

**Erection**

- quick and easy
- few tolerance problems if embedded plates are wider than angle
- welding may be difficult when connection is below grade
- space under wall usually filled with grout

**Variations**

- connections may be placed on both sides of wall to develop nominal moment resistance
- angles may be bolted to wall and/or foundation
- plates may be used in place of connection angles

**VARIATIONS**

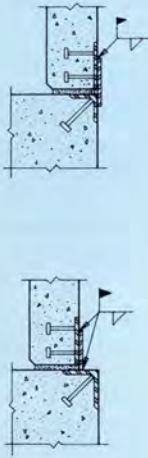
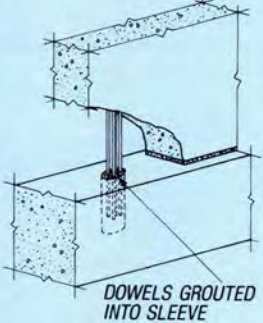


Fig. 22. Wall to Foundation (WF1).

**Design**

- shear resistance is achieved
- capacity can be increased by use of confinement reinforcement around sleeve and bars



**Production**

- projecting dowels from panel can cause difficulties in storing and transporting panel
- location and alignment of dowels is critical

**Erection**

- grouting coordination required
- location and alignment of sleeve is critical
- no connection for panel during erection; necessary to brace
- use grout under panel
- alignment of panel must be made before initial set of grout
- must weather protect sleeve to prevent ice, water or debris from filling cavity

**Variations**

- sleeve may be placed in panel to receive dowels from foundation
- grout can be pumped into sleeve after alignment or before panel erection
- proprietary sleeve systems
- use insert or coupler and add threaded dowel in the field to reduce production and transportation problems
- single dowel is most commonly used

Fig. 23. Wall to Foundation (WF2).

floor or roof members to precast concrete walls (see Figs. 27 to 30). Connections joining the slabs and walls may require load transfer or bearing, diaphragm action, and moment resistance. Secondary forces caused by temperature fluctuations, long-term shrinkage and creep, and bending moments induced by end restraints, are usually of minor importance.

Gravity transfer may be through a continuous ledge (corbel) or individual (spot) corbels or connection hardware.

Blockouts in wall panels can also be used to support floor members. Such pockets in wall panels or spandrels greatly decrease torsion stresses, and

also minimize twist and eccentricity during erection. These pockets require substantial draft on their sides [1/2 in. (12.7 mm) every 6 in. (152 mm) depth] and should have at least 2 1/2 in. (64 mm) cover to the exposed face. More cover [3 in. (76 mm) minimum] is required if the exterior surface has an architectural finish.

In the case of a fine textured finish, there can be a light area (the approximate size of the blockout) shown on the face of the panel due to differential drying. This will usually be apparent, despite the uniformity of the texture. The initial cure of the 2 1/2 to 3 in. (64 to 76 mm) of concrete versus 8 to 9 in.

(203 to 229 mm) in the surrounding area will make the difference.

When the slab functions as a diaphragm, the connections must transmit diaphragm shear and chord forces to a structural core, thus reducing the load on individual exterior wall or spandrel units and their connections. In those instances, simple welded connections can be employed to join panels. When the wall participates more actively in lateral or shear resistance, larger and more numerous welded connections are required. Flat, stemmed or hollow-core slabs may be used. When the slab is used with a composite topping, some connections

**Design**

- hardware layout drwg. required for G. C.
- size joint for welding access

**Production**

- simple
- insert must be jugged so that bolt is plumb

**Erection**

- quick and easy
- allows vertical adjustment without crane

**Variations**

- bolt head may be welded for tensile and shear capacity
- plate may be eliminated but adjustment becomes more difficult
- use embedded bolt and projecting sleeve nut
- insert may be in foundation

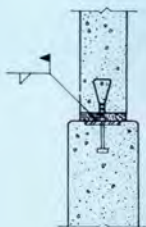


Fig. 24. Wall to Foundation (WF3).

**Design**

- two directional stiffness
- hardware layout drwg. required for G.C.

**Production**

- care required in jugging angles in form to ensure proper alignment

**Erection**

- may require temporary bracing

**Variations**

- if wall needs to be tied to floor slab, weld reinforcement to connection

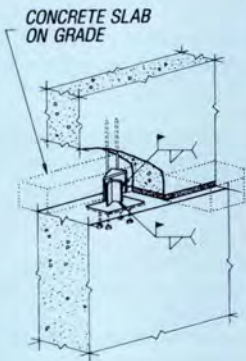


Fig. 25. Wall to Foundation (WF4).

**Design**

- develops moment resistance at base
- can be used to resist uplift forces
- no positive connection until bar is tensioned
- hardware layout drwg. required for G. C.

**Production**

- duct placement tolerance in wall panel is critical
- grout vents may be required

**Erection**

- may require temporary bracing
- bar, duct and hardware placement tolerance in foundation and wall panel is critical
- requires drypack to reach design strength prior to tensioning
- post-tensioning equipment necessary

**Variations**

- shim under panel
- bars may be coupled at top of foundation
- post-tensioned bar may or may not be grouted

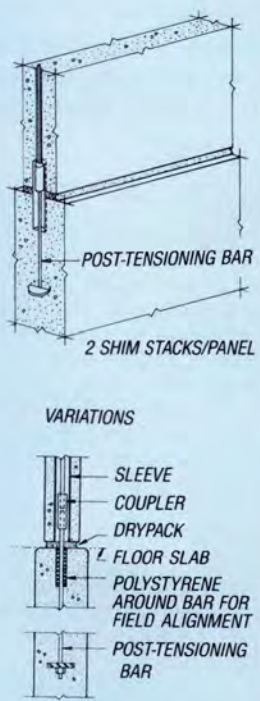


Fig. 26. Wall to Foundation (WF5).

may be necessary to achieve stability of the structure during erection with the final diaphragm connection achieved using dowels from the wall to the topping.

Most designs result in some degree of continuity for these connections.

However, a fully fixed connection is generally not desirable. The degree of fixity can be controlled by a judicious use of bearing pads in combination with clamping forces, or by welding to anchor plates placed in the floor members. Reinforcing steel can also

be doweled, threaded, or welded to the walls.

Connections to shear walls along the (non-bearing) sides of floor or roof slabs should be able to transmit lateral loads and should either allow some vertical movement to accommodate

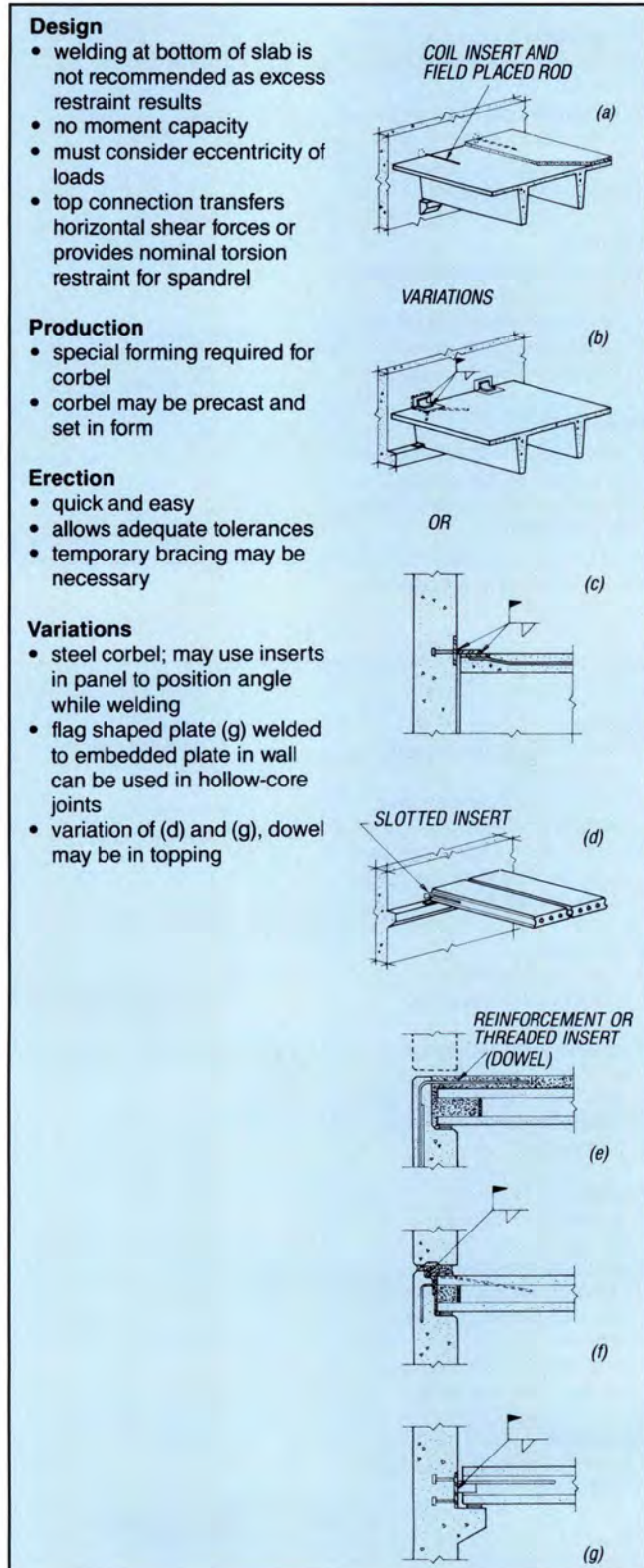


Fig. 27. Slab to Wall (SW1).

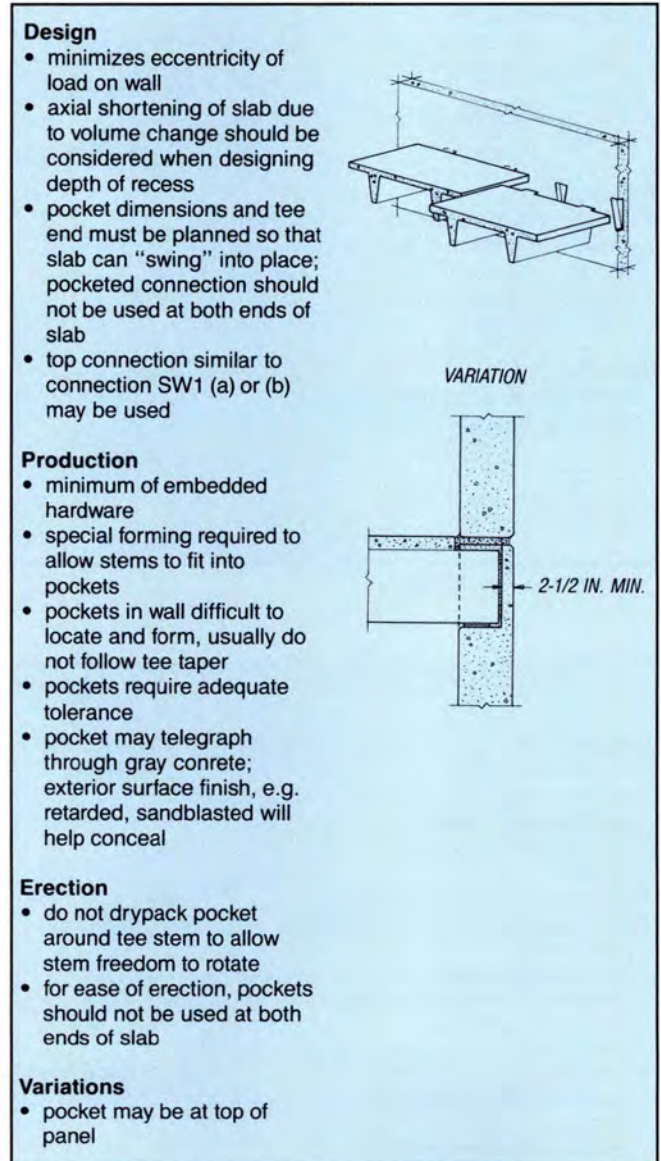
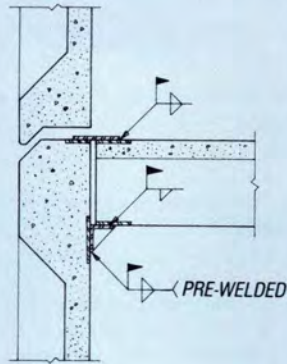


Fig. 28. Slab to Wall (SW2).

**Design**

- develop a rigid, moment connection
- avoid use of this detail at both ends of slab to prevent excessive restraint
- rotation of wall elements and effects on bracing wall connections and volume changes must be considered
- arrangement of weld plates must allow for welding access
- avoid overhead welding, if possible



**Production**

- plate jiggling is necessary since embed is top-in-form as cast
- steel congestion must be well thought out

**Erection**

- welding must be completed before setting panel above

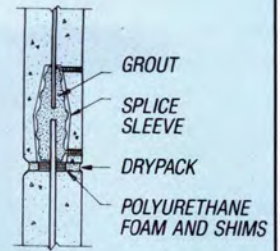
**Variations**

- wall corbel in lieu of angle seat

Fig. 29. Slab to Wall (SW3).

**Design**

- continuity through the connections
- connection is concealed and protected
- no connection between walls until splice sleeves or ducts are grouted
- sleeve and sleeve grout are proprietary



**Production**

- hardware placement is critical
- projecting dowels can cause difficulties in storing and transporting panels if dowels project from bottom of panel

**Erection**

- may be necessary to heat grout in cold weather
- temporary brace required
- requires a grout crew in addition to setting crew

**Variations**

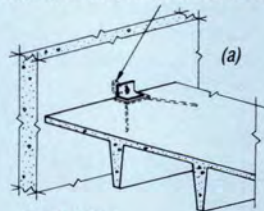
- sleeve connector can be placed in either upper or lower panel — upper panel is preferred

Fig. 31. Wall to Wall (WW1).

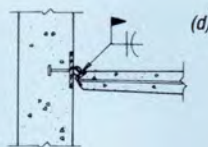
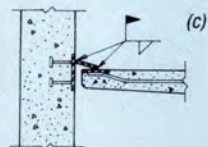
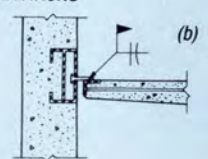
**Design**

- connection allows movements caused by temperature changes
- positive horizontal force transfer
- connection (c) allows vertical movement by flexing of plate and welds
- connection (d) allows vertical movement through flexibility of double tee flange

THREADED INSERT IN WALL PANEL



VARIATIONS



**Production**

- insert must be plumb and true
- washer must be oversize so it does not bind in the slot
- simple

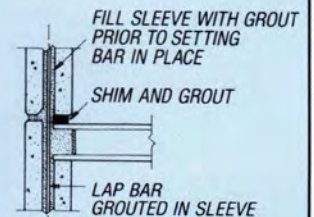
**Erection**

- quick and easy
- tolerance problems minimized
- do not overtighten bolt in (a)

Fig. 30. Slab to Wall (SW4).

**Design**

- can be used to withstand uplift forces
- connection is hidden and protected
- connection is not developed until tensioning is completed (bars are anchored)



**Production**

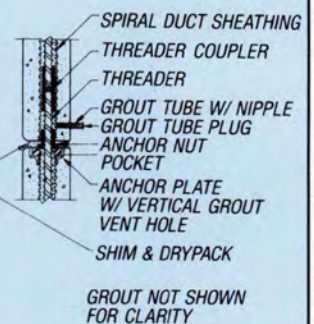
- duct and hardware placement in panels is critical
- tolerance on slab length critical
- thin panel outer lip projection subject to damage during handling

VARIATIONS



**Erection**

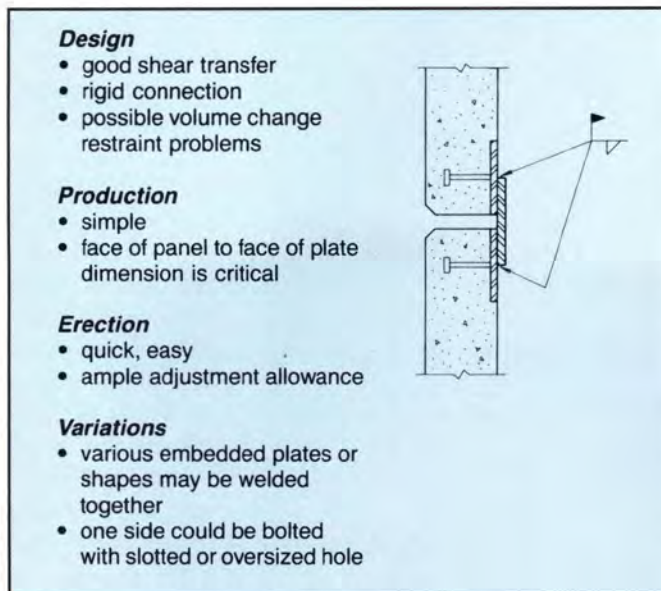
- temporary bracing is required
- drypack, tensioning, grouting sequence may limit erection to one story at a time
- grouting requires care to ensure complete filling



**Variations**

- bars may or may not be post-tensioned

Fig. 32. Wall to Wall (WW2).



require no grouting or at the very least a minimum amount of field grouting.

## APPLICATIONS

In the last 40 years, many tall structures have been constructed with load-bearing architectural precast concrete window wall panels. Among them is the 20-story Mutual Benefit Building in Philadelphia, Pennsylvania, built in 1969 (see Fig. 34). The panels measure 12 ft high and 20 ft wide (3.66 x 6.10 m) and each has four openings. The mullions are designed for column action. Spandrels are hidden behind dark glass panels permitting an accent of vertical lines.

Loadbearing sandwich window wall panels for the 20-story, 300 ft (91 m) tall One Hundred Washington Square office building in Minneapolis, Minnesota, are 13 ft high and 10 ft wide (3.96 x 3.05 m) (see Fig. 35).<sup>11,12</sup> They have a 16 in. (406 mm) interior wythe, 2½ in. (64 mm) of insulation and a 3 in. (76 mm) exterior skin. The corner columns have cladding at the base and then serve as insulated formwork for cast-in-place concrete for the rest of the height.

Fig. 33. Welded Alignment (WA2).

camber and deflection of the floor units, or be designed to develop forces induced by restraining the units.

### Wall-to-Wall Connections

Wall-to-wall connections are primarily intended to position and secure the walls, although with proper design and construction, they are capable of

carrying lateral loads from shear wall or frame action as well (see Figs. 31 to 33). The two locations of wall-to-wall connections are horizontal joints (usually in combination with floor construction) and vertical joints.

The most practical connection is one that allows realistic tolerances and ensures transfer of load between panels. It also is desirable that the connection



Fig. 34. Twenty-story Mutual Benefit Life, Philadelphia, Pennsylvania.



Fig. 35. Window wall panels serve as elements of Vierendeel truss on One Hundred Washington Square office building, Minneapolis, Minnesota.





Fig. 36.  
The 32-story Tannen  
Towers, Atlantic City,  
New Jersey.

The 32-story Tannen Towers condominium project in Atlantic City, New Jersey, completed in 1987 uses portal frames at the base, and bearing walls in the upper levels (see Fig. 36). The building is subdivided from top to bottom by a central corridor. A row of 37 ft (11.3 m) long bearing walls, which are typically 8 in. (203 mm) thick, runs along either side of the corridor. The walls cantilever 11 ft (3.35 m) beyond the face of the base structure on both sides of the building. To stabilize the structure, the design links pairs of bearing walls across the corridor with steel ties — back-to-back angles reinforced with a continuous plate.

The majority of loadbearing buildings built in recent years, however, have been less than ten stories.

A typical application of loadbearing spandrels is in parking structures. The Boston College parking structure in Chestnut Hill, Massachusetts, is an entirely precast/prestressed concrete building comprised of precast columns and beams with precast spandrels supporting double tees (see Fig. 37a).<sup>13</sup> An early construction shot of the parking structure (see Fig. 37b) shows the erection of the precast frame.



Fig. 37a. The Boston College parking structure in Chestnut Hill, Massachusetts.

The Barnett Bank parking facility in Jacksonville, Florida, is part of a campus serving as a national headquarters (see Fig. 38). The loadbearing spandrels, which are 40 ft (12.2 m) long, eliminate the need for cladding and framing and make use of the section properties of the framing members.

The six-story precast concrete Community Service Building Garage in Wilmington, Delaware, fits in with the neighboring architectural landscape in color, style, and ornamentation (see Fig. 39). In addition, the building is designed to serve as the architectural base for a future nine-story office building. The cornice spandrel at the roof is over 4 ft (1.22 m) thick and weighs over 80,000 lbs (36290 kg). The elevation adjacent to an existing building and invisible from the street is constructed of precast concrete loadbearing shear walls.

The architect for the Interlocken Office Campus in Broomfield, Colorado, innovatively used the same molds to create three unique all-precast office buildings (see Fig. 40a). Architectural



Fig. 37b. Early construction shot of the Boston College parking structure.



Fig. 38. Barnett Bank parking facility, Jacksonville, Florida.



Fig. 39. Community Service Building Garage, Wilmington, Delaware.



Fig. 40a.  
Interlocken Office  
Campus, Broomfield,  
Colorado.



Fig. 40b.  
Construction showing  
use of columns and  
spandrels in  
Interlocken Office  
Campus.



Fig. 41. Internal Revenue Service office building, Oklahoma City, Oklahoma.

loadbearing spandrels and columns minimized the contractor's time and risk in completing the core and shell (see Fig. 40b). The architectural exterior used an acid-etch finish with two colors and an ashlar stone formliner.

The all-precast 10-story Internal Revenue Service office building in Oklahoma City, Oklahoma, has 8 in. (203 mm) thick prestressed rectangular

spandrels supporting 44 ft long x 10 ft wide x 28 in. deep (13.4 m x 3.05 m x 711 mm) double tees (see Fig. 41).<sup>14</sup>

The horizontal mass of the Crescent VIII building in Crescent Town Center in Denver, Colorado, is broken by expressed vertical pilasters (see Fig. 42a). The architect wanted to maximize the window space while also

maintaining a heavier, substantial wall form. This was achieved with the detailing and implication of the beam-and-column look to the precast panels (see Fig. 42b).

Shepard's/McGraw-Hill World Headquarters in Colorado Springs, Colorado, has 12 in. (305 mm) thick acid etched window box panels supporting 32 in. (813 mm) deep double-tee floor and roof members spanning 60 ft (18.3 m), creating large column-free areas (see Figs. 43a and b).

Perhaps the single most important factor to influence the design of the 11-story Orange County Regional Service Center in Orlando, Florida, was energy consumption (see Fig. 44). To simplify construction, the architectural precast elements became structural, loadbearing units with a built-in eyebrow for sun screening. The loadbearing 12 ft wide x 12.5 high ft x 3 ft deep (3.66 x 3.81 x 0.91 m) window boxes, with fully operable windows recessed 3 ft (0.91 m) from the building exterior surface provide total shade on the glass during most of a typical summer day, when heat gain to the building interior would peak.

The loadbearing window wall units on the Aurora, Colorado Municipal Justice Center are two stories high and weigh 20,000 lbs (9080 kg) each (see Fig. 45a). They are boldly detailed



Fig. 42a. The Crescent Town Center Campus in Denver Technological Center, Denver, Colorado, features a series of buildings designed around an open, park-like crescent.



Fig. 42b. The use of integrated loadbearing/architectural spandrel panels erected in 8 weeks facilitated a tight construction schedule (The Crescent Town Center Campus, Denver, Colorado).



Fig. 43a. Shepard's/McGraw-Hill World Headquarters, Colorado Springs, Colorado.



Fig. 43b. Construction showing window box panels supporting double-tee floor and roof members (Shepard's/McGraw-Hill World Headquarters, Colorado Springs, Colorado).

Fig. 44. Loadbearing window boxes on Orange County Regional Service Center, Orlando, Florida.



with bullnoses, cornices, and friezes (see Fig. 45b).

The all-precast Jefferson Avenue Parking Structure in Detroit, Michigan, features modules with punched openings measuring four stories high and 10 ft (3.05 m) wide. Doubling them vertically provides the total height (see Fig. 46a). This small module allows the façade to curve in response to the shape of the nearby Renaissance Center. The precast concrete bearing wall system supports 4 ft wide x 12 ft long (1.22 x 3.66 m) hollow-core slabs and 10 ft wide x 55 ft long (3.05 x 16.8 m) double tees in various areas (see Fig. 46b).

The Denver Wastewater Management Building in Denver, Colorado, is an all-precast structure including the core and shear walls with loadbearing window wall and solid panels (see Fig. 47a) featuring highly articulated Art Deco detailing (see Fig. 47b). The six-story office tower is topped by two mechanical floors with a curved pediment (see Fig. 47c).

Hardened criteria for the walls and roof of the Conrail Computer Technology Center in Philadelphia, Pennsylvania, included the ability to withstand the impact of an irregular object at 200 miles per hour (320 km/hr) and an equivalent explosive force (see Fig. 48). The use of 12 in. (305 mm) thick, 40 ton (36 t) precast wall panels not only met these criteria, but in their capacity as bearing walls, lessened the cost of the building.

The 10 x 30 ft (3.05 x 9.14 m) bearing walls of the gymnasium at the United States Olympic Training Center in Colorado Springs, Colorado are 13 in. (330 mm) thick insulated wall panels (see Fig. 49a). Lateral forces are resisted by shear wall action of the exterior interconnected wall panels (see Fig. 49b).

## CONCLUDING REMARKS

Architectural precast concrete's full potential as loadbearing walls can be realized when the entire design or design/build team — architect, engineer of record, mechanical engineer, contractor, and precaster — has the opportunity to develop a project jointly starting at the project's preliminary



Fig. 45a. Two-story window wall units supporting double tees for Aurora, Colorado Municipal Justice Center, Aurora, Colorado.

Fig. 45b. Details on loadbearing panels for Aurora Municipal Justice Center, Aurora, Colorado.



Fig. 46a. Jefferson Avenue Parking Structure, Detroit, Michigan.



Fig. 46b. Hollow-core units supported by walls in walkway areas (Jefferson Avenue Parking Structure, Detroit, Michigan).

design stage. Finish types, shapes, repetitive use of efficient and economical precast concrete modules, joint locations, access or site restriction, erection procedures and sequencing, all become important considerations for a project's successful completion. Properly implemented, an early and continuing dialogue between the designers and precaster will ensure maximum product quality and appearance at a minimum installed construction cost.

The following additional benefits can be derived by using architectural precast concrete units as loadbearing walls:

- Prefabrication combined with speed of erection saves valuable overall construction time. Production of precast concrete components and site preparation can proceed simultaneously. On-site labor cost is minimized, and erection is possible in all kinds of weather. Construction is much faster with a fully integrated structure and skin system where loadbearing wall panels provide both structural support and architectural finish. Rapid enclosure allows earlier access by finishing trades. Faster completion reduces interim financing costs and results in earlier cash flows.
- Loadbearing wall panels become part of the structural framing. They



Fig. 47a. Construction of total precast Denver Wastewater Management Building, Denver, Colorado.



Fig. 47b. Closeup of Art Deco details in Denver Wastewater Management Building, Denver, Colorado.

form the supporting structure for floors and roof at the building perimeter. This generates interior space free of perimeter columns and interior bearing walls, providing maximum floor plan layout flexibility. When a loadbearing wall panel building is erected, the architect and owner receive single-source responsibility for the building shell. This reduces the number of subcontractors and minimizes trade coordination.

- ❑ Elimination of separate structural frames from exterior walls results in savings far exceeding the minimal additional costs of increased reinforcement and connections required for loadbearing units. This savings is most apparent in buildings with a large ratio of wall-to-floor area.
- ❑ Precast concrete, manufactured in factory-controlled conditions assures the highest quality possible, thus ensuring a uniformly high quality façade in the desired shapes, colors, and textures. Greatest economy is achieved by using an integral architectural finish for both exterior and interior faces. Integral finishes not only result in a savings of material and labor, but also reduces the overall thickness of the exterior wall. This permits maximum interior space utilization. Precast concrete panels resist weather and corrosion, requiring little or no maintenance. Their aesthetic versatility is virtually unmatched by any other material.



Fig. 47c. Final erection shot of Denver Wastewater Management Building, Denver, Colorado.

- ❑ Panels can be designed as receptacles and distributors for electrical, mechanical, plumbing and HVAC sub-systems, thereby decreasing trade overlap problems and eliminating the need for a separate wall cavity.
- ❑ Loadbearing window wall panels can inherently form deeply recessed

window frames to provide a high degree of sun shading. This can minimize air-conditioning system costs by reducing thermal load. Also, the thermal mass of concrete and the possibility of incorporating insulation into a sandwich wall panel contribute to reducing heating and cooling costs.



Fig. 48. Conrail Computer Technology Center, Philadelphia, Pennsylvania.

□ Design flexibility for the precast exterior allows unique expressions while interior framing can be simple and standard. This provides an economical solution for structures with varying loading, fire and space planning requirements. Precast concrete's aesthetic flexibility simplifies changes in plane, relief, color, and texture. Wall panels can be custom designed in desired shapes and sizes or may be selected from a variety of standard sections depending

on the building's intended use and budget. For walls requiring repetitive fenestration, precast concrete can offer sculptured architectural effects with maximum simplicity of structural design and minimum erection cost. Final results are limited only by the designer's imagination.

□ Precast concrete loadbearing wall units, comprising structural-aesthetic functional features, provide the opportunity to construct an eco-

nomical, attractive building. Such structures contribute significantly to the development of contemporary architectural philosophy — specifically, a system in which the walls are actually doing the structural work they appear to be doing.

- Architectural loadbearing wall panels can be used effectively to renovate and rehabilitate old deteriorated structures.
- Architectural loadbearing wall panels can be used not only in all-precast structures but also in structural steel framed structures and cast-in-place concrete structures.
- Architectural precast concrete used innovatively for loadbearing walls makes possible a nearly unlimited range of aesthetic expression, new design concepts and more efficient and less costly construction.

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Fig. 49a. U.S. Olympic Training Center, Colorado Springs, Colorado.



Fig. 49b. Erection of main roof system consisting of 40½ in. (1029 mm) deep lightweight double tees spanning 111 to 140 ft (34 to 43 m) from bearing wall to bearing wall (United States Olympic Training Center, Colorado Springs, Colorado).

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