

Designing with Precast and Prestressed Concrete



foreword

Concrete has proven to be a durable, versatile material since the Romans first used it to build their aqueducts and so many other long-standing and iconic structures. Precast concrete was first devised in the 1920s, and techniques for improving its capabilities continue to evolve to meet the needs of designers and owners.

As an engineered, highly controlled product, precast concrete can be adapted in many ways to meet a wide variety of design challenges. But as an engineered product, its properties must be well understood to maximize its efficiency in design, production, delivery, erection, and maintenance.

This manual represents a first for the industry. It summarizes key information from all of the current materials produced by the Precast/Prestressed Concrete Institute—manuals, periodical publications, brochures, and other printed and web-based offerings—to provide designers with a one-stop reference for designing with precast concrete. Extensive annotations allow users who are so inclined to research any topic in greater depth (for more information on the format, see the section “How to Use This Manual”).

Precast concrete building systems have proven to be highly adaptable, with new design concepts and technological advances arising more frequently each year. To accommodate this rapid evolution, this manual was designed to be easily updated with the latest information on design concepts and techniques. The availability of new information will be announced on the PCI website www.pci.org, and, as always, the extensive technical resources of PCI are available with a call or a click.

Finally, this comprehensive resource can serve as not only a quick reference, but also as a place to start for stimulating design ideas. I encourage you to use it when new projects have been commissioned as well as when your imagination needs a jumpstart.

James G. Toscas, P.E., President





HOW TO USE THIS manual

A Guide to Designing with Precast/Prestressed Concrete was designed for easy reference to all information about precast concrete required by building developers, architects, engineers, and others on the construction team. The manual provides a summary of available documentation and information available from the Precast/Prestressed Concrete Institute (PCI).

The manual is divided into chapters that provide a comprehensive overview of all aspects of the building process in which precast concrete plays a role.

The manual has been designed to allow updates and expansions as they become available and new technologies and documentation are created. These updates will be provided to manual users. Current manual owners may contact PCI at (312) 786-0300 or info@pci.org to learn if updates to their version are available.

To learn more about any of the topics and information noted in this manual, or to obtain hardcopy versions of the materials and manuals noted in this book, contact PCI or your local precaster.

CHAPTER ONE — Introduction

A general overview of precast's history, benefits, components, and technological advancements in recent years.

CHAPTER TWO — Building Types

A pictorial presentation of the wide range of building types in which precast concrete has been used successfully in both structural and architectural applications.

CHAPTER THREE — Design Considerations

A review of some of the key design considerations that arise in constructing a building and how precast concrete can be used to aid in meeting these challenges.

CHAPTER FOUR — Components, Systems, & Connections

A detailed description of each type of precast concrete component and its capabilities, the systems in which the material is used, and documentation of connection systems among components and with other materials.

CHAPTER FIVE — Precast Concrete Guide Specifications

Information on guide specifications for both architectural and structural precast concrete.

CHAPTER SIX — PCI Resources

Indexes that offer a complete listing of available resources from PCI as well as provide an aid in locating a particular subject mentioned in the manual. The index is coded to the chapter and page location within that chapter (e.g., 6A-10 means the 10th page in Chapter 6).

EACH SECTION INCLUDES TWO SETS OF DOCUMENTATION:

References are listed in the body text, with the complete annotation listed at the end of the section. These explain where the facts used in the text are more fully documented or the location for the source of the information used. A Reference listing indicates that all material between the previous and the new citation was derived from the reference source noted.

Resource lists that follow the reference lists at the end of each section provide additional literature and references that are currently available from PCI. These materials can be acquired from PCI for free or a nominal cost (depending on the piece) by requesting a copy of the piece by reference number and/or title.

All of the material noted in the References and Resources was taken from existing and current resources available through PCI. All of these resources can be accessed on the web at PCI's website, www.pci.org. Each section of the manual is listed along with the corresponding materials. To learn more details about any topic summarized in this manual, go to the section listing at the site and click on the appropriate link.



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CHAPTER
INTRODUCTION

One

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What Is Precast Concrete?

Precast concrete consists of concrete (a mixture of cement, water, aggregates and admixtures) that is cast into a specific shape at a location other than its in-service position. The concrete is placed into a form, typically wood or steel, and cured before being stripped from the form, usually the following day. These components are then transported to the construction site for erection into place. Precast concrete can be plant-cast or site-cast, but this book deals specifically with plant-cast concrete.

Precast concrete components are reinforced with either conventional reinforcing bars, strands with high tensile strength, or a combination of both. The strands are pretensioned in the form before the concrete is poured. Once the concrete has cured to a specific strength, the strands are cut (detensioned). As the strands, having bonded to the concrete, attempt to regain their original untensioned length, they bond to the concrete and apply a compressive force. This “precompression” increases load-carrying capacity to the components and helps control cracking to specified limits allowed by building codes (see References 1-2.)

Precast components are used in various applications and projects of all types. Key components include:

- **Wall panels**, which can include an inner layer of insulation and be load-supporting if desired;
- **Spandrels**, which generally span between columns and are used with window systems in office buildings or in parking structures;
- **Double tees**, so named due to the two extending “stems” perpendicular to the flat horizontal deck. These tees are often used for parking structures and buildings where long open spans are desired;
- **Hollow-core slabs**, which are long panels in which voids run the length of the pieces, reducing weight while maintaining structural strength;
- **Columns and beams**, including columns and a variety of beam shapes;
- **Bridge components** for both substructure and superstructure designs, including girders in a variety of shapes, box beams, and deck panels; and



- **Piers, piles, caps** and other supporting components for bridges. (See Chapter 4, “Components, Systems & Details,” and Reference 3.)



Baha'i Temple; Wilmette, Ill.; Photo: ©2006 KEL Photography.

Prestressed concrete has been used in European buildings and structures since the early 1900s. The Baha'i Temple in Winnetka, Ill., which began construction in the 1910s, also used architectural concrete techniques to build its façade. But it wasn't until the 1950s that prestressing and, later, precast concrete techniques became a significant influence in the American construction industry.

The first true U.S. project to incorporate prestressed concrete components was the Walnut Lane Memorial Bridge in Philadelphia, Pa., which was built in 1950 with prestressed concrete girders. The concept was the brainchild of Professor Gustave Magnel of Belgium. He initially developed the concept of prestressed concrete in the 1940s while at the University of Ghent. After he visited America in 1946 and published a book on the concepts, his ideas began to grow in popularity (see References 4-5.)



Walnut Lane Memorial Bridge; Philadelphia, Pa.

Despite the relative youth of precast concrete in the United States, the advantages of this medium are apparent to owners, designers, and contractors. (See Chapter 1B, “Design Advantages” and References 6-8.) Key benefits include:

- **Speed of construction**, owing to the ability to begin casting components for the superstructure while foundation work is in progress. Precast concrete components can also be cast and erected year-round, without delays caused by harsh weather;
- **Aesthetic flexibility**, due to the variety of textures, colors, finishes and inset options that can be provided. Precast is extremely plastic and can mimic granite, limestone, brick, and other masonry products. This allows it to blend economically with nearby buildings finished with more expensive materials;
- **Design flexibility**, resulting from the long-span capabilities to provide open interiors;
- **Durability**, which allows the material to show minimal wear over time and resist impacts of all types without indicating stress;
- **Energy efficiency**, due to the material's high thermal mass. This is enhanced by the use of insulated panels, which include an insulated core;
- **Environmental friendliness**, as seen in its contributions to achieving certification in the Leadership in Energy & Environmental Design (LEED) program from the U.S. Green Building Council (USGBC); and
- **High quality**, resulting from the quality control achieved by casting the products in the plant. Plants certified by PCI undergo stringent audits of their quality procedures, ensuring the quality of fabrication in these facilities.

Designers and fabricators continue to expand the boundaries of precast concrete's capabilities as they use the material to confront new challenges. Because it is a fabricated product manufactured under controlled conditions, its production continues to be refined and improved. In recent years, new capabilities have been added to enhance its uses. These include:



Hearst Tower, Charlotte, N.C.; Architect: Small, Reynolds, Stewart, Stewart & Associates Inc., Atlanta, Ga.
Photo: Carolina Photography Group.

- **Total precast structures**, in which architectural and structural components are combined into a single component and used with other structural components such as columns and beams, flooring components, and stair and elevator shafts (see Chapter 4B, “Precast Concrete Systems”);
- **Self-consolidating concrete**, which incorporates higher proportions of fine aggregates and water-reducing admixtures to increase fluidity. This added workability allows the material to fill forms with complex shapes and speed casting. It also improves freeze/thaw durability and bond strength while creating a smooth surface without the need for finishing (see Chapter 1E, “Technical Innovations”);
- **Ultra-high-performance concrete (UHPC)**, which provides a compressive strength as high as 30,000 psi (compared to a more typical 5,000 to 8,000 psi for precast concrete components and 8,000 to 15,000 for high-performance concrete) (see Chapter 1E, “Technical Innovations”); and
- **Seismic connections**, which have been tested through the PCI-cosponsored Precast Seismic Structural Systems (PRESSSS) research program. The research created five new approaches, using existing technology in different ways, to enable buildings to withstand seismic events. These techniques allow buildings to withstand high seismic forces and can even re-right the building after the event (see Chapter 4B, “Precast Concrete Systems”).

As a fabricated material, precast concrete continues to evolve as new designs require new solutions and members of the design team push the boundaries of what can be achieved. New admixtures, concrete mixtures, fabrication techniques, and other innovations continue to change and expand the applications of the material and its benefits to owners, designers, engineers, contractors, and end users.

REFERENCES:

1. Chapter 1.1.1, “Background,” and Chapter 1.1.2, “Features and General Principles,” PCI MNL-120-04: *PCI Design Handbook, Sixth Edition*.
2. Chapter 1.1, “Manual Contents and Concepts,” PCI MNL-122-89: *Architectural Precast Concrete, Second Edition*.
3. Chapter 1.1.3, “Common Products,” PCI MNL-120-04: *PCI Design Handbook, Sixth Edition*.
4. Part 1, Chapter 1, “An Industry On The Rise,” *Visions Taking Shape: Celebrating 50 Years of the Precast/Prestressed Concrete Industry*; Cherbo Publishing Co. with PCI, 2004.
5. Chapter 1.2, “Applications of Architectural Precast Concrete,” PCI MNL-122-06: *Architectural Precast Concrete, Third Edition*.
6. Chapter 1.3, “Advantages of Architectural Precast Concrete,” *Architectural Precast Concrete, Third Edition*; PCI, 2006.
7. MK-35-03: *Precast Concrete Makes The Grade For K-12 School Facilities*; 12 pp., 2004.
8. MK-34-03: *Precast Concrete Panels: Tilt-Up Doesn't Measure Up*; 12 pp., 2004.

OTHER RESOURCES:

Architectural Precast Concrete Color and Texture Selection Guide, 2nd Edition; PCI, 2003.

Part One, Chapter Two, “The Pioneers,” *Visions Taking Shape: Celebrating 50 Years of the Precast/Prestressed Concrete Industry*; Cherbo Publishing Co. with PCI, 2004.

Part One, Chapter Three, “Concrete Ideas,” *Visions Taking Shape: Celebrating 50 Years of the Precast/Prestressed Concrete Industry*; Cherbo Publishing Co. with PCI, 2004.

Part One, Chapter Four, “Built To Last (PCI's Top 50 Most Significant Precast Concrete Projects),” *Visions Taking Shape: Celebrating 50 Years of the Precast/Prestressed Concrete Industry*; Cherbo Publishing Co. with PCI, 2004.

Part One, Chapter Five, “Voice of the Industry,” *Visions Taking Shape: Celebrating 50 Years of the Precast/Prestressed Concrete Industry*; Cherbo Publishing Co. with PCI, 2004.

Part Three, “Looking Ahead,” *Visions Taking Shape: Celebrating 50 Years of the Precast/Prestressed Concrete Industry*; Cherbo Publishing Co. with PCI, 2004.

ASCENT:

“Past Is Prologue To Precast's Future,” *ASCENT*, Winter 2004; pp. 32-37.

“PCI Regional Offices Offer Design Support,” *ASCENT*, Winter 2004; pp. 38-40.

“The 50 Most Significant Precast Concrete Projects,” *ASCENT*, Winter 2004, pp. 10-31.

Design Benefits

Precast concrete offers a wide range of benefits and advantages to the designer to help meet all of the owner's goals.

Precast concrete's most dramatic benefit may be the speed with which it can be designed, cast, delivered, and erected. This can ensure that projects stay on schedule and meet tight deadlines. Precast concrete can speed the construction process in a variety of ways.

Precast concrete components can be fabricated while foundation work progresses, giving contractors a significant headstart before the site is available. As the single-source supplier for a large portion of the structural system, precasters help maintain the critical-path scheduling required to meet deadlines. Precasters can also offer a high degree of technical assistance to speed the process.

Precast concrete components can begin to be erected shortly after foundations are ready and can be installed quickly, often cutting weeks or months from the schedule. This allows construction to get into the dry more quickly and enables interior trades to begin work earlier. The fast enclosure also decreases concerns for weather or material damage during erection, reducing the contractor's risks and costs.

Because precast components are fabricated under factory-controlled conditions at the plant, harsh winter weather does not impact the production schedule or product quality. This enhances the construction timetable by eliminating the need to add "cushions" to the timetable to accommodate unforeseen schedule creep due to delays caused by weather or site requirements. Precast components also can be erected through the winter months to meet a tight schedule, cutting overhead costs and readying the building for faster occupancy.

Precast concrete insulated sandwich panels provide a finished interior wall that avoids the time and cost of furring and drywalling while still providing energy efficiency. Using hollow-core slabs to combine ceiling and flooring units can speed construction further.

For more about this topic, see Chapter 1D, "Construction Issues," Chapter 3D, "Initial & Life-Cycle Costs," and References 1-5.



*Panel-to-panel connections were designed to expedite construction of the University of Nebraska Duplex housing complex in Nebraska.
Architect: Kenneth Hahn Architects, Omaha, Neb.;
Photo: Tadros and Associates.*

DESIGN FLEXIBILITY

Architectural precast concrete panels can be sculpted to resemble a wide range of finish materials, including limestone and brick. This substitution ensures the building blends with nearby structures, whether contemporary or historic, or projects its own striking, cutting-edge appearance while meeting a tight budget.



*Eagleton Courthouse, Kansas City, Mo.;
Architect: Hellmuth, Obata + Kassabaum, St. Louis;
Photo: Hellmuth, Obata + Kassabaum.*

A brick façade can be easily achieved with precast concrete using inset thin-brick techniques, in which thin (1/2 to 1 in.) clay tiles are cast into the panel's face. Alternatively, formliners can be used to create a molded look on the panel's face that replicates a brick appearance. Either technique eliminates the long scheduling needs of laid-up brick while removing several trades from the site. It ensures a high-quality, evenly spaced appearance that is difficult to achieve with field-laid-up brickwork. And the panelized system provides fast erection of entire walls, speeding construction.

Architectural precast concrete panels offer a plasticity in shapes, curves, and geometries that can interface smoothly with glass and other modern materials. The designer can also add pigment to the concrete and provide several tones within one panel by using various surface finishes. These capabilities give designers more versatility in designing panels while minimizing the number of components. A wide range of finish combinations and textures can be achieved, with more than one finish provided within one component.

Company names, emblems, and other custom touches can be cast into panels, creating unique accents. Glass fiber-reinforced concrete (GFR) can create sculptural forms for custom designs that create a standout facility.

For more about this topic, see Chapter 3B, "Integration & Coordination with Other Building Systems," and References 1-5.

CONTROLLED PRODUCTION

Casting components under controlled factory conditions provides an unsurpassed level of quality assurance. This quality level produces advantages that benefit the project in many ways.

Designers exert more control over the final appearance of the structures using precast concrete because they can view finish and range samples as well as mockup panels prior to full-scale production. The architect and owner can visit the precast plant to monitor progress, ensuring that no surprises arise at the site.

Plant production's high quality-control standards result in tighter tolerances. This approach ensures a smoother, faster fit during erection that speeds construction and minimizes the need for on-site adjustments.

As the single source for so many architectural and structural components, and the source for brickwork, natural stone, or other finishes, the precaster works closely with the construction team to ensure satisfaction with the design and quickly alleviates any on-site challenges that may arise.



When using precast concrete wall panels, several trades and materials are eliminated from the construction process. The impermeable wall structure eliminates moisture migration, which can arise with other construction materials, thus avoiding eventual moisture, mold, and mildew concerns. When present, those problems can result in a deterioration in indoor air quality.

CERTIFIED QUALITY

The precast concrete plants of PCI members meet a stringent quality-control program that encompasses the plant, materials, and personnel. Every plant undergoes two unannounced inspections each year to review their quality-control procedures and ensure that each product meets rigorous standards. More than 120 areas are inspected and tracked over time. PCI certification meets International Building Code requirements and eliminates the need for special inspections.

Certified precast concrete plants bring a host of skills and efficiencies to each job that can aid the construction process, especially if the precaster is brought into the design process early. The architect, with the assistance of the precaster, can create architectural effects, efficient sizes and shapes, value-engineering options, state-of-the-art connection systems, and other aspects that produce aesthetically pleasing, functional, and cost-effective precast concrete designs.

For more about this topic, see Chapter 1F, “Value of Certification,” and References 1-5.

SAFETY AND SECURITY



Lloyd D. George United States Courthouse, Las Vegas, Nev.; Design Architect: Langdon Wilson Architects; Photo: Langdon Wilson Architects.

Precast concrete is a noncombustible material that can meet fire-code provisions with no additional design or spray-on fireproofing material. This resistance speeds construction, eliminates added trades from the site, and provides an inherent level of protection that doesn't need to be activated at the time of a fire. It won't give off lethal smoke and maintains its structural integrity even when subjected to the most intense heat.

Designing with a total-precast system allows the durable structural framework and panels to work together to compartmentalize any fire. This approach can maximize the time for detection, evacuation, and suppression.

Precast concrete panelized systems can meet the requirements for any seismic zone. New connection techniques that help re-right buildings after a seismic event can ensure that buildings aren't permanently or structurally damaged by an earthquake, allowing them to reopen quickly.

The dense mass of precast concrete components and their panelized design help meet federal requirements for blast-resistant structures, as well. Precast concrete can also be used to create planters and other barricades at street level that are prescribed by government regulations.

The off-site fabrication of precast concrete components also enhances safety during construction. It provides a controlled fabrication environment and eliminates trades and job waste from the site.

For more about this topic, see Chapter 3H, “Safety & Security,” and Reference 1-5.

SUSTAINABILITY

Precast concrete helps projects attain several of the rating criteria used by the LEED standards from the USGBC. For instance, the material is typically produced locally, generates no job waste, has no outgassing, and can incorporate fly ash, silica fume, and blast-furnace slag to reduce the amount of cement used. Precast concrete components offer high durability, which means fewer chemicals are needed to keep it clean and maintained.

The use of insulated sandwich wall panels, which typically include 2 in. or more of high-performance insulation between two wythes of concrete, provides high energy efficiency. Precast concrete’s high thermal mass also minimizes energy consumption naturally.

Precast concrete ensures that building users will have a safe and healthy workplace environment throughout the facility’s long lifetime. The material’s minimal joints or water-penetration points ensure that no devastating mold growth will occur, and it offers no outgassing that can cause deteriorated air quality.

For more about this topic, see Chapter 3E, “Sustainability & LEED,” and Reference 1-5.



The United States Department of Transportation facility in Lakewood, Colo., used an all-precast concrete structure to help it achieve LEED Silver Certification. Design Architect: Oz Architecture; Architect/engineer: Opus Architects & Engineers Inc.; Photo: Oz Architecture.

LAYOUT FLEXIBILITY

Precast hollow-core slabs and double tees provide long, clear spans, opening interior spaces in projects from office buildings to parking structures in order to allow designers to maximize functional layouts. Loadbearing precast concrete wall panels can reach heights of 55 ft, while double tees can span 80 ft or more.

Precast concrete insulated sandwich wall panels provide a thin cross-section that maximizes interior floor space while minimizing the footprint. A typical precast concrete panel is 8 in. thick (3 in. exterior wythe, 2 in. insulation layer, 3 in. interior wythe). Saving space over other construction materials throughout the building cuts material costs, speeds construction, and produces a more energy-efficient building.

For more about this topic, see Chapter 4A, “Components,” and Reference 2.

LOW MAINTENANCE



Park Tower, Chicago, Ill.; Architect: Lucien Lagrange & Associates Ltd., Chicago; HKS Inc., Dallas, Tex.; Photo: Precast Concrete Specialties, Inc.

Precast concrete panels require caulking only every 15 to 20 years to maintain their reliability. This makes precast concrete easier to maintain than other façade materials. The panels' fewer locations for moisture penetration prevent unsightly stains or damage to interiors. Joints can be inspected quickly to find any locations that need attention. Precasters work with designers and owners to ensure that building management understands the few maintenance needs required to keep the building looking new for decades.

For more about this topic, see Chapter 3D, "Initial & Life-Cycle Costs," and Reference 1-5s.

ACOUSTICAL CONTROL

Precast concrete's mass and insulation create strong acoustical performance, producing a quieter, less disruptive environment, particularly in taller structures that use hollow-core slabs for flooring. Its mass and damping qualities also reduce vibration for buildings where that is desirable, including housing, schools, and hospitals.

For more about this topic, see Chapter 3G, "Acoustics," and References 2-3.



Bemidji High School, Bemidji, Minn.; Photo: © Don F. Wong.

MOLD RESISTANCE

Because concrete is an inorganic material, it will not aid the growth of mold spores. Typical panel layouts provide fewer locations where moisture can penetrate, and these joints can be inspected and repaired quickly and easily if necessary. In addition, precasters work with designers to create a system of water control to ensure that rainwater is directed away from the building in an efficient manner to alleviate any residual moisture that could penetrate the building or allow mold to gain a foothold.

For more about this topic, see Chapter 3F, "Health & Indoor Air Quality," and Reference 2.

CONTROLLED ENVIRONMENTS

Precast concrete designs can be provided for buildings with functions that require extreme cleanliness, particularly food-preparation, -processing, and -delivery areas or laboratory research areas. The durability of precast concrete panels ensures that they can resist mildew and bacteria while withstanding regular cleaning by harsh chemicals.

Freezer compartments that often are required in food-processing plants can be created with precast concrete panels, providing the tight insulation required while also supplying separation from surrounding surfaces that can induce humidity or groundwater to freeze and disrupt the structure.

For more about this topic, see Chapter 2B, “Building Types: Institutional and Public Buildings: High-Tech and Laboratory Facilities,” Chapter 2D, “Building Types: Industrial Buildings: Food-Processing Plants,” and Reference 6.



University of Illinois Molecular Research Biology Building, Chicago, Ill.; Architect: Lohan Associates; Photo: Hedrich-Blessing.

EXPANSION CAPABILITIES

Precast concrete systems can provide the option for expanding a building in the future when needs grow or change. This can be accomplished by either adding new adjoining space or merging the new space with the existing structure. In some cases, an existing facility clad with precast concrete panels can be expanded by disconnecting the non-loadbearing panels on the end wall from the framing and adding panels and framing on each side. With the new structure in place, the end panels can be replaced.

Precast concrete designs also can provide structural support, so a second level can be added onto the existing roof if later desired, expanding the structure without eliminating any green space.

Because the panels are produced under factory-controlled conditions, the textures and designs of the new addition can reflect the original aesthetic look created for the existing structure. The result is an addition that offers a similar look to the original precast concrete design.

ECONOMY



Starz Encore Headquarters (total precast), Englewood, Colo.; Architect: Barber Architecture; Photo: David Cornwell Photography.

Precast concrete's speed of construction can eliminate months from a construction schedule, resulting in less time to carry financial bonds, lower contractor overhead costs and risk, elimination of expenses for other trades, and reduced subcontractor costs by giving more responsibility to a single-source supplier.

Total precast concrete systems save by combining both architectural and structural components into one piece. In some cases, panels can have foundation pieces cast into them, eliminating those separate components. A smaller amount of footing is required, due to the thin cross-section of a precast concrete wall compared to a masonry design (8 in. vs. 16 in.). This also reduces the overall weight of the structure, cutting the size of flooring packages by as much as 25% over the cost of a brick/block/steel construction.

These advantages come into play in varying degrees on each project, based on its specific needs, logistics, location, and budget. By working with the precaster early in the design phase, the full benefits possible with precast concrete can be included in the design. Efficiencies in component size, connections, delivery, and erection can be factored into the design, maximizing the benefits offered by precast concrete.

For more about this topic, see Chapter 3D, "Initial & Life-Cycle Costs," and References 1-6.

RESOURCES:

- CD/IGS-1-00: Housing CD-ROM.
- CD/IGS-3-01: Stadiums CD-ROM.
- CD/IGS-4-01: Hollowcore CD-ROM.
- CD/IGS-5-01: Industrial CD-ROM.
- CD/IGS-6-02: Parking CD-ROM.
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- MK-16-98: Precast Concrete Wall Panels: Manufacturing Facilities; 6 pp.
- MK-17-98: Precast Concrete Wall Panels: High-Tech Facilities; 6 pp.
- MK-18-98: Precast Concrete Wall Panels: Food-Processing Facilities; 6 pp.
- MK-19-98: Precast Concrete Wall Panels: Retail Buildings; 6 pp.
- MK-20-98: Precast Panels for Industrial Buildings; 6 pp.
- MK-21-98: Parking Structures: Team Solutions Timeline; 8 pp.
- MK-33-03: Precast Concrete Fire Prevention: Setting The Record Straight; 12 pp.
- MK-34-03: Precast Concrete Makes The Grade For K-12 School Facilities; 12 pp.
- MK-35-03: Precast Concrete Panels: Tilt-up Doesn't Measure Up; 12 pp.
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3. MK-35-03: Precast Concrete Panels: Tilt-up Doesn't Measure Up; 12 pp., 2004.
4. Certified Quality For People, Products and Performance; 10 pp. 2003.
5. MK-21-98: Parking Structures: Team Solutions Timeline; 8 pp., 1998.
6. MK-20-98: Precast Panels for Industrial Buildings; 6 pp., 1998.

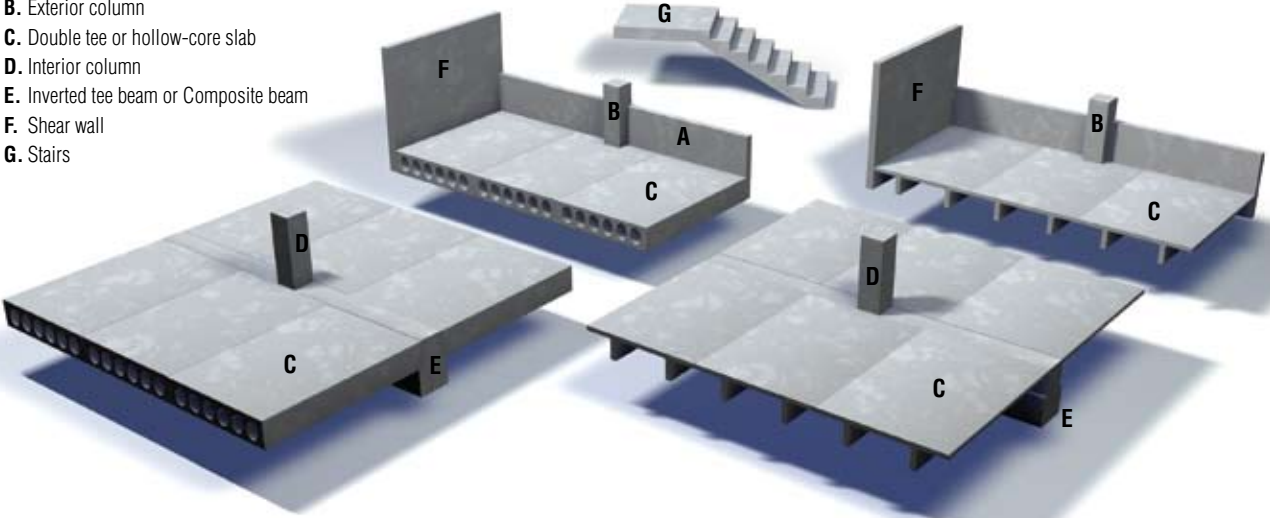


Components & Systems

Precast concrete's plasticity allows it to be cast into a wide variety of shapes and sizes. Although precasters routinely produce custom designs and shapes, designers typically take full advantage of speed and economics by using standard components that can be cast and replicated many times with existing forms. To this end, precasters provide a number of typical components that meet the vast majority of traditional design challenges.

Below are the components used most often in building applications. For details on each of these components, including typical span-to-depth ratios, manufacturing processes and finish details, see Chapter 4, "Systems, Components and Details," and Reference 1.

- A. Loadbearing architectural spandrel
- B. Exterior column
- C. Double tee or hollow-core slab
- D. Interior column
- E. Inverted tee beam or Composite beam
- F. Shear wall
- G. Stairs



HOLLOW-CORE SLAB SYSTEM

DOUBLE-TEE SYSTEM

BEAMS

Horizontal members that support deck components such as double tees and hollow-core slabs, beams typically are considered structural components. Three types cover the majority of uses: rectangular beams, inverted tee beams, and L-beams.

COLUMN COVERS

Column covers are thin, convex, or three-sided pieces that essentially do what their name implies. They provide an architecturally finished exterior for a structural column. Typically, two similar pieces are joined on either side to provide a complete cover for the column, providing whatever shape is required for the finished look.

COLUMNS

Columns typically support cross members such as beams, spandrels, or panels. Traditionally square or rectangular in profile, they are usually cast as multilevel components ranging in length from a single story to six or more levels.

DOUBLE TEES

These components are used primarily as deck, floor, and roof components, contributing in large part to precast concrete's ability to create long spans and open interior plans. They can be used for any type of building but most often are used in parking structures, office buildings, and industrial facilities.

Double tees can be pretopped in the factory to create a flange thickness of 4 in. They also can be field-topped by creating a 2 in. flange and applying a cast-in-place concrete composite topping of 2 to 4 in. at the job site. Roof tees usually have a 2 in. flange and receive roofing materials directly.

HOLLOW-CORE SLABS

Hollow-core slabs, also known as planks, are used in a wide range of buildings as floor/wall components. These include multifamily and single-family housing, schools, hotels, health-care centers, offices, manufacturing facilities, and other structures.

Hollow-core slabs typically measure 8 to 12 in. thick, but they can be made as thin as 4 in. or as thick as 16 in. Long hollow cores, or voids, run the entire length of each piece, giving the material its name. In some applications, the cores can be used to run mechanical and electrical equipment.

INSULATED SANDWICH WALL PANELS

Insulated sandwich wall panels typically include 2 in. or more of high-performance insulation between two wythes of concrete. This configuration provides high energy efficiency and an interior concrete wall that can be finished, avoiding the need for a finish treatment of furring strips and drywall. Precast concrete's high thermal mass also minimizes energy consumption naturally.

Historically favored for industrial buildings such as distribution centers and warehouses, sandwich wall panels' range of finishes and benefits is expanding the component's applications to schools, retail, residential, office, and other uses.



New Street Parking Garage, Staunton, Va.; Architect: Fraizer Associates; Photo: Jason Hottel Photography.

LITEWALLS

Used primarily in parking structures, litewalls are shear walls with central openings through the panel that lessen the weight and allow light to pass through. This added visual space in the structural walls allows daylight to penetrate more deeply into the structure, provides a visual connection for visitors to better orient themselves to their destination, and eliminates visual blocks that can be a security concern.

MODULAR UNITS

Complete precast concrete modular units have traditionally been used for prison construction, but their uses are expanding to include schoolrooms and other applications where a large quantity of similarly sized and outfitted rooms are needed to meet tight deadlines. These modules can be designed for structures from one to twelve levels.



Henderson County Jail, Henderson, N.C.; Photo: Tindall Corporation.

The ability to cast the modules and outfit them with many of their required mechanical systems and accoutrements—including plumbing, electrical, beds, mirrors, and windows—has made them especially popular for prison facilities. The modules are cast as single- or multi-cell units, with as many as four cells in one monolithic component.

The configuration of a double-cell module typically includes a vertical chase between the two cells for mechanical, electrical, and plumbing accommodation. The utilities are stubbed into the chase for final hook-up at the site. Exterior walls are typically insulated with 2 in. of rigid insulation and nonconductive carbon fiber ties, which increase the thermal performance of the structure.

MULLIONS

As the name implies, mullions are support pieces inside a larger void space that typically produce a decorative, geometric appearance. These pieces can create right-angle designs, as in a divided-lite window, or they can be cast at angles, producing a decorative grille effect. These thinner pieces are cast into the overall panel, reducing the number of pieces and providing faster installation than if a different material is used for the dividers or grille work.

PILES



Bath Iron Works Land Level Transfer Facility, Bath, Maine.

Pilings are used to support structures in poor soil conditions, especially in marine environments, due to their excellent adaptability and resistance to corrosion. Smaller pile sizes, 10 to 14 in., are typically used for building projects such as convention centers, hotels, and other large facilities.

Most piles are square, octagonal, or round (cylindrical) in cross-section. Square piles are the simplest to manufacture, and are available throughout the United States. Octagonal piles are gaining popularity due to code changes that make ductility more of a governing requirement for seismic design. Cylinder piles are most often used with bridges where foundation members require exceptionally large axial, buckling, or bending capacities.

Precast concrete piles can be spliced to create longer piles. Spliced piles are used primarily where longer piles are required but transportation needs make the longer lengths more difficult or costly to handle, due to escort needs and the need for specialized rigs. In some areas, piles as large as 115 ft 12 in. can be transported with no difficulty.

RAKER BEAMS

Raker beams are beams cast with an angled surface with right-angled notches spaced along the top surface. The beams are used as support members for single-, double-, and triple-row stadium risers.

SHEAR WALLS

Shear walls provide a solid concrete, standalone structural brace that is typically used in total precast concrete and parking structures. It provides support throughout interior spaces to handle overhead spanning components and to counter lateral loads on the structure. These components are designed to withstand wind and seismic loads. In some cases, they are designed with central voids and are known as litewalls (page 1C-3).

SHEET PILES

Sheet piles are precast concrete structural panels that connect together to form a supportive barrier, typically to act as a retaining wall.

SOLID SLABS

Solid slabs are used as structural deck components similar to hollow-core slabs. Their sizes can vary to meet the structural requirements of the design.

SPANDRELS

Spandrels consist of horizontal members, typically of less height than a traditional floor-to-floor architectural panel. These panels are used in a variety of applications to meet structural-support and architectural needs in parking structures and as cladding for office buildings with long expanses of windows.

In loadbearing designs, these units include an interior ledge, which can support deck components such as double tees and hollow-core slabs. Loadbearing designs also can include pockets cast into the thickness of the spandrel, into which the stem of a double tee fits. Nonloadbearing designs are used as cladding for a wide range of buildings.



Ravens Stadium at Camden Yards; Baltimore, Md.

STADIUM RISERS

Stadium risers are used to support seating in stadiums, indoor arenas, performing-arts theaters, and other grandstand-type applications. They can be cast as single-, double-, or triple-row units, with heights designed to create optimum sight lines in the venue. The use of each type of riser will depend on the structure layout and may be dictated by other variables, such as weight and crane access during construction.



STAIRS

Precast concrete stairs can be used in any application where a stair tower or individual steps are required. They are fabricated either in an open-Z configuration, in which the upper and lower landings are cast in one piece along with the tread/riser section, or as shorter components consisting of only the tread/stair section supported by separate landing components.

TOTAL-PRECAST CONCRETE SYSTEMS

Total-precast concrete systems combine a variety of precast concrete components into an entire structural system. Typically, this includes precast concrete columns, beams, and wall panels to create a structural frame, hollow-core slabs or double tees as span members, and wall panels as a cladding. The design can save material, labor, and scheduling costs by combining several components, both architectural and structural, into one piece.



WALL PANELS

Precast concrete wall panels are versatile components that can be used as architectural, structural, or combination elements within a building's design. Wall panels can be designed as loadbearing or non-loadbearing components.

Non-loadbearing panels can be attached to any type of structural frame, including precast concrete, cast-in-place concrete, or steel. They can be erected in a horizontal position, as in a multifamily housing or office application, or in a vertical position, typically used in warehouse designs.

REFERENCES:

1. Chapter 2, "Preliminary Design of Precast, Prestressed Concrete Structures," MNL-120-04: *PCI Design Handbook, Sixth Edition*.

RESOURCES:

- BM-20-04: *Precast Prestressed Concrete Piles Manual*, Chapter 20.
- CD/IGS-4-01: Hollow-core CD-ROM.
- MNL-115-68: *Fundamentals of Prestressed Concrete Design*.
- MNL-119-90: *PCI Drafting Handbook, Second Edition*.
- MNL-120-04: *PCI Design Handbook, Sixth Edition*.
- MNL-122-07: *PCI Architectural Precast Concrete Manual, Third Edition*.
- MNL-126-98: *Manual for the Design of Hollow Core Slabs, Second Edition*.
- MNL-135-00: *Tolerance Manual for Precast and Prestressed Concrete Construction*.

Construction Issues

Owners and architects face a wide range of issues when designing and constructing their project, beginning with selection of the construction team, proper siting, and establishing infrastructure needs. In many cases, precast concrete manufacturers can aid in creating efficiencies and economies if they are involved in the project from the earliest design phases.



Logan International Airport Central Parking Garage Expansion, Boston, Mass.; Architect: TAMS/Fennick/McCredie Architecture Ltd.; Photo: Blakeslee Prestress Inc.

ADAPTING DESIGNS TO PRECAST CONCRETE

Precast concrete components can provide a number of advantages to a project, but these advantages can be maximized only if the design accommodates the material from the conceptual stages. Using precast concrete components to construct a design that was originally planned as a cast-in-place project, for instance, will require changes and adaptations to the precast concrete pieces to create the monolithic style the cast-in-place design provided. Those changes may not work to precast concrete's efficiencies, creating a design that is more cumbersome and difficult to erect than one in which precast concrete was the material of choice from the start.

At best, precasters should have the opportunity to value-engineer an existing design to make full use of the precast concrete's efficiencies. For instance, precast concrete can provide dense and durable mixes that can provide higher strength, making it easier to create long spans and eliminate columns. Value-engineering the design can allow the designers to reduce costs and expand design flexibility, opening the door to other potential changes.

DESIGNING WITH PRECAST CONCRETE

The precaster can provide information on a variety of topics that will impact the ultimate design, including options for performance characteristics, durability requirements, life-cycle needs, and costs. When the construction team understands the performance capabilities that can be reached and each option that can achieve those goals, the proper solutions become apparent.



*Jefferson Street Parking Ramp, Wausau, Wis.;
Architect: Mudrovich Architects;
Photos: Precast Concrete Specialties, Inc.*

Precasters can consult on the project early on without having to be given a commitment to producing the components they help conceptualize. After the project is designed with the precast concrete components outlined, the job can be put out to bid among a variety of precasters. This approach ensures that low costs are maintained while still achieving maximum value from precast concrete's capabilities.

The precaster can provide significant input on a variety of topics of critical importance to the project's ultimate design. Some of these topics include:

- Mix durability and strength;
- Panelization (sizes and layout);
- Bay sizes;
- Repetition possibilities for reducing form materials and cost;
- Efficient shipping sizes and configuration;
- Seismic needs for joints;
- Finish options;
- Connection issues such as prewelding;
- Scheduling, including production timing and sequencing of cranes; and
- Cost data, including helping to create a guaranteed maximum price.

For more on this topic and the responsibilities of both the architect and the precaster in the design and construction process, see Chapter 3C, "Team Responsibilities."

KEY DESIGN ELEMENTS

Precasters can aid designers with a variety of key design elements that must be considered beyond simply manufacturing the components, especially when using total precast concrete structural systems. These factors include:

- **Structural considerations.** These aspects include placement of columns and beams, number of structural supports, and other criteria. In parking structures, they also can include helping to devise the ramp configuration and determining how many supported levels will be needed;
- **Frame analysis.** With tighter seismic requirements across the country, former structural designs are no longer sufficient in some locations. The precaster can work with the engineer of record to find a precast concrete connection system that will meet the seismic needs of the specific site;
- **Aesthetics.** Precasters can provide a range of aesthetic options that can eliminate significant budget concerns by replicating more expensive materials such as laid-up brick, limestone, granite, and cut stone. These options allow the budget to be shifted to other areas where it is needed. The ability to cast more than one color into an architectural panel and to use formliners to create sculptural looks provides more flexibility while reducing costs;





- **Code compliance.** Precasters can supply expertise in meeting structural and fire codes, especially regarding the latest seismic conditions. Precast concrete's noncombustible composition eliminates the need to treat structural elements to protect against fire, and precast concrete stairwells and elevator cores readily meet building-code requirements;
- **Durability.** Owners' concerns about long-term maintenance and replacement needs can be alleviated by using precast concrete mixes that offer more strength and durability. Precast concrete manufacturers typically use type III high early-strength cements as well as extremely low water/cement ratios in their casting processes. This results in 3000 to 5000 ksi design strengths overnight, which routinely translates into 7000 to 9000 psi in field applications; and
- **Parking attributes.** Because of the large percentage of the budget for these facilities devoted to their structure, precasters can provide significant help in completing these designs. Among the aspects where early involvement by the precaster can help create an efficient design are these areas:

Security, by creating designs that help open interior spaces and allow daylight to reach into the space;

Drainage, by designing components' slope and joint locations to ensure that water will drain efficiently and completely, avoiding ponding or stagnation that could create a dowdy image or cause corrosion;

Traffic flow, by creating column spacings and ramp layouts that ensure smooth flow to the exits;

Exit designs, which can be located at efficient locations for access to infrastructure and designed with eye-catching appearances that lead drivers to the appropriate points; and

Cashiering options, which can impact how the space is laid out, with paying before or after retrieving the car, magnetic-strip access, and passes impacting how the space is laid out most efficiently.

ERECTION CONSIDERATIONS

Once the site is selected and the design is approved from structural, aesthetic, and budgetary aspects, there are additional considerations with which the precast concrete manufacturers can help create an efficient construction process. These include:

- **Site restrictions**, including nearby buildings that will require special efforts to maneuver around to bring in materials or erect components. In many cases, staging areas can be located nearby, away from the congested area, or trucks can be picked directly as they arrive each day with the scheduled components, avoiding the need for space at the site for storage;
- **Owner requirements**, such as needing minimal disruption to the site so business can continue to be conducted or customers can access adjoining locations. Owners can also require designs to match existing aesthetics or even align with existing buildings for walkways or connecting bridges between them. Precasters can help with these various requirements, including working in off-peak hours as needed;



- **Site logistics**, including the need to close off streets or avoid damage to a wooded location;
- **Scheduling**, to ensure that each trade has access to the needed spaces when those crews have been scheduled to be there. The ability of precast concrete to enclose the shell quickly and get the project into the dry helps expedite scheduling and allows interior trades to begin work earlier; and
- **Project management**, such as bringing all of the elements together rather than keeping each construction-team member focused on a specific element of design, construction, materials, or systems.

LONG-TERM CONSIDERATIONS

Buildings, and particularly parking structures, will benefit from a long-term maintenance program that ensures that the project retains its durability and aesthetic appeal throughout its life. In parking structures, a maintenance program is a major part of the operating budget and should be considered from the inception of their design.

The precaster can help the owner create a maintenance timetable that ensures that the structure receives the appropriate attention. Such a program includes a monitoring schedule that allows the owner's representative to inspect the structure quickly and thoroughly. This takes a small amount of time with precast concrete designs because the regular joint spacing reduces the random cracking that is common with some other materials.

As joints and cracks are the most common sources of maintenance problems such as spalling from freezing and thawing, inspectors can quickly and precisely locate the most likely trouble spots.

The precaster can also supply information on how to maintain the structure, including when to inspect joints and sealants and how often to update caulks or toppings. In some cases, precasters will even offer a warranty to assure owners that the materials used in construction will meet their goals, provided maintenance is performed as scheduled. (For more on this topic, see Reference 1.)

REFERENCES:

1. MK-21-98: *Parking Structures: Team Solutions Timeline*.

RESOURCES:

- MK-21-98: *Parking Structures: Team Solutions Timeline*.
 MK-22-98: *The Precast Prestressed Advantages for Owners and Developers*.
 MK-23-98: *Parking Structures: Tips & Techniques*.
 MNL-115-68: *Fundamentals of Prestressed Concrete Design*.
 MNL-120-04: *PCI Design Handbook, Sixth Edition*.
 MNL-122-07: *PCI Architectural Precast Concrete Manual, Third Edition*.



Fifth and Lafayette Parking Structure, Royal Oak, Mich.

Technical Innovations

As a fabricated material produced under closely controlled plant conditions, precast concrete provides the capability to adapt its composition and design to new techniques that arise. As a result, architects, engineers, and precasters continue to push the boundaries of the material's applications and design parameters.

Some of these innovations develop as designers require new technologies to meet specific design challenges. Others arise as precasters find new mixes and casting techniques to make the material's applications more efficient or extensive. Some relate to aesthetic improvements, others impact functional capabilities, and still others provide benefits in both areas. In all cases, the goal is to continually improve the material to produce better looking, more economical, and more efficient designs.

SELF-CONSOLIDATING CONCRETE

Self-consolidating concrete (SCC) incorporates high-range water-reducing admixtures that significantly increase the material's workability and fluidity. As a result, it flows quickly into place, fills every corner of a form, and surrounds even densely packed reinforcement.



Self-consolidating concrete flows quickly into place to fill every nook, leaving no voids and producing a smooth, densely packed finish.

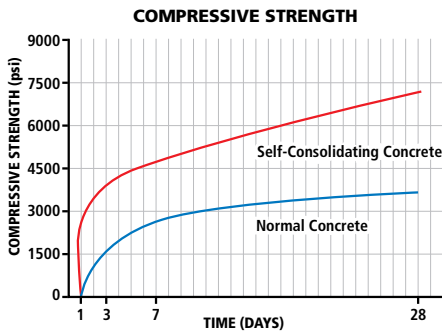
The two key attributes of self-compacting concrete are its high degree of workability and its stability during and after placement. SCC's workability is typically characterized by using a modification of the traditional ASTM C 143 slump test method, called the slump flow test.

In this procedure, the concrete is not rodded after placement in the slump cone, and the horizontal spread of concrete (slump flow) is measured instead of the vertical slump. This test measures the unconfined fluidity of the concrete and gives a relative indication of how far the concrete can travel. The spread is generally between 18 and 30 in.

The concrete's stability is an indication of its ability to resist segregation of the paste from the aggregates. Although there is no standard test to measure SCC stability, some of the flow measurements, such as slump flow, provide a qualitative assessment of the concrete's stability.

In general, setting time requires 30 to 90 minutes longer than conventional concrete. Accelerating or retarding admixtures can be used to produce concrete with the desired setting characteristics.

A variety of advantages can be derived from the use of SCC that benefit the owner and designer. These include:



This chart contrasts the compressive strengths of SCC and normal concrete. SCC can attain significantly higher early and 28-day strengths.

- **High quality.** Because the material flows so readily to fill any gaps, no voids or “bug holes” develop. This reduces the time needed to inspect each component, as well as any labor or time to rub the pieces redundant to create a smooth finish. It produces an aesthetically superior finish;
- **Aesthetic value.** The smooth finish that can be created produces an aesthetically pleasing component without any additional finish. SCC also produces a consistently lighter color with reduced discoloration;
- **Speed.** Because SCC flows so smoothly, it can be poured quickly and eliminates the need to vibrate the concrete into tight spaces and around densely packed reinforcement. That expedites the entire production process. The speed with which it gains strength also eliminates the need for steam or heat curing of concrete to facilitate early strength gain. SCC will create fast turn-around and reduced cycle times;
- **Design flexibility.** Because SCC flows so readily into thin sections and details, it opens the potential for using complex shapes and intricate surfaces. SCC works particularly well with vertical components that include obstructions to the form at the top, such as tall columns with blockouts. It alleviates concerns about aggregate reaching the bottom of the form and not segregating due to obstructions. It also ensures no patching of holes after casting or potential damage to pieces during vibration. This is especially significant for delicate panels, such as those with brick insets; and
- **Durability.** The material's ability to remain stable during and after placement maximizes the structural integrity and durability of the concrete. The admixtures provide a higher compressive strength than traditional concrete, making it substantially stronger. It also offers less permeability due to the high consolidation of material, allowing it to resist chemical attack and improve the component's durability. It provides a high modulus of elasticity, ensuring low elastic deformation of the concrete under dynamic and static loads (see Reference 1).



Type	Slump/Spread Ranges
Normal	<8 in. (200 mm) slump
Self-consolidating	18 to 26 in.+ (450–600 mm)+ spread

Source: Master Builders Inc.

ULTRA-HIGH-PERFORMANCE CONCRETE (UHPC)

Ultra-high-performance concrete (UHPC) consists of steel fiber-reinforced, reactive-powder concrete that provides a compressive strength of 30,000 psi, more than twice that of any high-performance concrete used to date. The material was developed by Bouygues S.A. in Paris, France, in 1995 and has been produced by LaFarge S.A. in Paris.

The basis for its enhanced properties is a mix design specifically engineered to produce a highly compacted concrete with a small, disconnected pore structure. Eliminating coarse aggregate and substituting finely ground powders creates the structure. This combination minimizes the paste-aggregate bond-failure mechanism that limits the strength of typical high-performance concretes.

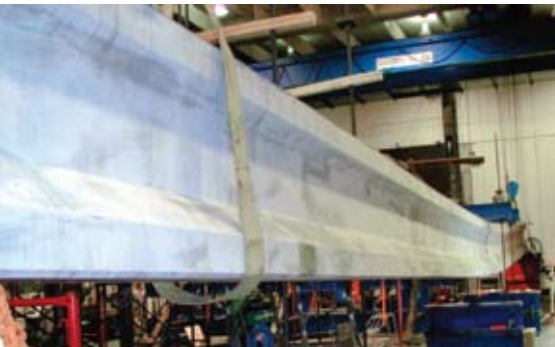
The material also includes fine sand, quartz flour, and steel or organic fibers measuring 1/2 in. long and 6 mm in diameter. These fibers are responsible for much of the tensile strength and toughness of the material. UHPC provides significant postcracking strength due to the large number of fibers in the matrix confining the material.

Tests on the material have been conducted at the Turner-Fairbank Highway Research Center Structures Laboratory in McLean, Va. During the tests, an 80-ft-long girder donated by LaFarge and Prestress Services deflected 19 in. before failing. The beam deflected 12 in. with no visible cracking, including examination under 300% magnification. When the beam did fail, it occurred because the prestressing strand broke at the single location where gross cracking was observed.

Both I-beams and roof beams were cast initially. The roof panel was found to be so strong that it could be cast 2 in. thick at its maximum depth.

Precasters have learned that batching and sorting with this material must be done differently, requiring a different setup for the precasting operation. Batching requires being able to handle very fine aggregates as well as the sharp steel fibers that make up about 2% of the mixture. The fibers are typically delivered in crates and transferred to the batching operation with pitchforks or similar tools. The sharp edges stick out from the components when first set, requiring careful handling.

The incredible strength of the UHPC components means that component designs need to be altered to take advantage of the material's abilities. Current designs allow space for significant strand, for instance, and using UHPC could change the typical stout, compact shape to a thinner and lighter design. The best shapes to maximize the material's use are still being studied and will depend on specific applications (see References 2-3).



Ultra-high-performance concrete, shown here being tested by the Federal Highway Administration to a deflection of more than 18 in., can achieve strengths of 30,000 psi.

CARBON-REINFORCED PRECAST CONCRETE

Carbon-reinforced precast concrete, currently produced under the name CarbonCast by Altus Group, a nationwide consortium of precast concrete companies, uses conventional steel for primary reinforcing and a resin-bonded, carbon fiber grid for secondary reinforcing and shear transfer. The use of a carbon-based product eliminates the potential for corrosion in the precast concrete member caused by secondary reinforcing. This, in turn, eliminates the excess concrete cover normally needed to protect steel from corrosion that results from exposure to moisture.

Steel mesh-reinforced precast concrete components require coverage of 1 to 3 in. to minimize the potential for water penetration and the corrosion it causes. The carbon fiber grid reduces that coverage to about 1/4 in., as it only needs cover to function for structural integrity, not corrosion protection. As a result, the CarbonCast pieces are lighter in weight and can have thinner profiles than steel-reinforced products.

In addition, the concrete taken out of the precast concrete component can be replaced with expanded polystyrene (EPS) insulating foam, making the piece considerably more energy efficient while still retaining a thin profile.

The carbon fiber material used in the grid has a tensile strength of 550 ksi, up to seven times that of steel reinforcing. It can minimize shrinkage cracks up to 50% better than steel mesh. The epoxy-coated composite, made with cross-laid carbon fiber, has a component cost that is currently more than that of the steel it replaces. But that cost can be returned through lessened material cost in structural supports, lighter weight for handling and erecting, no maintenance needed to resist corrosion, and higher energy efficiency.

Several components have been produced to date. These include architectural wall panels, insulated sandwich wall panels, and double tees. Multiple-unit residential products comprise foundation panels, wall panels, and floor/roof decks (see Reference 4).

'MOLDED' CONCRETE

A recent project in Calgary, Alberta, Canada, shows the versatility that can be achieved by adapting precast concrete components as new challenges arise. In this design, precast concrete was used to create 3/4-in.-thick, arched precast concrete canopies for a light-rail train station. The designers used ultra-high-performance, fiber-reinforced concrete (UHPC). The concrete offered a compressive strength of 22,000 psi and flexural strength of 3600 psi.

The material was cast into 24 off-white, thin-shell precast concrete canopies that measure 19 ft 8 in. wide, 16 ft 9 in. deep, 18 ft 5 in. tall, and only 3/4 in. thick. The ultra-thin canopies, which curve in two planes, do not use any passive reinforcements for support.



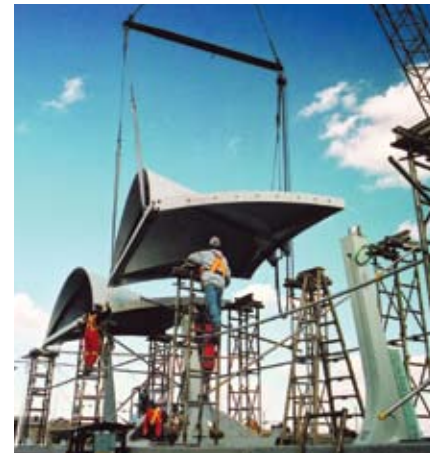
Shawnessy Light Rail Transit Station, Calgary, Alberta, Canada; Photo: © Tucker Photo.



Demolding of the precast concrete canopy element. Photo: © Tucker Photo.



Installation of the prototype canopy at the University of Calgary's Centre for Innovative Technology. Photo: courtesy LaFarge.



Crane set of canopy over assembly cross. Photo: LaFarge.

The canopies, originally designed as steel constructs, were cast using an injection-mold casting technique adopted from other industries. This helped minimize trapped-air voids while providing a uniform finish on all exposed surfaces. The canopies were cast on edge, while the columns were cast vertically. The injection port was placed near the bottom of the forms, so the material would be subjected to head pressure as the form filled.

The canopies' steel form could rotate 90° in either direction from vertical. The first rotation turned the canopy shell upside down in the form. The form's top portion was released to allow unrestrained shrinkage as the concrete set. When it set, the top portion was resecured and the form was rotated 180° to the canopy's upright position. This allowed the piece to be stripped from the form.

The low weight and thinness that can be produced by this “molded” casting concept allows the material to be cast for a wider range of applications. A high-quality finish can be achieved in a durable, quickly erected component (see References 5-6).

OTHER TRENDS

Other trends becoming more commonplace include:

- **Taller, unitized buildings:** Building heights are not being restrained by the use of total precast systems, with even 50-story buildings being designed. Unitized walls also are becoming more common. More buildings are featuring precast concrete panels outfitted with glazing in window openings and even with stud backups applied at the plant. These designs allow the entire panel to be lifted into place with virtually no other prep needed. Since the panels can be fabricated off site while site work finishes, this approach speeds up the project and eliminates on-site congestion (see Reference 7).
- **Earlier input:** Owners, designers and precasters are working together more often at the earliest stages—sometimes before bids are let—to ensure that the most effective designs are produced. Quality materials with precise pricing are already helping to create efficient, cost-effective precast concrete designs early in the process (see Reference 8).
- **Elaborate finishes:** Precasters are creating more complex finishes for architectural panels, surpassing the traditional finishes that designers have expected. Custom formliners, heavier textures, multicolored panels, and intricate designs are becoming more popular. (See Chapter 3A, “Aesthetics” and Reference 9.)
- **Life-cycle focus:** Owners and designers are gaining a better understanding of the importance of life-cycle costs in the overall budget, and that they have more impact on long-term economics than first costs. Precast concrete’s certified quality and high durability will help designers achieve goals for allowing buildings to remain in place longer than other materials can provide. This will require designers to think beyond initial costs, but that paradigm is already beginning to change. (See Chapter 3D, “Initial and Life Cycle Costs.”)
- **Sustainability:** Green building procedures are growing in popularity, spurred by the LEED standards. Among the attributes that make precast concrete an environmentally friendly product are efficiency of production, thermal mass, reflective qualities with lighter aggregates, local production, the use of admixtures such as fly ash to reduce cement content, and the recyclability of both the concrete and reinforcement. (See Chapter 3E, “Sustainability & LEED.”)



The Starz Encore building in Denver, Colo., features several finishes, including a cut-stone style created with a formliner made from actual stone samples.





Precast concrete's noncombustible composition creates passive fire resistance for buildings. Photo: ©Photodisc.

- **Security:** The need for blast-resistant structures and the ability to resist progressive collapse are two areas of growing interest. Precast concrete designs are evolving to meet these needs, and several large projects have been completed that comply with these standards. Structural integrity has become more important, and precast concrete offers the potential to enhance overall integrity without impacting the building's economy. (See Chapter 3H, "Safety & Security.")

- **Fire safety:** Fire-protection standards are becoming more sophisticated. Within the next 20 years, the methods for determining and applying fire ratings will change. These new approaches will benefit precast concrete construction due to its inherent fire resistance. (See Chapter 3H, "Fire Resistance.")

These are only a sampling of the evolutions and innovations that will continue in the coming years. Designers and precasters continue to find new ways to use existing precast concrete technology and to expand its applications to create more efficiently constructed, cost-effective, and aesthetically pleasing structures of all types.

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Value of Certification

From raw materials to installed building components, PCI qualifies the process of manufacturing and erecting precast, prestressed concrete components. This certification of people, products, and performance assures owners, architects, engineers, and contractors that quality is achieved throughout the design, production, and erection phases. PCI certifies the supply chain in three ways: through its products, its people, and its erection performance. Information sheets outlining the details of each program and certified companies are included in this binder in Chapter Four and Chapter Six.

PRODUCTS

Since 1967, PCI's Plant Certification program has ensured that each plant has developed and documented an in-depth, in-house quality system based on time-tested national industry standards. Each plant is inspected twice per year by independent auditors, who inspect the company for each product being manufactured.



In the yard, the auditor ensures that components are stored properly. These double tees have been painted with green dots to indicate that they have passed the precaster's quality control check.



All PCI Producer Members are required to maintain PCI Certification for their plants. Nonmember producers may take advantage of the program as well. This inclusive approach ensures that designers have many bid options available whenever they specify PCI-Certified precast concrete as a standard in their contracts. Owners, architects, engineers, and contractors all benefit from precast concrete plants that have been certified by PCI. The advantages include:

- **Prequalified bidders.** Specifying products from a PCI-Certified plant ensures that bidders have an ongoing quality system in place from precasters that offer the capability to produce a superior product. There are no surprises during construction when quality has been included in the specification process;
- **Expanded design options.** Certified plants can quickly be identified that can produce any special needs or unusual designs the specifier may want to include. Owners and architects are assured that creative building systems can be achieved in a cost-effective manner;
- **Lower costs.** Doing the job right the first time saves material and labor costs. Certification also helps produce uniform, consistent products that eliminate waste due to differences in colors or texture, and minimizes the approval process for mockups;
- **Faster erection.** Quality products mean more efficient production, a systematic staging schedule, and tighter tolerances. Quality-control systems ensure that components arrive on time in the appropriate number and order and then fit together quickly, cutting on-site labor and scheduling costs;
- **Reliability.** Established producers, many of which have been in business for more than 25 years, can be counted on to produce a product consistent with the design specifications. This assures everyone on the construction team that the project will move smoothly, with minimal adjustments or surprises; and
- **No added cost.** There is no cost to the owner or specifier for using a certified plant. The auditing fees are paid by the producer as a cost of doing business.

Certified precast concrete plants bring to each job a host of skills and efficiencies that can aid the construction process, especially if the precaster is brought into the design process early. The precaster can provide input on dramatic architectural effects, efficient sizes and shapes, value-engineering options, state-of-the-art connection systems, and other aspects that produce aesthetically pleasing, functional, and cost-effective precast concrete designs.

Precast concrete plants may be certified in as many as six general groups of products. These six are Group A—Architectural, Group B—Bridge Products, Group BA—Bridge Products with an architectural finish, Group C—Commercial (Structural) products, Group CA—Commercial (Structural) Products with an architectural finish, and Group G—GFRC products.

Architectural and GFRC producers manufacture specially finished precast concrete components and cladding for buildings and other structures. Bridge producers, in Group B, manufacture precast concrete American Association of



For this bridge girder being manufactured, cutting torches are being used to detension the strand.



The slump test is a measure of concrete consistency. It is a way to test that the concrete has been made in accordance with design specifications.

Highway Transportation Officials (AASHTO) girders, bulb tees, piers, and other products used in bridges. Commercial producers, in Group C, provide a wide range of primary and secondary structural products for commercial buildings. Precasters certified in Groups BA and CA produce Bridge and Commercial structural components that also serve as architectural pieces.

Many organizations require PCI's plant certification as part of their specification process. These include government agencies in 29 states and many municipalities including Seattle, Wash., Houston, Tex., Phoenix, Ariz., Portland, Ore., and Las Vegas, Nev.

Federal agencies that require PCI plant certification include the General Services Administration, the Federal Bureau of Prisons, the U.S. Army Corps of Engineers, the U.S. Naval Facilities Engineering Command, the Department of Agriculture, and the Department of the Interior's Bureau of Reclamation. The American Institute of Architects' Masterspec program also requires PCI plant certification (see References 1-2).

PEOPLE



PCI provides three levels of instruction for the precaster's personnel.

The Plant Quality Personnel Certification program, begun in 1985, provides three levels of instruction to produce trained, knowledgeable quality-control personnel. PCI also has created a program to train Certified Field Auditors (CFA), who audit and certify precast erectors, extending personnel qualifications into the field.

Plant Quality Personnel Certification: Conducting an effective quality-control program requires knowledgeable and motivated testing and inspection personnel. These employees must understand the key ingredients that produce overall quality, the necessity for controls, the specifics of how each product is manufactured, and how to conduct precise tests and inspections. PCI has been training quality-control personnel since 1974 and published its first technician training manual in 1985 (see Reference 1).

Three levels of Plant Quality Personnel Certification can be achieved. They are:

- **Level 1:** This basic level requires six months of industry experience and focuses on the fundamental requirements of the many quality-control issues normally encountered in a precast concrete plant. Certification also requires current certification in the American Concrete Institute (ACI) Concrete Field Testing Technician Program, Grade 1;
- **Level 2:** This intermediate level requires one year of industry experience, plus Level 1 and current ACI Level 1 Certification. It provides greater detail in maintaining and improving quality levels, such as tensioning and elongation corrections, effects of accelerated curing, material-control tests, and a variety of plant topics; and
- **Level 3:** The highest level of certification provides significant instruction in concrete materials and technology. Certification requires two years of industry experience, attendance at a four-day PCI school, and attainment of PCI Level 2 Certification.



Sample cylinders are loaded and tested to satisfy the specified strength.

Certified Field Auditor: This program, instituted in 1999, provides training and certification for field personnel, allowing them to conduct field audits of erection procedures in compliance with PCI's standards. Certification ensures that the high quality achieved in the plant through rigorous controls continues through the installation process.

Owners, architects, engineers, and contractors benefit by working with precast concrete plants that have certified quality-control personnel. These employees can provide considerable input through their abilities to produce cost-effective designs, enhance shop drawings, troubleshoot options, and fine-tune concrete mixtures. This input helps cut costs while producing efficient and effective precast concrete components (see Reference 1).

PERFORMANCE (ERECTOR CERTIFICATION)

The Field Qualification program to standardize erection procedures for precast concrete was also introduced in 1999, extending PCI's quality performance standards to the erection process. A certification program was added in 2005. Certification provides customers with the assurance that the quality of manufacturing produced by the rigid factory conditions continues into the field during installation.

The installation process is vital to ensuring the final performance of the finished product in the field. Installing the pieces properly, and without any handling concerns, requires well-trained personnel who focus on key needs and understand every aspect of lifting, maneuvering, and connecting each piece, regardless of shape or size.



All three structures in the Starz Encore complex in Denver, Colo., feature total precast structural systems and were designed, fabricated, and erected in 11 months.



Field Certification training is available to all erectors of precast concrete products, including manufacturing plants, independent erectors, and general contractors. The process allows erectors to demonstrate and declare that they are in compliance with national industry standards and project specifications. It also shows their commitment to an internal quality-control program in accordance with the program created for precast concrete producers.

An erector may qualify in up to three classifications:

- **Category S1 (Simple Structural Systems):** This includes horizontal decking members (e.g., hollow-core slabs on masonry walls), bridge beams placed on cast-in-place abutments or piers, and single-lift wall panels;
- **Category S2 (Complex Structural Systems):** This includes everything contained in S1 as well as total precast, multiproduct structures (vertical and horizontal members combined) plus single- or multistory loadbearing members, including those with architectural finishes; and
- **Category A (Architectural Systems):** This includes non-loadbearing cladding and GFRC products, which may be attached to a support structure.

A CFA determines the applicability of the categories and audits the erection procedures for each category in evidence during each audit. If the CFA determines that the erector is qualified to erect a building category for which he previously was not qualified, the CFA notifies PCI so this new category may be added (see References 3-4).

The PCI industry standards for quality production and erection are difficult to achieve. Once attained and practiced regularly, these standards contribute to improved and continuing customer satisfaction. They have been shown to reduce the in-ground and long-term costs of the building for the owner, and make the construction process move more quickly and smoothly for everyone involved.



This typical panel contains four preglazed windows for a 42-story building. Each panel has four tones of color created by heavy and light sandblasting of two colors of precast concrete.

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Commercial & Entertainment **2A**

- Office & Corporate **2A-1**
- Retail **2A-5**
- Stadiums & Arenas **2A-9**
- Parking Structures **2A-13**
- Mixed-Use **2A-17**

Institutional **2B**

- Educational Facilities
 - K-12 **2B-1**
 - Higher Education **2B-5**
- Justice & Correctional **2B-9**
- Government & Public Buildings **2B-13**
- Religious Architecture **2B-17**
- Health Care **2B-21**
- High-Tech & Lab Facilities **2B-25**

Housing & Residential **2C**

- Single-Family **2C-1**
- Multifamily **2C-5**
- Dormitories **2C-9**
- Condominiums **2C-13**
- Hotels **2C-17**
- Retirement Housing **2C-21**
- Assisted Living **2C-25**

Industrial **2D**

- Warehouses **2D-1**
- Distribution Facilities **2D-5**
- Manufacturing **2D-9**
- Food-Processing Facilities **2D-13**

Miscellaneous **2E**

- Pedestrian & Bicycle Bridges,
Soundwalls, Water Tanks,
Towers, Unique Structures, etc.

CHAPTER **two**
BUILDING TYPES

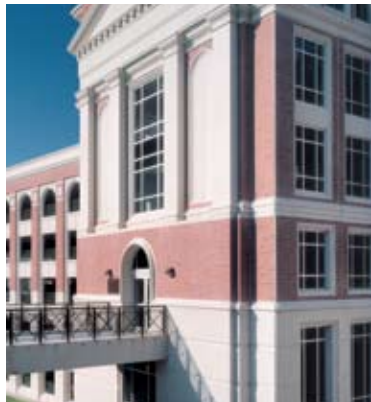


CHAPTER TWO

a.

COMMERCIAL
& ENTERTAINMENT
BUILDINGS

Commercial buildings must meet a wide range of needs while providing an aesthetically pleasing look. These facilities must adapt to users who visit the structures for short periods, as well as those who inhabit the facilities on a regular basis. Precast concrete helps meet these challenges with a variety of capabilities that aid the owner, designer, and contractor and provide long-term benefits to users.





Case-Highland Oaks Corporate Park, Tampa, Fla.;
 Architect: ADD Inc., Cambridge, Mass.;
 Photo: Rob Bovarnick, Rob/Harris Production Inc.

office & CORPORATE BUILDINGS

Design Challenges

Precast Concrete Solutions

<p><i>Provide open interior spaces to create open-floor layouts and allow for rearrangement of spaces as needs change.</i></p>	<p><i>Hollow-core slab or double-tee floor and roof components have long span capabilities that eliminate columns and provide unobstructed runs for utilities in the cores of hollow-core or between double-tee stems.</i></p>
<p><i>Ensure sufficient structural support for computer and storage systems.</i></p>	<p><i>High-strength flooring provides support for heavy loads now and in the future.</i></p>
<p><i>Create secured parking beneath office levels.</i></p>	<p><i>Precast concrete structural systems can be used to create parking on lower levels, provide fire-rated separation, and allow flexible layout options for office space.</i></p>
<p><i>Increase energy efficiency.</i></p>	<p><i>Thermal mass helps regulate temperatures; insulated precast concrete sandwich panels provide added energy efficiency due to insulation in the core.</i></p>
<p><i>Offer superior fire resistance.</i></p>	<p><i>Inherently non-combustible composition, along with compartmentalization designs, contains fire to specific limited areas and allows for detection, evacuation, and suppression.</i></p>
<p><i>Provide early occupancy to meet leasing needs.</i></p>	<p><i>Component casting begins when the shop drawings are complete, ensuring that erection begins as soon as the site is prepared.</i></p> <p><i>Year-round, all-weather construction ensures that schedules are met.</i></p> <p><i>Elimination of sub-framing, bracing, and scaffolding saves time and money.</i></p> <p><i>A total precast concrete system expedites construction, minimizes the number of component pieces by combining structural and architectural attributes into a single piece, and offers single-source responsibility from the precaster.</i></p>
<p><i>Minimize congestion and safety concerns on site and in the general vicinity during construction.</i></p>	<p><i>Precast concrete components can be brought to the site as needed for that day's erection, and staging areas can be arranged nearby. Fabrication of components off site ensures less traffic on the site and less congestion in the vicinity during construction.</i></p>
<p><i>Meet the area's seismic requirements.</i></p>	<p><i>Precast concrete systems, using proven connection technology, allow precast concrete components to be used in all seismic zones.</i></p>
<p><i>Provide proper aesthetic style to blend with the surrounding neighborhood, whether contemporary or historic, and to create a distinctive image reflecting the owner's stature.</i></p>	<p><i>Architectural precast concrete panels use colors, textures, reveals, finishes, formliners, or thin-brick insets to match any needed design style.</i></p>

office & CORPORATE BUILDINGS



South Trust Bank of Charleston, S.C.; Architect: Liollo Architecture; Photo: ©2003 Brian Dressler/www.dresslerphoto.com.



Two Buckhead Plaza Office Building, Atlanta, Ga.; Architect: Corcoran, Nelson, Nardone Associates Inc.; Photos: Reel Video & Stills Inc./Brian Erkens.



Hearst Tower, Charlotte, N.C.; Architect: Smallwood, Reynolds, Stewart, Stewart & Associates Inc.; Photo: Carolina Photography Group.



Best Buy Corporate Campus, Richfield, Minn.; Architect: Opus Architects & Engineers; Photo: Jeff Gleason and Daniel Young Dixon.



Brighton Landing, Brighton, Mass.; Architect: ADD Inc.; Photo: Warren Jagger Photography Inc.



United Parcel Services Corporate Offices, Atlanta, Ga.; Architect: Thompson, Ventulett, Stainback & Associates (TVS&A); Photo: Brian Gassel, TVS&A.



Sabre Holdings Headquarters, Southlake, Tex.; Architect: HKS Inc.; Photo: ©Ed Lacasse, Lacasse Photography.



Merrill Lynch Hopewell Campus, Pennington, N.J.;
Architect: Thompson, Ventulett, Stainback &
Associates (TVS&A); Photo: TVS&A.



Adtran Corporate Headquarters Phase IV, Huntsville, Ala.; Architect: Cooper Cary Inc.; Photo: ©Gabriel Benzur.



State Street Financial Center, Boston, Mass.;
Architect: Jung/Brannen Associates Inc.,
Boston, Mass.; Photo: Peter Vanderwarker.

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Las Olas Center, Ft. Lauderdale, Fla.;
 Architect: Cooper Carry Inc.;
 Photo: Ed Zealy, John Gillan Photography Inc.

retail

BUILDINGS

Design Challenges

Precast Concrete Solutions

<p><i>Create tall, open interiors to allow for flexible merchandising space.</i></p>	<p><i>Architectural precast concrete panels can be designed to provide high ceilings.</i></p>
<p><i>Design a durable envelope that can withstand impact from forklifts.</i></p>	<p><i>Precast concrete's high strength and density provide durability that will withstand impacts.</i></p>
<p><i>Provide easily accessed delivery docking space.</i></p>	<p><i>Precast concrete panels' capability to be cast in 12 ft widths or wider allows docking doors to be built into a single panel, providing inherent stability and fast erection.</i></p>
<p><i>Provide for future expansion of the facility.</i></p>	<p><i>Expansion can be accomplished by removing end panels and adding new panels onto the sides. Original mixtures and aggregates can be replicated in added panels to match the existing structure.</i></p>
<p><i>Minimize congestion and safety concerns on site and in the general vicinity during construction.</i></p>	<p><i>Precast concrete components can be brought to the site as needed for that day's erection, and staging areas can be arranged nearby. Fabrication of components off site ensures less traffic on the site and less congestion in the vicinity during construction.</i></p>
<p><i>Expedite construction to provide faster return on investment.</i></p>	<p><i>A total precast concrete system expedites construction, minimizes the number of component pieces by combining structural and architectural attributes into a single piece, and offers single-source responsibility from the precaster.</i></p> <p><i>Component casting begins when the shop drawings are complete, ensuring that erection begins as soon as the site is prepared.</i></p> <p><i>Year-round, all-weather construction ensures that schedules are met.</i></p>
<p><i>Meet the area's seismic requirements.</i></p>	<p><i>Precast concrete systems, using proven connection technology, allow precast concrete components to be used in all seismic zones.</i></p>
<p><i>Fit the structure into surroundings while meeting corporate-identity needs.</i></p>	<p><i>Architectural precast concrete panels use colors, textures, reveals, finishes, formliners, or thin-brick insets to match any needed design style. These looks can be used for warehouse-type retailers, additions to malls, stand-alone stores in upscale neighborhoods, and other specific location needs.</i></p>

retail

BUILDINGS



Lazarus Department Store, Pittsburgh, Pa.; Architect: Cooper Carry Inc.



Saks Majestic Square Complex, Charleston, S.C.; Architect: LS3P Associates Ltd.; Photo: ©Rick Alexander & Associates Inc.



Fashion Mall Expansion, Indianapolis, Ind.; Architect: CSO.



Target, Stamford, Conn.; Architect: Street-Works; Photo: Jeffrey M. Brown & Associates.



Rich's Department Store, Alpharetta, Ga.; Architect: Cooper Carry Inc.



Nordstrom Palm Beach Gardens, Palm Beach Gardens, Fla.; Architect: Callison Architecture Inc.; Photos: Vern Smith, Gate Precast.



Sherman Oaks Galleria, Sherman Oaks, Calif.; Architect: Gensler.



Tommy Hilfiger Retail Incorporated, Beverly Hills, Calif.; Architect: Allan Greenberg, Architect; Photo: David Rath.

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Miller Park, Milwaukee, Wis.: Architect: HKS Sport & Entertainment Group/NBBJ Sports & Entertainment/Eppstein Uhen Associated Architects, a joint venture. Photo: Eric Oxendorf.

stadiums & ARENAS

Design Challenges

Precast Concrete Solutions

<p><i>Design economical rows of seating that can withstand heavy loading.</i></p>	<p><i>Seating risers, especially economical double and triple risers, are the dominant choice for seating sections in outdoor stadiums and many indoor arenas. Shapes can vary to create needed sight lines, and vibrations can be controlled so that motion during use gives a sense of strength and security.</i></p>
<p><i>Create an interior structure with smooth traffic flow in and out as well as easy access to all sections.</i></p>	<p><i>Raker beams, columns, vomitory walls, and other structural components offer cost and time savings with close tolerances, while meeting the configuration requirements of any pedestrian-flow requirement.</i></p>
<p><i>Ensure all materials can withstand year-round weather for many years with minimal maintenance required.</i></p>	<p><i>Precast concrete mixtures ensure a long life cycle with the capability to withstand use by large-capacity crowds.</i></p>
<p><i>Minimize congestion and safety concerns on site and in the general vicinity during construction.</i></p>	<p><i>Precast concrete components can be brought to the site as needed for that day's erection, and staging areas can be arranged nearby. Fabrication of components off site ensures less traffic on the site and less congestion in the vicinity during construction.</i></p>
<p><i>Meet the area's seismic requirements.</i></p>	<p><i>Precast concrete systems, using proven connection technology, allow precast concrete components to be used in all seismic zones.</i></p>
<p><i>Create a fast construction pace to ensure that scheduled events occur on time or that new events can be scheduled quickly, providing faster revenue generation.</i></p>	<p><i>A total precast concrete system expedites construction, minimizes the number of component pieces by combining structural and architectural attributes into a single piece, and offers single-source responsibility from the precaster.</i></p> <p><i>Component casting begins when the shop drawings are complete, ensuring that erection begins as soon as the site is prepared.</i></p> <p><i>Year-round, all-weather construction ensures that schedules are met.</i></p>
<p><i>Create an aesthetic design that fits the owner's need, whether it is a contemporary look or an old-fashioned stadium design with modern amenities.</i></p>	<p><i>Architectural precast concrete panels use colors, textures, reveals, finishes, formliners, or thin-brick insets to match any needed design style.</i></p>

stadiums & ARENAS



Camden Yards Ballpark, Baltimore, Md.; Architect: Hellmuth, Obata & Kassabaum Sports Facilities Group.



Nebraska Memorial Stadium, Lincoln, Neb.; Architect: Sinclair Hills & Associates Inc. and DLR Group Sports of Tampa, Fla.



Gund Arena, Cleveland, Ohio; Architect: Ellerbe Becket Inc.; Photo: Timothy Hursley.



Ericsson Stadium, Charlotte, N.C.; Architect: HOK Sports Inc.



Adelpia Stadium, Nashville, Tenn.; Architect: HOK Sports Group.



Staples Arena, Los Angeles, Calif.; Architect: NBBJ Sports & Entertainment.



U.S. Olympic Center, Colorado Springs, Colo.; Photo: John Miller, Hedrich Blessing.



Rose Garden Arena, Portland, Ore.;
Photo: Chris Eden/Eden Arts.



Centennial Olympic Stadium, Atlanta, Ga.; Photo: ©Aerial Innovations of Georgia Inc.



PNC Park, Pittsburgh, Pa.; Architect: HOK Sports and L.D. Astorino & Associates Ltd.; Photo: Massery Photography Inc.



Indian Wells Tennis Center, Indian Wells, Calif.;
Architect: Rosetti Associates Architects.

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Emory University Parking Structure, Atlanta, Ga.;
 Architect: Thompson, Ventulett, Stainback and Associates
 Architects (TVS); Photo: Brian Cassel/TVS.

parking

STRUCTURES

Design Challenges

Precast Concrete Solutions

<p><i>Design open interior spaces to maximize parking layout and provide secure environment.</i></p>	<p><i>Double tees can span long distances to eliminate columns and provide unobstructed views through the levels.</i></p> <p><i>Moment frames, K frames, litewalls, and other unique structural supports can open interiors and smooth traffic flow.</i></p>
<p><i>Provide early occupancy to ensure readiness when other buildings are ready.</i></p>	<p><i>Component casting begins when the shop drawings are complete, ensuring that erection begins as soon as the site is prepared.</i></p> <p><i>Year-round, all-weather construction ensures that schedules are met.</i></p>
<p><i>Maximize green space.</i></p>	<p><i>Precasters can help ensure the most economical, functional layout to maximize access, number of floors, ramp flow, and other factors that minimize the footprint.</i></p>
<p><i>Ensure high durability.</i></p>	<p><i>Concrete with low water–cement ratios and high-quality, plant-produced components projects against chloride penetration from deicing chemicals.</i></p>
<p><i>Allow for proper drainage.</i></p>	<p><i>Precasters ensure that joint placement and drainage in floors meet the needs of each unique design.</i></p>
<p><i>Provide easy long-term maintenance.</i></p>	<p><i>Maintenance is minimized by annual inspections at key joints and routine recaulking at long-term intervals.</i></p>
<p><i>Minimize congestion and safety concerns on site and in the general vicinity during construction.</i></p>	<p><i>Precast concrete components can be brought to the site as needed for that day's erection, and staging areas can be arranged nearby. Fabrication of components off site ensures less traffic on the site and less congestion in the vicinity during construction.</i></p>
<p><i>Meet the area's seismic requirements.</i></p>	<p><i>Precast concrete systems, using proven connection technology, allow precast concrete components to be used in all seismic zones.</i></p>
<p><i>Reduce the structure's scale so as not to overwhelm or dominate the landscape and create the proper aesthetic look to blend with the surrounding neighborhood, whether contemporary or historic.</i></p>	<p><i>Architectural precast concrete panels use colors, textures, reveals, finishes, formliners, or thin-brick insets to match any needed design style and break up the mass of the structure's façade.</i></p>

parking

STRUCTURES



Fifth & Lafayette Parking Structure, Royal Oak, Mich.; Architect: Rich & Associates Inc.



South Spring Street Garage, Greenville, S.C.; Architect: Craig Gaulden Davis, Greenville, S.C.; Consulting Architect: LS3P Associates Ltd., Charlotte, N.C.



University of Denver College of Law Parking Structure, Denver, Colo.; Architect: University of Denver School of Architecture.



Resurrection Medical Center Southeast Parking Structure, Chicago, Ill.; Architect: Loeb Schlossman & Hackl.



Hull Street Parking Deck, Athens, Ga.; Architect: Smallwood, Reynolds, Stewart, Stewart & Associates Inc.; Photo: Jim Roof.



Orlando County Courthouse Parking Structure Expansion, Orlando, Fla.; Architect: Burke, Hogue & Mills Associates Inc.



Union Plaza Transit Terminal and Parking Garage, El Paso, Tex.; Architect: Synthesis Architecture Inc.



Arcade Parking Structure, Providence, R.I.;
Architect: Maguire Group.

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"Architectural Precast Beautifies Parking Structure, Building Awards," *ASCENT*; Fall 2002, pp. 24-25.

"City of Orlando/Orlando County Courthouse Parking Garage Expansion, Building Awards," *ASCENT*; Fall 2004, p. 32.

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"Library District Parking Garage," *ASCENT*; Fall 2005, p. 36.

"North Shore Garage, Building Awards," *ASCENT*; Fall 2002, p. 31.

"Parking Structure Design Offers Office Aesthetic," *ASCENT*; Winter 2003, pp. 24-27.

"Precast Aids Work At Historic Site," *ASCENT*; Summer 2003, pp. 28-30.

"Precast Concrete Offers Advantages For Office, Parking Structures," *ASCENT*; Spring 2001, pp. 6-11.

"Precast Helps Office, Parking Facilities Meet Tight Schedules," *ASCENT*; Spring 2001, pp. 22-23.

"Precast Concrete Offers 'Better Way To Skin Cat,'" *ASCENT*; Summer 2004, pp. 28-30.

"Precast Parking Structures Help Mall Make Design Statement," *ASCENT*; Spring 2001, pp. 18-21.

"Resurrection Medical Center Southeast Parking Structure, Building Awards," *ASCENT*; Fall 2003, p. 33.

"River Street Garage, Building Awards," *ASCENT*; Fall 2002, p. 24.

"Saks Parking Structure, Building Awards," *ASCENT*; Fall 2003, p. 32.

"The Shops at Willow Bend Parking Structures, Building Awards," *ASCENT*; Fall 2001, pp. 46-47.

"Stacking Precast Office, Parking Saves Space," *ASCENT*; Summer 2002, pp. 24-26.

"Surgery Center Built Atop Precast Parking Structure," *ASCENT*; Spring 2001, pp.24-28.

"Total Precast Parking Features Brick Blend," *ASCENT*; Summer 2005, pp. 18-20.

"Universities Exploit Precast For Mixed-Use Projects," *ASCENT*; Summer 2004, pp. 24-27.

"University of Georgia Carlton Street Parking Structure, Special Awards," *ASCENT*; Fall 2002, p. 10.

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"All-Precast Concrete Design for the Saratoga Street Parking & Office Structure for the University of Maryland," *PCI Journal*; March-April 2004, pp. 34-47.

"Hull Street Parking Structure, Athens, Georgia," *PCI Journal*; July-August 2005, pp. 144-149.

"New Jersey Transit—Route 17 Regional Rail Park-N-Ride Station, Ramsey, New Jersey," *PCI Journal*; September-October 2005, pp. 106-111.

"Precast Parking Structures Enhance the Shops at Willow Bend," *PCI Journal*; September-October 2001, pp. 36-45.

"Project Study: Dutton Avenue Office and Parking Facility, Waco, Texas," *PCI Journal*; March-April 2006, pp. 102-107.

"Saks Parking Garage, Kansas City, Missouri," *PCI Journal*; May-June 2005, pp. 102-107.

"Tiffany & Company Office Building Addition and Parking Structure," *PCI Journal*; November-December 2003, pp. 154-156.

"UGA's Carlton Street Parking Facility Meets University Demands for Construction Speed and Aesthetics," *PCI Journal*; November-December 2002, pp. 26-47.



Olympic Park Plaza, Louisville, Ky.;
Architect: Cooper Carry Inc.

mixed – USE BUILDINGS

Design Challenges

Precast Concrete Solutions

<p><i>Create a distinctive character that projects an upscale image while allowing each function with the building to maintain its own in design.</i></p>	<p><i>The plasticity of precast concrete components, and the variety of finishes that can be used, ensure that designs blend with any surroundings and project any needed corporate image, while also allowing for diversity.</i></p>
<p><i>Ensure that parking areas do not overwhelm other functions in the building, and fit with the surrounding neighborhood.</i></p>	<p><i>Precast concrete designs can feature set-in brick, granite, and punched-window effects that replicate housing or other types of surrounding architecture. Reveals, finishes, and other techniques can reduce the visual mass of the building.</i></p>
<p><i>Ensure that code requirements for fire separation between parking and other functions are met.</i></p>	<p><i>Precast concrete hollow-core slabs and double tees provide the necessary separation between parking and other functional areas of the mixed-use facility.</i></p>
<p><i>Design open interior spaces to maximize parking layout and provide a secure environment.</i></p>	<p><i>Double tees can span long distances to eliminate columns and provide unobstructed views through the levels.</i></p> <p><i>Moment frames, K frames, litewalls and other unique structural supports can open interiors and smooth traffic flow.</i></p>
<p><i>Provide structural support for many small rooms above open, column-free ballrooms and conference areas.</i></p>	<p><i>Hollow-core slabs span long distances while providing structural support, minimizing columns on lower floors.</i></p>
<p><i>Create high fire resistance.</i></p>	<p><i>Precast concrete's non-combustible composition minimizes the spread of fire, while compartmentalization design techniques provide time for detection, evacuation, and suppression.</i></p>
<p><i>Use durable materials that will not show dents and other misuse.</i></p>	<p><i>The compressive strength of the material minimizes chances for damage to interior walls or ceilings by guests.</i></p>
<p><i>Meet the area's seismic requirements.</i></p>	<p><i>Precast concrete systems, using proven connection technology, allow precast concrete components to be used in all seismic zones.</i></p>
<p><i>Expedite construction to provide faster return on investment and meet scheduling commitments.</i></p>	<p><i>A total precast concrete system expedites construction, minimizes component pieces by combining structural and architectural elements, and provides single-source responsibility.</i></p> <p><i>Component casting begins when the shop drawings are complete, ensuring that erection begins as soon as the site is prepared.</i></p> <p><i>Year-round, all-weather construction ensures that schedules are met.</i></p>

mixed-USE BUILDINGS



South Carolina Aquarium Parking Structure, Charleston, S.C.; Architect: LS3P Associates Ltd.; Photo: ©Rick Alexander & Associates Inc.



St. Regis Museum Tower, San Francisco, Calif.; Architect: Skidmore, Owings & Merrill LLP



Fairbanks Chrysler/Jeep/Dodge, Tamarac, Fla.



The Ninth Square, New Haven, Conn.; Architect: Herbert S. Newman & Partners, PC; Photo: ©1995 Norman McGrath.



116 Huntington Avenue, Boston, Mass.; Architect: CBT/Childs Bertman Tseckares Inc.; Photos: Wayne Soverns Jr. Architectural Photography.



MacArthur Center Mall, Norfolk, Va.; Architect: Hobbs & Black Inc.



Enterprise IV Corporate Center, Bridgeport, Conn.; Architect: Kasper Group Inc.; Photo: Blakeslee Prestress.



Esquire Plaza, Sacramento, Calif.; Architect: HOK/SF;
Photo: Ed Asmus Photography.



Central Florida Chrysler/Jeep/Dodge, Orlando, Fla.



Mizner Park, Boca Raton, Fla.; Architect: Cooper Carry Inc.

RESOURCES:

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"Precast Concrete Offers Advantages For Office, Parking Structures," *ASCENT*; Spring 2001, pp. 6-11.

"Precast Helps Office, Parking Facilities Meet Tight Schedules," *ASCENT*; Spring 2001, pp. 22-23.

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"Universities Exploit Precast For Mixed-Use Projects," *ASCENT*; Summer 2004, pp. 24-27.

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"Precast Parking Structures Enhance the Shops at Willow Bend," *PCI Journal*; September-October 2001, pp. 36-45.

"Project Study: Dutton Avenue Office and Parking Facility, Waco, Texas," *PCI Journal*; March-April 2006, pp. 102-107.

"Saks Parking Garage, Kansas City, Missouri," *PCI Journal*; May-June 2005, pp. 102-107.

"St. Regis Hotel & Residences—A Vibrant Gem in San Francisco's Fire Arts Center," *PCI Journal*; March-April 2006, pp. 56-75.

"Tiffany & Company Office Building Addition and Parking Structure," *PCI Journal*; November-December 2003, pp. 154-156.

b.

CHAPTER TWO

INSTITUTIONAL & PUBLIC BUILDINGS

Institutional and public buildings of all types require a strong, impressive façade to project the proper image to employees, visitors, and the general public. This need remains constant, whether these facilities are used for education, adjudication, administration, imprisonment, or worship services. But they must achieve that look, and all of their functional needs, on tight budgets that impress the public with economic stewardship. Achieving that balance, while meeting many other individual challenges, can be accomplished with precast concrete components in a variety of ways.

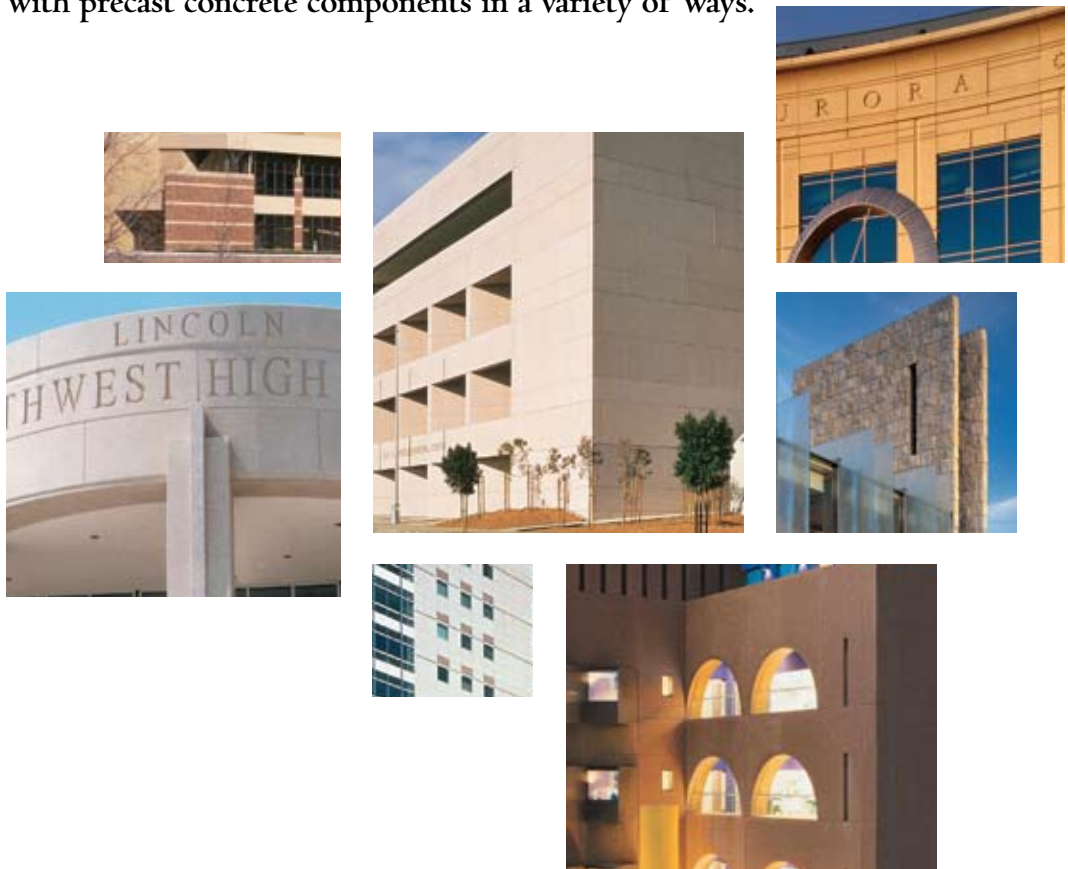




Photo: ©PhotoDisc

GRADES K - 12 educational FACILITIES

Design Challenges

Precast Concrete Solutions

<p><i>Meet strict budgeting needs based on tax revenues.</i></p>	<p><i>A total precast concrete system expedites construction, minimizes the number of component pieces by combining structural and architectural attributes into a single piece, and offers single-source responsibility from the precaster, saving costs throughout the construction process.</i></p>
<p><i>Ensure that the building is ready for the school year in the fall or to meet other deadlines.</i></p>	<p><i>Component casting begins when the shop drawings are complete, ensuring that erection begins as soon as the site is prepared.</i></p> <p><i>Year-round, all-weather construction ensures that schedules are met.</i></p>
<p><i>Maximize interior floor space.</i></p>	<p><i>Insulated sandwich wall panels offer an efficient, thin cross-section that maximizes interior floor space while minimizing the footprint.</i></p>
<p><i>Create needed long-span areas, such as gymnasiums and pools.</i></p>	<p><i>Hollow-core slabs and double tees can span long spaces to minimize or eliminate columns where needed.</i></p>
<p><i>Provide for future addition or expansion of classroom spaces.</i></p>	<p><i>Expansion can be accomplished by removing end panels and adding new panels onto sides. Original mixtures and aggregates can be replicated in added panels.</i></p>
<p><i>Create a highly fire-resistant structure.</i></p>	<p><i>Inherently noncombustible composition, along with compartmentalization designs, contains fire to specific areas and allows for detection, evacuation, and suppression.</i></p>
<p><i>Minimize operating costs throughout the life of the building.</i></p>	<p><i>Minimized joints, compared with brick or block construction, require less maintenance throughout the building's life.</i></p> <p><i>Insulated sandwich wall panels provide high levels of energy efficiency, reducing HVAC costs.</i></p>
<p><i>Project an image of environmental friendliness by using low-impact products.</i></p>	<p><i>Precast concrete meets many of the rating criteria used by the LEED standards.</i></p>
<p><i>Minimize congestion and safety concerns on site and in the general vicinity during construction.</i></p>	<p><i>Precast concrete components can be brought to the site as needed for that day's erection, and staging areas can be arranged nearby. Fabrication of components off site ensures less traffic on the site and less congestion in the vicinity during construction.</i></p>
<p><i>Meet the area's seismic requirements.</i></p>	<p><i>Panelized wall systems and proven connection technology allow precast concrete components to be used in all seismic zones.</i></p>
<p><i>Provide a strong, institutional look that conveys an educational image.</i></p>	<p><i>Architectural precast concrete panels use colors, textures, reveals, finishes, formliners, or thin-brick insets to match any needed design style.</i></p> <p><i>School names, emblems, and other custom touches can be embedded into panels, creating unique accents.</i></p>

GRADES K-12
educational
FACILITIES



Jack Britt High School, Fayetteville, N.C.; Architect: Shuller Ferris Landstrom & Associates.



Lynwood High School, Lynwood, Calif.; Photo: ©1997 Wayne Thom.





Centralia High School, Centralia, Ill.; Architect: FGM Architects Engineers, Inc.; Photos: Gate Precast.



Woodmont High School, Piedmont, S.C.; Architect: Perkins & Will Design Architect; Architect of Record: Craig Gaulden Davis; Photo: Craig Gaulden Davis Architects/Photographer-Working Pictures.



Spring Union Free School, East Hampton, N.Y.



Durham Academy Elementary and Preschool, Durham, N.C.



Alberta Lea High School, Alberta Lea, Minn.; Photo: ©Don F. Wong.



Lincoln Southwest High School, Lincoln, Neb.

RESOURCES:

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Chapter 1.2.1.4, "Other Building Structures," PCI MNL-120-04: *PCI Design Handbook, Sixth Edition*.

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"PCI's School Brochure Outlines Key Benefits," *ASCENT*; Fall 2003, pp. 16-18.

"Precast Helps Schools Meet Attendance Boom," *ASCENT*; Summer 2002, pp. 16-22.

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"Precast Speeds School Construction Learning Curve," *ASCENT*; Summer 2003, pp. 24-26.

"Schools Tap Precast For Massive Program," *ASCENT*; Spring 2004, pp. 26-29.

PCI Journal:

"Project Study: Elk Grove High School Natatorium, Elk Grove, Illinois," *PCI Journal*; January-February 2006, pp. 116-119.



Photo: ©PhotoDisc

HIGHER educational FACILITIES

Design Challenges

Precast Concrete Solutions

<p><i>Provide a strong, institutional appearance that conveys an educational image.</i></p>	<p><i>Architectural precast concrete panels use colors, textures, reveals, finishes, formliners, or thin-brick insets to match any needed design style.</i></p> <p><i>A total precast concrete system can be adapted to a variety of designs and functions, including theaters, dormitories, classrooms, laboratories, and other facilities.</i></p>
<p><i>Design a conceptual look that allows buildings with different functional uses (theaters, dormitories, classrooms, laboratories) to work together aesthetically.</i></p>	<p><i>School names, emblems, and other custom touches can be embedded into panels, creating unique accents.</i></p>
<p><i>Meet strict budgeting needs based on tax revenues.</i></p>	<p><i>A total precast concrete system expedites construction, minimizes the number of component pieces by combining structural and architectural attributes into a single piece, and offers single-source responsibility from the precaster, saving costs throughout the construction process.</i></p>
<p><i>Ensure that the building is ready for the school year by fall, or as soon as possible for additions onto existing structures.</i></p>	<p><i>Component casting begins when the shop drawings are complete, ensuring that erection begins as soon as the site is prepared.</i></p> <p><i>Year-round, all-weather construction ensures that schedules are met.</i></p>
<p><i>Maximize interior floor space.</i></p>	<p><i>Insulated sandwich wall panels offer an efficient, thin cross-section that maximizes interior floor space while minimizing the footprint.</i></p> <p><i>Hollow-core slabs and double tees can span long spaces to minimize or eliminate columns where needed.</i></p>
<p><i>Create a highly fire-resistant structure.</i></p>	<p><i>Inherently noncombustible composition, along with compartmentalization designs, contains fire to specific areas and allows for detection, evacuation, and suppression.</i></p>
<p><i>Minimize operating costs throughout the life of the building.</i></p>	<p><i>Minimized joints, compared with brick or block construction, require less maintenance throughout the building's life.</i></p> <p><i>Insulated sandwich wall panels provide high levels of energy efficiency, reducing HVAC costs.</i></p>
<p><i>Create an image of environmental friendliness by using low-impact products.</i></p>	<p><i>Precast concrete meets many of the rating criteria used by the LEED standards.</i></p>
<p><i>Minimize congestion and safety concerns on site and in the general vicinity during construction.</i></p>	<p><i>Precast concrete components can be brought to the site as needed for that day's erection, and staging areas can be arranged nearby. Fabrication of components off site ensures less traffic on the site and less congestion in the vicinity during the construction.</i></p>
<p><i>Meet the area's seismic requirements.</i></p>	<p><i>Precast concrete systems, using proven connection technology, allow precast concrete components to be used in all seismic zones.</i></p>

HIGHER educational FACILITIES



*John A. Burns School of Medicine,
Honolulu, Hawaii; Architect: Zimmer
Gunsul Frasca Architects.*

*Social Sciences Building, University of North Florida (UNF), Jacksonville, Fla.;
Architect: TLC Engineering for Architecture; Photo: Gate Precast Co.*





Rectory Building at the University of Monterrey, Nuevo Leon, Mexico; Architect: Bernardo Hinojosa Architects & Planners; Photos: Francisco Lubbert.



School of Architecture at Florida International University, Miami, Fla.; Architect: Bernard Tschumi Architects and BEA International (joint venture); Photos: Thomas Dellback.



University of Illinois Molecular Research Biology Building, Chicago, Ill.; Architect: Lohan Associates; Photos: Hedrich-Blessing.



Francois-Xavier Bagnoud Building, Harvard School of Public Health, Boston, Mass.; Architect: Payette Associates Inc.

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PCI Journal:

"All-Precast Concrete Design Delivers On-Time Opening for Florida's LECOM Medical Students," *PCI Journal*; January-February 2006, pp. 82-97.
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Lloyd D. George United States Courthouse, Las Vegas, Nev.; Executive Architect: Langdon Wilson Architects; Photo: Langdon Wilson Architects.

justice & CORRECTIONAL FACILITIES

Design Challenges

Precast Concrete Solutions

<p><i>Provide a durable, tough interior that will stand up to abuse.</i></p>	<p><i>Precast concrete's inherent toughness ensures no weaknesses in the walls, floors, or ceilings that can be exploited.</i></p>
<p><i>Offer long-span interiors in assembly areas to minimize supervision needs.</i></p>	<p><i>Hollow-core slabs and double tees can be used to span long distances, eliminating columns that could pose a security risk.</i></p>
<p><i>Create a secure facility with few joints that inmates can use to hide contraband.</i></p>	<p><i>Precast concrete components, including exterior loadbearing insulated wall panels, double tee roof slabs, precast concrete columns and beams, and interior precast concrete loadbearing and non-loadbearing walls, minimize joints compared to other construction products.</i></p>
<p><i>Construct the facility in the fastest time possible to alleviate overcrowded conditions.</i></p>	<p><i>Component casting begins when the shop drawings are complete, ensuring that erection begins as soon as the site is prepared.</i></p> <p><i>Year-round, all-weather construction ensures that schedules are met.</i></p> <p><i>Large 10 by 30 or 40 ft. precast concrete walls can be erected quickly, enclosing the space early to allow interior work to begin sooner.</i></p> <p><i>Interior walls constructed of precast concrete minimize joints and are erected in a faster time frame than masons can provide, especially in rural areas where many prisons are built.</i></p> <p><i>A total precast concrete system expedites construction, minimizes the number of component pieces by combining structural and architectural attributes into a single piece, and offers single-source responsibility from the precaster.</i></p> <p><i>Prefinished cell modules arrive at the site with walls, ceiling, and floor constructed in one unit and many finishes in place. Typically, two-cell modules are cast together, although triples and quads can also be created. The modules are preplumbed and prewired, with furniture, toilets, sinks, electrical fixtures, windows, and doors already installed.</i></p>
<p><i>Minimize congestion and safety concerns on site and in the general vicinity during construction.</i></p>	<p><i>Precast concrete components can be brought to the site as needed for that day's erection, and staging areas can be arranged nearby. Fabrication of components off site ensures less traffic on the site and less congestion in the vicinity during construction.</i></p>
<p><i>Meet the area's seismic requirements.</i></p>	<p><i>Precast concrete systems, using proven connection technology, allow precast concrete components to be used in all seismic zones.</i></p>
<p><i>Design an appearance that is secure and imposing while meeting the needs of the local community.</i></p>	<p><i>Architectural precast concrete panels use colors, textures, reveals, finishes, formliners, or thin-brick insets to match any needed design style.</i></p>

justice & CORRECTIONAL FACILITIES



George R. Vierno Center Addition, Rikers Island, New York; Architect: STV/Silver & Ziskind; Photo: S. Barker.



Thomas F. Eagleton United States Courthouse, St. Louis, Mo.; Architect: Hellmuth, Obata + Kassabaum.



United States Federal Courthouse, Jacksonville, Fla.; Architect: KBJ Architects Inc.; Photo: Aerial & Architectural Photo Inc.



East Los Angeles Municipal Courts Building, East Los Angeles, Calif.; Architect: Kanner Architects Inc.; Photo: Ron Pollard.



David L. Moss Criminal Justice Center, Tulsa, Okla.; Architect: BKL Inc./HDR Architecture Inc.



Douglas County Courthouse, Douglasville, Ga.; Architect: Cooper Cary Inc.; Photo: Brian Gassel/TVS.





Charles Evans Whittaker United States Courthouse, Kansas City, Mo.; Architect: Ellerbe Becket/Abend Singleton Associated Architects; Photo: Timothy Hursley.



Michael D. Antonovich Antelope Valley Courthouse, Lancaster, Calif.; Architect: Mosakowski-Lindsey Associates.



Federal Metropolitan Detention Center, Philadelphia, Pa.; Architect: Ewing Cole Cherry Brott; Photo: Jeffrey Totaro.



DeKalb County Sheriff's Headquarters & Jail, Decatur, Ga.; Architect: Rosser International Inc.



El Paso County Jail, Colorado Springs, Colo.; Architect: CSNA Architects.

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Center of Science & Industry, Columbus, Ohio;
Architect: Arata Isozaki & Associates
and NBBJ Architects Inc.

GOVERNMENT & public BUILDINGS

Design Challenges

Precast Concrete Solutions

<p><i>Create an imposing, stately appearance that reflects well on the city, state, or federal government while conveying an institutional function.</i></p>	<p><i>Architectural precast concrete panels use colors, textures, reveals, finishes, formliners, or thin-brick insets to match any needed design style.</i></p> <p><i>City emblems, names, and other aesthetic touches can be added to edifices to create imposing, unique elements.</i></p>
<p><i>Provide a low-maintenance façade that will be easy to fit into the operations budget for the life of the project.</i></p>	<p><i>Precast concrete's factory-controlled fabrication ensures consistency between panels and colorfastness in all mixtures to ensure no fading or inconsistencies in color.</i></p> <p><i>Minimized joints, compared with brick or block construction, require less maintenance throughout the building's life.</i></p>
<p><i>Meet strict budgeting needs based on tax revenues.</i></p>	<p><i>A total precast concrete system expedites construction, minimizes the number of component pieces by combining structural and architectural attributes into a single piece, and offers single-source responsibility from the precaster, saving costs throughout the construction process.</i></p>
<p><i>Minimize operating costs throughout the life of the building.</i></p>	<p><i>Insulated sandwich wall panels offer an energy-efficient façade that aids in controlling heating and cooling costs.</i></p>
<p><i>Create a highly fire-resistant structure.</i></p>	<p><i>Inherently noncombustible composition, along with compartmentalization designs, contains fire to specific areas and allows for detection, evacuation, and suppression.</i></p>
<p><i>Meet all blast-resistance requirements and create a secure environment.</i></p>	<p><i>Modular components and durable composition provide key design ingredients for creating secure exteriors that meet federal requirements.</i></p>
<p><i>Create an image of environmental friendliness by using low-impact products.</i></p>	<p><i>Precast concrete meets many of the rating criteria used by the LEED standards.</i></p>
<p><i>Minimize congestion and safety concerns on site and in the general vicinity during construction.</i></p>	<p><i>Precast concrete components can be brought to the site as needed for that day's erection, and staging areas can be arranged nearby. Fabrication of components off site ensures less traffic on the site and less congestion in the vicinity during the construction.</i></p>
<p><i>Meet the area's seismic requirements.</i></p>	<p><i>Precast concrete systems, using proven connection technology, allow precast concrete components to be used in all seismic zones.</i></p>
<p><i>Expedite construction to ensure no cost overruns for leases and scheduling needs.</i></p>	<p><i>Component casting begins when the shop drawings are complete, ensuring that erection begins as soon as the site is prepared.</i></p> <p><i>Year-round, all-weather construction ensures that schedules are met.</i></p> <p><i>A total precast concrete system expedites construction, minimizes the number of component pieces by combining structural and architectural attributes into a single piece, and offers single-source responsibility from the precaster.</i></p>

GOVERNMENT &
public
BUILDINGS



*Walsh Library at Seton Hall University, South Orange, N.J.; Architect: Skidmore, Owings & Merrill;
Photos: Edward Hueber/Archphoto.com.*



Aurora Municipal Center, Aurora, Colo.; Architect: Barber Architecture.



Salt Lake City Public Library, Salt Lake City, Utah; Architect: Moshe Safdie and Associates Inc. and VCBO Architecture; Photos: Timothy Hursley.



Washington Convention Center, Washington, D.C.; Architect: Thompson, Ventulett, Stainback & Associates.



Utoy Creek Water Reclamation Center, Atlanta, Ga.; Architect: ; Photos: .



French Embassy, Mexico D.F., Mexico;
Architect: Bernard Kohn Associates and Eduardo Terrazas y Associates (joint venture); Photo: Bernard Kohn Associates.



Bartle Hall Conference Center, Kansas City, Mo.; Architect: Berkebile Nelson Immenschuh McDowell Architects.

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"Lloyd D. George United States Courthouse, Building Awards," *ASCENT*; Fall 2002, p. 20.

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"Precast Built Better Courthouse For Less, Building Awards," *ASCENT*; Fall 2002, pp. 28-29.

"Public Projects Favoring Design-Build Format," *ASCENT*; Winter 2006, pp. 24-21.

Salt Lake City Public Library, Building Awards," *ASCENT*; Fall 2003, p. 29.

"San Diego Convention Center, Building Awards," *ASCENT*; Fall 2002, p. 17.



Grace Church, Eden Prairie, Minn.; Architect: HGA.

religious

ARCHITECTURE

Design Challenges

Precast Concrete Solutions

<p><i>Create an imposing, impressive appearance that conveys the stature of the institution while providing a welcoming atmosphere for visitors.</i></p>	<p><i>Architectural precast concrete panels use colors, textures, reveals, finishes, formliners, or thin-brick insets to create any needed design style.</i></p>
<p><i>Design a low-maintenance façade that can be maintained in excellent condition on a low operating budget.</i></p>	<p><i>Minimized joints, compared with other types of construction (brick or block) require less maintenance through the building's life.</i></p>
<p><i>Provide traditional interior spaces for worship as well as all functional needs, including meeting rooms, kitchen facilities, and offices.</i></p>	<p><i>Hollow-core slabs and double tees can span long distances and provide maximum support to allow for open gathering spaces on lower floors.</i></p>
<p><i>Provide energy efficiency to help control operating costs throughout the life of the structure.</i></p>	<p><i>Insulated sandwich wall panels offer an energy-efficient façade that aids in controlling heating and cooling costs.</i></p>
<p><i>Create a highly fire-resistant building.</i></p>	<p><i>Inherently noncombustible composition, along with compartmentalization designs, contains fire to specific areas and allows for detection, evacuation, and suppression.</i></p>
<p><i>Minimize congestion and safety concerns on site and in the general vicinity during construction.</i></p>	<p><i>Precast concrete components can be brought to the site as needed for that day's erection, and staging areas can be arranged nearby. Fabrication of components off site ensures less traffic on the site and less congestion in the vicinity during the construction.</i></p>
<p><i>Meet the area's seismic requirements.</i></p>	<p><i>Precast concrete systems, using proven connection technology, allow precast concrete components to be used in all seismic zones.</i></p>
<p><i>Expedite construction to ensure schedules are met.</i></p>	<p><i>Component casting begins when the shop drawings are complete, ensuring that erection begins as soon as the site is prepared.</i></p> <p><i>Year-round, all-weather construction ensures that schedules are met.</i></p> <p><i>A total precast concrete system expedites construction, minimizes the number of component pieces by combining structural and architectural attributes into a single piece, and offers single-source responsibility from the precaster.</i></p>

religious

ARCHITECTURE



Grace Church, Eden Prairie, Minn.; Architect: HGA.



Prince of Peace Catholic Church, Taylors, S.C.; Architect: Craig Gaulden Davis; Photos: Metromont.





Old St. Mary's Church, Chicago, Ill.; Architect: Serena Sturm Architects Ltd.





Bigelow Chapel at United Theological Seminary of the Twin Cities, New Brighton, Minn.; Architect: Hammel, Green & Abrahamson Inc.



The Church of Jesus Christ of Latter-day Saints, Lake Oswego, Ore.; Architect: Lee, Ruff, Stark Architects and Leland Gray Architects.

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PCI Journal:

"Precast Concrete Provides Function and Inspiration for Prince of Peace Church, Taylors, South Carolina," *PCI Journal*; March-April 2005, pp. 28-43.



Shriners Hospital for Children, Sacramento, Calif.;
Architect: HDR.

health care

FACILITIES

Design Challenges

Precast Concrete Solutions

<p><i>Design a visually pleasing, reassuring façade that invokes an image of authority and comfort.</i></p>	<p><i>Architectural precast concrete panels use colors, textures, reveals, finishes, formliners, or thin-brick insets to create any needed design style.</i></p>
<p><i>Provide flexibility in layout so spaces can be adapted as new technologies are introduced that require different access needs.</i></p>	<p><i>Hollow-core slabs can span long distances and allow open floor plans that can be adapted as needed for future uses.</i></p>
<p><i>Create a low-maintenance façade that will not be difficult to fit into maintenance budgets.</i></p>	<p><i>Minimized joints, compared with brick or block construction, require less maintenance throughout the building's life.</i></p>
<p><i>Minimize operating costs to keep budgets under control.</i></p>	<p><i>Insulated sandwich wall panels offer an energy-efficient façade that aids in controlling heating and cooling costs.</i></p> <p><i>A total precast concrete system expedites construction, minimizes the number of component pieces by combining structural and architectural attributes into a single piece, and offers single-source responsibility from the precaster.</i></p>
<p><i>Create a highly fire-resistant structure.</i></p>	<p><i>Inherently noncombustible composition, along with compartmentalization designs, contains fire to specific areas and allows for detection, evacuation, and suppression.</i></p>
<p><i>Minimize congestion and safety concerns on site and in the general vicinity during construction.</i></p>	<p><i>Precast concrete components can be brought to the site as needed for that day's erection, and staging areas can be arranged nearby. Fabrication of components off site ensures less traffic on the site and less congestion in the vicinity during the construction.</i></p>
<p><i>Meet the area's seismic requirements.</i></p>	<p><i>Precast concrete systems, using proven connection technology, allow precast concrete components to be used in all seismic zones.</i></p>
<p><i>Expedite construction to provide faster return on investment and to alleviate overcrowding.</i></p>	<p><i>Component casting begins when the shop drawings are complete, ensuring that erection begins as soon as the site is prepared.</i></p> <p><i>Year-round, all-weather construction ensures that schedules are met.</i></p> <p><i>A total precast concrete system expedites construction, minimizes the number of component pieces by combining structural and architectural attributes into a single piece, and offers single-source responsibility from the precaster.</i></p>

health care

FACILITIES



Mary Birch Women's Hospital at Sharp Healthcare Center, San Diego, Calif.; Architect: HKS; Photo: TS Gordon.



Enders Research Laboratory, Boston, Mass.; Architect: Ellenzweig Associates; Photo: ©Steve Rosenthal.



MD Anderson Cancer Center, Houston, Tex.; Architect: LAN/HKS Inc. (a joint venture).



McLaren Regional Medical Center Patient Tower, Flint, Mich.; Architect: Perkins & Will; Photo: Marco Lornzetto/Korah Hedrich Blessing.



Children's Medical Center, Dallas, Tex.; Architect: HKS; Photo: Rick Grunbamm.



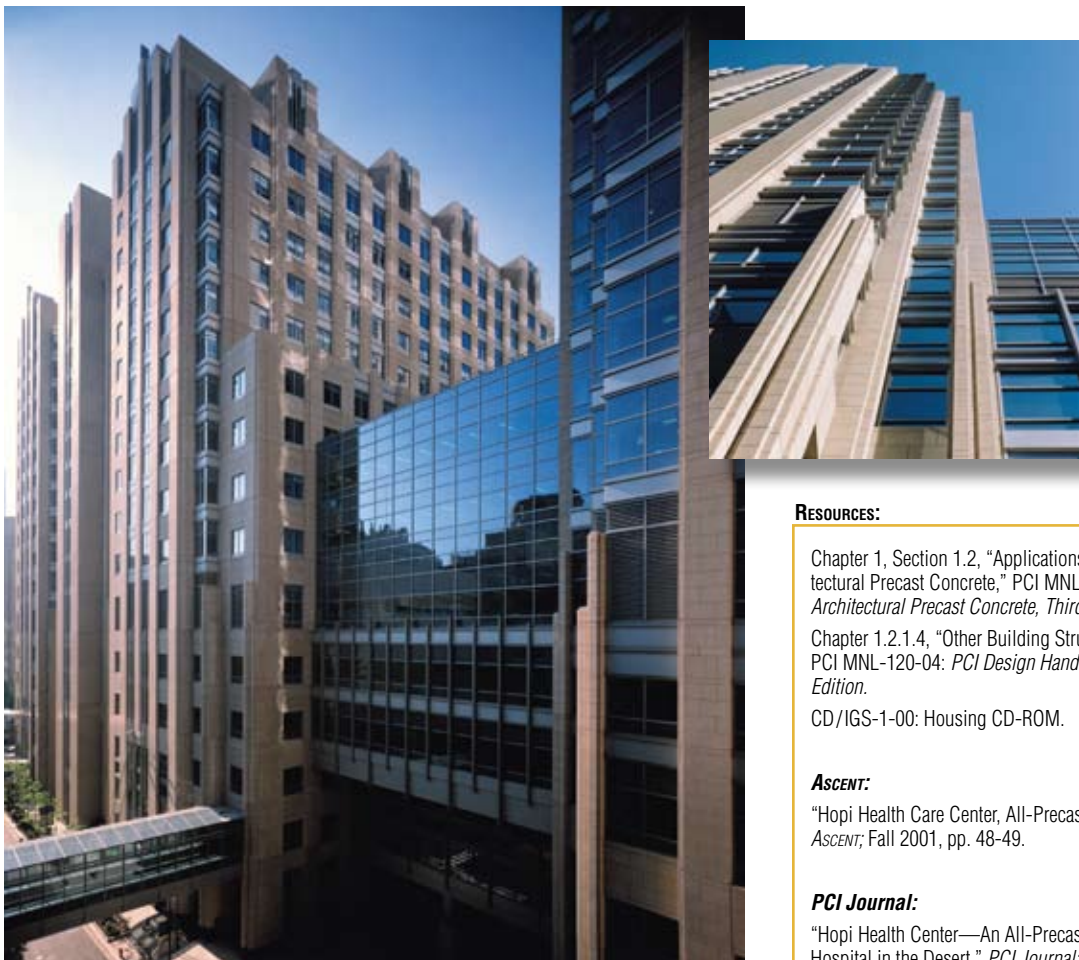
Abraham Pediatric Research Center, Children's Hospital of Philadelphia, Pa.; Architect: Ellenzweig Associates; Photo: Tom Crane.



Center for Women & Newborns, Brigham & Women's Hospital, Boston, Mass.; Architect: Tsoi/Kobus Associates Inc.; Photo: ©Steve Rosenthal.



Hopi Healthcare Center, Polacca, Ariz.; Architect: FKW Architects Inc. and Gresham & Beach Inc. (formerly NBBJ).



Northwestern Memorial Hospital, Chicago, Ill.; Architect: Ellerbe Becket Inc., Hellmuth, Obata & Kassabaum Inc. and VOA Associates Inc.

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"Hopi Health Care Center, All-Precast Awards," *ASCENT*; Fall 2001, pp. 48-49.

PCI Journal:

"Hopi Health Center—An All-Precast Concrete Hospital in the Desert," *PCI Journal*; July-August 2001, pp. 44-55.



Pharmacia Building Q, Skokie, Ill.; Architect: Flad & Associates; Photo: ©Burne Photo Imaging Inc.

high-tech

RESEARCH

Design Challenges

Precast Concrete Solutions

<p><i>Create specialized spaces for technical processes and equipment.</i></p>	<p><i>Precast concrete components can provide the design flexibility and durability needed to provide added HVAC infrastructure, such as larger clearances in shafts, ceiling spaces, plenums, and chases. They can also help meet needs for floors that are accessible.</i></p>
<p><i>Eliminate vibration that could disrupt sensitive experiments.</i></p>	<p><i>Precast concrete's solid mass and structural support for HVAC and other equipment helps ensure that rooms are not impacted by equipment operating elsewhere.</i></p>
<p><i>Design clean rooms that can remain completely free of dust or particles.</i></p>	<p><i>Treatments are available to help precast concrete panels ensure that no outside particles interfere with clean-room research. Precast concrete systems can also provide the large open-span spaces that are required for mechanical equipment to filter air, while providing the vibration resistance needed to ensure that sensitive equipment performs properly.</i></p> <p><i>The panels can be rubbed with mortar after casting to fill every pin-sized air void before the final finish is applied, ensuring a solid surface with no microscopic ledges to hold contaminants. They also can be treated to fight bacteria growth and resist mildew.</i></p>
<p><i>Provide a durable interior environment that can be kept clean and withstand harsh chemical treatments.</i></p>	<p><i>Precast concrete insulated sandwich wall panels provide a durable, finished interior side that can withstand cleaning, as well as high humidities that would corrode metal. They can also be designed to achieve a maximum four-hour fire rating to help contain accidents.</i></p>
<p><i>Provide a secure enclosure that protects research and prevents disruptions.</i></p>	<p><i>Precast concrete's high durability and impenetrability ensures no security breaches through wall penetrations. Inherently noncombustible composition, along with compartmentalization designs, contains fire to specific areas and allows for detection, evacuation, and suppression. The material also provides strong resistance to harsh weather.</i></p>
<p><i>Minimize operating costs to keep budgets under control.</i></p>	<p><i>Insulated sandwich wall panels offer an energy-efficient façade that aids in controlling heating and cooling costs. A total precast concrete system expedites construction, minimizes the number of component pieces by combining structural and architectural attributes into a single piece, and offers single-source responsibility from the precaster.</i></p>
<p><i>Meet the area's seismic requirements.</i></p>	<p><i>Precast concrete systems, using proven connection technology, allow precast concrete components to be used in all seismic zones.</i></p>
<p><i>Expedite construction to provide faster return on investment.</i></p>	<p><i>Component casting begins when the shop drawings are complete, ensuring that erection begins as soon as the site is prepared.</i></p> <p><i>Year-round, all-weather construction ensures that schedules are met.</i></p> <p><i>A total precast concrete system expedites construction, minimizes the number of component pieces by combining structural and architectural attributes into a single piece, and offers single-source responsibility from the precaster.</i></p>

high-tech

RESEARCH



Levine Science Research Center at Duke University, Durham, N.C.; Architect: Payette Associates Inc.; Photo: Brian Vanden Brink.



Stovers Institute, Kansas City, Kans.; Architect: Peckham Guyton Albers & Viets Inc. Architects; Photo: P-Tn/Photo-Technique.



Apple Computer Inc., Cupertino, Calif.; Architect: Hellmuth, Obata + Kassabaum (HOK); Photo: ©John Sutton.



Chiron Corp. Life Sciences Center, Emeryville, Calif.; Architect: Flad & Associates.



Biochemistry Building at the University of Wisconsin, Madison, Wis.; Architect: Flad & Associates; Photo: Christopher Barrett-Hedrich Blessing.



Dell Computer Corp.'s PS1, PS2, PS3 & Link, Austin, Tex.; Architect: DLR Group; Photo: ©Don F. Wong.



Bayer Corp. B27 Building, West Haven, Conn.; Architect: Flad & Associates; Photo: ©Burne Photo Imaging Inc.

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CHAPTER TWO

HOUSING

Housing designs must encompass a wide range of needs, as users may be owners or permanent residents, or they may be transient guests. Privacy, safety, and durability are key in constructing these projects to meet owners' needs, as is an aesthetically pleasing exterior that will attract users and project a welcoming, attractive appearance. Precast concrete components help meet many of these needs.





Craftsman-style Home, Inner Grove Heights, Minn.; Architect: Sala Architects Inc.

single - FAMILY HOMES

Design Challenges

Precast Concrete Solutions

<p><i>Create an attractive, comfortable appearance that fits with the surrounding neighborhood, whether historic or contemporary.</i></p>	<p><i>Architectural precast concrete panels use colors, textures, reveals, finishes, formliners, or thin-brick insets to match any needed design style.</i></p>
<p><i>Provide a high-quality, easily maintained façade.</i></p>	<p><i>Durable concrete and few joints help ensure minimal maintenance of the exterior, even when using thin-brick insets to match nearby brick homes.</i></p>
<p><i>Ensure fire resistance to reduce insurance costs.</i></p>	<p><i>Inherently noncombustible composition helps contain fire, providing more time for detection, evacuation, and suppression. Concrete roofs and façade help ensure that fires in nearby homes do not spread.</i></p>
<p><i>Minimize energy use.</i></p>	<p><i>Insulated sandwich wall panels offer an energy-efficient façade that aids in controlling heating and cooling costs.</i></p>
<p><i>Maximize lower-level space and eliminate columns for more flexibility.</i></p>	<p><i>Hollow-core flooring can span long spaces, especially on sloped elevations, to add and open up below-grade spaces.</i></p>
<p><i>Control acoustics to provide privacy from neighbors.</i></p>	<p><i>Precast concrete wall panels minimize noise between units.</i></p>
<p><i>Design a foundation that minimizes chances for moisture penetration.</i></p>	<p><i>Precast concrete panels used as foundation walls minimize joints and maintenance to control moisture penetration.</i></p>
<p><i>Construct the home quickly to expedite occupancy.</i></p>	<p><i>A total precast concrete system expedites construction, minimizes the number of component pieces by combining structural and architectural attributes into a single piece, and offers single-source responsibility from the precaster.</i></p> <p><i>Component casting begins when the shop drawings are complete, ensuring that erection begins as soon as the site is prepared.</i></p> <p><i>Year-round, all-weather construction ensures that schedules are met.</i></p>
<p><i>Minimize congestion and safety concerns on site and in the general vicinity during construction.</i></p>	<p><i>Precast concrete components can be brought to the site as needed for that day's erection, and staging areas can be arranged nearby. Fabrication of components off site ensures less traffic on the site and less congestion in the vicinity during the construction.</i></p>
<p><i>Meet the area's seismic requirements.</i></p>	<p><i>Precast concrete systems, using proven connection technology, allow precast concrete components to be used in all seismic zones.</i></p>

single FAMILY HOMES



Fortified Home, LOCATION; Architect; Photo: Dukane Precast.



Frinrock Residence; Lake Mary, Fla.; Architect: Burke, Hogue & Mills & Associates Architects.



Precast Concrete Log Home, Missoula, Mont.; Architect: Beaudette Consulting Engineers with Cultured Log Systems; Photo: Cultured Log Systems.



Scattered Site Housing, Chicago, Ill.; Architect: Piekarz Associates P.C. Architects.

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"Precast Design Adds Safety To Residences," *ASCENT*; Spring 2005, pp. 18-22.

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"Davis Residence Garage," *PCI Journal*; September-October 2005, pp. 112-117.

"NU Precast Concrete House Provides Spacious and Energy Efficient Solution for Residential Construction," *PCI Journal*; May-June 2005, pp. 26-39.



808 Berry Place, St. Paul, Minn.; Architect: Walsh Bishop Associates Inc.; Photo: Molin Concrete Products Co.

multi FAMILY BUILDINGS

Design Challenges

Precast Concrete Solutions

<i>Create an attractive appearance that appeals to tenants and fits into the surrounding neighborhood.</i>	<i>Architectural precast concrete panels use colors, textures, reveals, finishes, formliners, or thin-brick insets to match any needed design style.</i>
<i>Provide a high-quality, easily maintained exterior.</i>	<i>Durable concrete and few joints minimize maintenance of the exterior, even when using thin-brick insets to match nearby brick homes.</i>
<i>Control acoustics so adjoining tenants' activities do not disturb neighbors.</i>	<i>Precast concrete wall panels, especially insulated panels, minimize noise between units.</i>
<i>Eliminate impact noise and vibration between floors.</i>	<i>Hollow-core slabs' ability to absorb impact and vibration helps minimize disturbance to those on lower floors. Their sound-transmission qualities help mitigate unwanted noises between living units.</i>
<i>Ensure fire resistance to reduce insurance costs.</i>	<i>Inherently noncombustible composition helps contain fire, providing more time for detection, evacuation, and suppression.</i>
<i>Minimize energy use.</i>	<i>Insulated sandwich wall panels offer an energy-efficient façade that aids in controlling heating and cooling costs.</i>
<i>Add secure, structurally sound balconies to all units.</i>	<i>Cantilevered hollow-core slab or solid slabs can provide monolithic balconies that are secure and quick to construct.</i>
<i>Minimize floor-to-floor heights to meet zoning codes and maximize the number of levels.</i>	<i>Hollow-core slabs serve as a combined ceiling/flooring unit, reducing building height and saving material costs.</i>
<i>Construct the building quickly to provide faster return on investment and reduce interest on construction loans.</i>	<p><i>A total precast concrete system expedites construction, minimizes the number of component pieces by combining structural and architectural attributes into a single piece, and offers single-source responsibility from the precaster.</i></p> <p><i>Component casting begins when the shop drawings are complete, ensuring that erection begins as soon as the site is prepared.</i></p> <p><i>Year-round, all-weather construction ensures that schedules are met.</i></p>
<i>Minimize congestion and safety concerns on site and in the general vicinity during construction.</i>	<i>Precast concrete components can be brought to the site as needed for that day's erection, and staging areas can be arranged nearby. Fabrication of components off site ensures less traffic on the site and less congestion in the vicinity during the construction.</i>
<i>Meet the area's seismic requirements.</i>	<i>Precast concrete systems, using proven connection technology, allow precast concrete components to be used in all seismic zones.</i>

multi FAMILY BUILDINGS



Trinity Place, Boston, Mass.; Architect: CBT/Childs Berman Tseckares Inc.



Grant Park Tower, Minneapolis, Minn.; Architect: Opus Northwest, LCC.



Park Terrace Row Houses, Milwaukee, Wis.; Architect: Vetter Denk Architects; Photo: The Spancrete Group.



University of Nebraska House, Omaha, Neb.; Architect: Kenneth Hahn Architects; Photo: Tadros and Associates.



Metropolitan Tower, Seattle, Wash.; Architect: Callison Architecture; Photo: ©2002 Chris Eden/Callison Architecture.



The Woodlawn, Chicago, Ill.; Architect: Campbell Tiu Campbell; Photo: Dukane Precast Inc.



Arcadia Place, Chicago, Ill.; Architect: Landon/Bone/Baker Architects; Photos: Prestress Engineering Corp.



Velocity, Hoboken, N.J.; Architect: Bodnar Architects & Associates and Equus Design Group; Photo: ©Thomas H. Kieren.

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"Precast Cladding Gives Dorm Terra Cotta Look, Building Awards," *ASCENT*; Fall 2002, pp. 16-17.

"Precast Lofts Help Build Chicago Neighborhood," *ASCENT*; Summer 2003, pp. 16-19.

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"Project Study: Archer Courts Townhouses, Chicago, Illinois," *PCI Journal*; November-December 2005, pp. 96-101.

"Project Study: 840 North Lake Shore Drive Tower, Chicago, Illinois," *PCI Journal*; November-December 2005, pp. 102-109.

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"University Village Mid-Rise Condominiums, Chicago, Illinois," *PCI Journal*; May-June 2005, pp. 108-111.



Residential Hall at Bryan College, Dayton, Tenn.;
Architect: The Troyer Group.

dormitory

BUILDINGS

Design Challenges

Precast Concrete Solutions

<p><i>Create a durable facility that can withstand hard use.</i></p>	<p><i>Precast concrete's compressive strength and impact resistance minimize the chance for damage by guests to interior walls or ceilings.</i></p>
<p><i>Design an exterior treatment that fits with the campus style.</i></p>	<p><i>Architectural precast concrete panels use colors, textures, reveals, finishes, formliners, or thin-brick insets to match any needed design style.</i></p>
<p><i>Provide a high-quality, easily maintained exterior.</i></p>	<p><i>Durable concrete and few joints help ensure minimal maintenance of the exterior, even when using thin-brick insets to match nearby campus buildings.</i></p>
<p><i>Allow open spaces on lower floors for gathering areas, cafeteria, etc., while providing support for smaller living spaces overhead.</i></p>	<p><i>Hollow-core slabs can span long distances to eliminate columns on lower floors and provide support for walls on upper floors.</i></p>
<p><i>Control acoustics between rooms and the exterior to aid studying and maintain privacy.</i></p>	<p><i>Precast concrete wall panels, especially insulated panels, minimize noise between units.</i></p>
<p><i>Minimize impact noise and vibration between floors.</i></p>	<p><i>Hollow-core slabs' ability to absorb impact and vibration helps minimize disturbance to those on lower floors.</i></p>
<p><i>Ensure fire resistance.</i></p>	<p><i>Inherently noncombustible composition helps contain fire, providing more time for detection, evacuation, and suppression.</i></p>
<p><i>Minimize energy needs throughout the life of the building.</i></p>	<p><i>Insulated sandwich wall panels offer an energy-efficient façade that aids in controlling heating and cooling costs.</i></p>
<p><i>Minimize congestion and safety concerns on site and in the general vicinity during construction.</i></p>	<p><i>Precast concrete components can be brought to the site as needed for that day's erection, and staging areas can be arranged nearby. Fabrication of components off site ensures less traffic on the site and less congestion in the vicinity during the construction.</i></p>
<p><i>Meet the area's seismic requirements.</i></p>	<p><i>Precast concrete systems, using proven connection technology, allow precast concrete components to be used in all seismic zones.</i></p>
<p><i>Expedite construction to ensure occupancy for new term.</i></p>	<p><i>A total precast concrete system expedites construction, minimizes the number of component pieces by combining structural and architectural attributes into a single piece, and offers single-source responsibility from the precaster.</i></p> <p><i>Component casting begins when the shop drawings are complete, ensuring that erection begins as soon as the site is prepared.</i></p> <p><i>Year-round, all-weather construction ensures that schedules are met.</i></p>

dormitory

BUILDINGS



Residence Hall One, University of South Florida, St. Petersburg, Fla.; Architect: KBJ Architects Inc.; Photos: Gate Precast Co.



Western Connecticut State University Dormitory, Danbury, Conn.; Architect: Herbert S. Newman & Partners PC; Photos: Blakeslee Prestress Co.



University Center of Chicago, Ill.; Architect: Antunovich Associates and VOA Associates; Photos: Antunovich Associates.



Ramapo College Phase 8, Mahwah, N.J.; Architect: PS&S Engineering; Photos: PS&S Engineering.



Villanova University, Villanova, Pa.; Architect: Hillier Group.



Residential Hall at the Art Institute, Chicago, Ill.; Architect: Booth Hansen Associates Inc.; Photo: Brian Fritz Photography.

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"Precast Cladding Gives Dorm Terra Cotta Look, Building Awards," *ASCENT*, Fall 2002, pp. 16-17.

PCI Journal:

"GFRC Panels Give Terra Cotta Look to Chicago Art Institute Residence Hall," *PCI Journal*, January-February 2002, pp. 14-25.



Bookends, Greenville, S.C.; Architect: Johnston Design Group LLC

condominium

BUILDINGS

Design Challenges

Precast Concrete Solutions

<p><i>Create an attractive appearance that provides comfort to tenants while blending with the surrounding neighborhood.</i></p>	<p><i>Architectural precast concrete panels use colors, textures, reveals, finishes, formliners, or thin-brick insets to match any needed design style.</i></p>
<p><i>Provide a high-quality, easily maintained exterior.</i></p>	<p><i>Durable concrete and few joints help ensure minimal maintenance of the exterior, even when using thin-brick insets to match nearby buildings.</i></p>
<p><i>Control sound transmission between rooms and the exterior to maintain privacy.</i></p>	<p><i>Precast concrete wall panels, especially insulated panels, minimize noise between units.</i></p>
<p><i>Minimize impact noise and vibration between floors.</i></p>	<p><i>Hollow-core slabs' ability to absorb impact and vibration helps minimize disturbance to those on lower floors.</i></p>
<p><i>Ensure fire resistance.</i></p>	<p><i>Inherently noncombustible composition helps contain fire, providing more time for detection, evacuation, and suppression.</i></p>
<p><i>Minimize energy needs throughout the life of the building.</i></p>	<p><i>Insulated sandwich wall panels offer an energy-efficient façade that aids in controlling heating and cooling costs.</i></p>
<p><i>Minimize congestion and safety concerns on site and in the general vicinity during construction.</i></p>	<p><i>Precast concrete components can be brought to the site as needed for that day's erection, and staging areas can be arranged nearby. Fabrication of components off site ensures less traffic on the site and less congestion in the vicinity during the construction.</i></p>
<p><i>Meet the area's seismic requirements.</i></p>	<p><i>Precast concrete systems, using proven connection technology, allow precast concrete components to be used in all seismic zones.</i></p>
<p><i>Expedite construction to provide faster occupancy.</i></p>	<p><i>A total precast concrete system expedites construction, minimizes the number of component pieces by combining structural and architectural attributes into a single piece, and offers single-source responsibility from the precaster.</i></p> <p><i>Component casting begins when the shop drawings are complete, ensuring that erection begins as soon as the site is prepared.</i></p> <p><i>Year-round, all-weather construction ensures that schedules are met.</i></p>

condominium

BUILDINGS



840 N. Lake Shore Drive, Chicago, Ill.; Architect: Lucien Lagrange Architects; Photo: Steinkamp/Ballogg Photography.



The Belvedere Residences, Boston, Mass.; Architect: CBT/Childs Bertman Tseckares Inc.; Photo: Jonathan Hillyer Photography Inc./Esto.



Bookends, Greenville, S.C.; Architect: Johnston Design Group LLC



The Metropolitan, San Francisco, Calif.; Architect: Heller Manus; Architects and HKS.



Villa d'Este, Houston, Tex.; Architect: Ziegler Cooper Architects; Photo: Aker/Zvonkovic Photography.



Glen Lakes Condominiums, Chicago's North Side; Architect: Andrian-Zemenides Inc.



University Village Mid-Rise Lofts, Chicago, Ill.; Architect: FitzGerald Associates Architects;
Photos: Jess Smith Photography.



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"University Village Mid-Rise Condominiums, Chicago, Illinois," *PCI Journal*; May-June 2005, pp. 108-111.



800J Lofts, Sacramento, Calif.; Architect: LPA Sacramento Inc.; Photo: John Swain.



*Third Avenue Marriott ExecuStay, New York City;
Architect: H. Thomas O'Hara Architects.*

hotel

BUILDINGS

Design Challenges

Precast Concrete Solutions

<i>Minimize floor-to-floor heights to increase the number of levels, even under strict zoning requirements.</i>	<i>Hollow-core slabs can serve as a combined ceiling/flooring unit, reducing the building's height.</i>
<i>Reduce noise between rooms.</i>	<i>Precast concrete wall panels, especially when insulated, and precast concrete floors block noise transmission.</i>
<i>Minimize impact noise and vibration between floors.</i>	<i>Hollow-core slabs' ability to absorb impact and vibration helps minimize disturbance to those on lower floors.</i>
<i>Provide structural support for many small rooms above open, column-free ballrooms and conference areas.</i>	<i>Hollow-core slabs span long distances while providing structural support, minimizing columns on lower floors.</i>
<i>Create high fire resistance.</i>	<i>Precast concrete's noncombustible composition minimizes the spread of fire, while compartmentalization design techniques provide time for detection, evacuation, and suppression.</i>
<i>Use durable materials that will not show dents and other misuse.</i>	<i>The compressive strength and impact resistance of precast concrete minimize chances for damage by guests to interior walls or ceilings.</i>
<i>Offer low moisture penetration around facilities such as pools.</i>	<i>Precast concrete, along with long spans with no joints, ensures that water penetration is minimized and moisture is controlled, even in pool areas.</i>
<i>Minimize congestion and safety concerns on site and in the general vicinity during construction.</i>	<i>Precast concrete components can be brought to the site as needed for that day's erection, and staging areas can be arranged nearby. Fabrication of components off site ensures less traffic on the site and less congestion in the vicinity during the construction.</i>
<i>Meet the area's seismic requirements.</i>	<i>Precast concrete systems, using proven connection technology allow precast concrete components to be used in all seismic zones.</i>
<i>Expedite construction to provide faster return on investment and meet reservation commitments.</i>	<i>A total precast concrete system expedites construction, minimizes component pieces by combining structural and architectural elements, and provides single-source responsibility.</i> <i>Component casting begins when the shop drawings are complete, ensuring that erection begins as soon as the site is prepared.</i> <i>Year-round, all-weather construction ensures that schedules are met.</i>
<i>Blend the structure with the local neighborhood, whether it is contemporary or historic.</i>	<i>Architectural precast concrete panels use colors, textures, reveals, finishes, formliners, or thin-brick insets to match any needed design style.</i>

hotel

BUILDINGS



Marriott Hotel, Bloomington, Minn.; Architect: Eleness Swenson Graham Architects Inc.



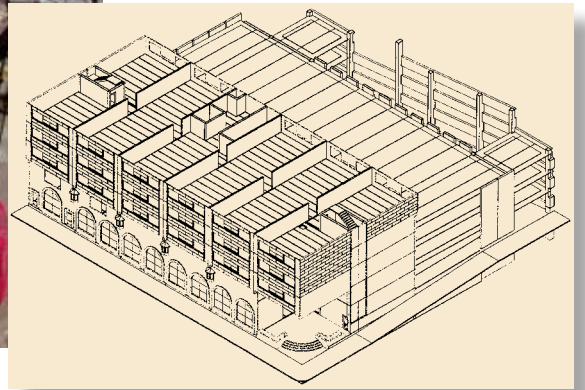
Plaza Towers, Grand Rapids, Mich.; Architect: A. Epstein & Sons International Inc.



Woodlands Waterway Marriott Hotel & Conference Center, The Woodlands, Tex.; Architect: Gensler.



Photo: Barry Coon, Commercial Photographers Inc.



Davenport Hotel Tower, Spokane, Wash.; Architect: Bernardo Willis Architecture PC;
Photo: Shawn Toner-Explosive Illusions Photography.



Fairmont Hotel, San Jose, Calif.;
Architect: HOK Architects;
Photo: George Cott.



Sheraton Grand Hotel, Sacramento, Calif.; Architect: HOK San Francisco; Photo: Michael Sechman.



Ballantyne Resort Hotel, Charlotte, N.C.; Architect: LS3P Associates Ltd.

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Photo: Liquid Library.

retirement

FACILITIES

Design Challenges

Precast Concrete Solutions

<p><i>Create an attractive appearance that provides comfort to tenants while blending with the surrounding neighborhood.</i></p>	<p><i>Architectural precast concrete panels use colors, textures, reveals, finishes, formliners, or thin-brick insets to match any needed design style.</i></p>
<p><i>Provide a high-quality, easily maintained exterior.</i></p>	<p><i>Durable concrete and few joints help ensure minimal maintenance of the exterior, even when using thin-brick insets to match nearby buildings.</i></p>
<p><i>Control sound transmission between rooms and the exterior to maintain privacy.</i></p>	<p><i>Precast concrete wall panels, especially insulated panels, minimize noise between units.</i></p>
<p><i>Minimize impact noise and vibration between floors.</i></p>	<p><i>Hollow-core slabs' ability to absorb impact and vibration helps minimize disturbance to those on lower floors.</i></p>
<p><i>Ensure fire resistance.</i></p>	<p><i>Inherently noncombustible composition helps contain fire, providing more time for detection, evacuation, and suppression.</i></p>
<p><i>Minimize energy needs throughout the life of the building.</i></p>	<p><i>Insulated sandwich wall panels offer an energy-efficient façade that aids in controlling heating and cooling costs.</i></p>
<p><i>Minimize congestion and safety concerns on site and in the general vicinity during construction.</i></p>	<p><i>Precast concrete components can be brought to the site as needed for that day's erection, and staging areas can be arranged nearby. Fabrication of components off site ensures less traffic on the site and less congestion in the vicinity during the construction.</i></p>
<p><i>Meet the area's seismic requirements.</i></p>	<p><i>Precast concrete systems, using proven connection technology, allow precast concrete components to be used in all seismic zones.</i></p>
<p><i>Expedite construction to provide faster occupancy.</i></p>	<p><i>A total precast concrete system expedites construction, minimizes the number of component pieces by combining structural and architectural attributes into a single piece, and offers single-source responsibility from the precaster.</i></p> <p><i>Component casting begins when the shop drawings are complete, ensuring that erection begins as soon as the site is prepared.</i></p> <p><i>Year-round, all-weather construction ensures that schedules are met.</i></p>

retirement

FACILITIES



San Francisco Towers, San Francisco, Calif.; Architect: Wurster Bernardi & Emmons Inc.; Photo: Clark Pacific.



USAA Retirement Center, San Antonio, Tex.; Architect: HKS Inc.



Homewood Residence, Westover Hills, Tex.; Architect: Earl Swensson Associates.



Lester Senior Housing, Whippany, N.J.; Architect: NK Architects.

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CD/IGS-1-00: Housing CD-ROM



Photo: Liquid Library.

assisted living

FACILITIES

Design Challenges

Precast Concrete Solutions

<p><i>Create an attractive appearance that provides comfort to tenants while blending with the surrounding neighborhood.</i></p>	<p><i>Architectural precast concrete panels use colors, textures, reveals, finishes, formliners, or thin-brick insets to match any needed design style.</i></p>
<p><i>Provide a high-quality, easily maintained exterior.</i></p>	<p><i>Durable concrete and few joints help ensure minimal maintenance of the exterior, even when using thin-brick insets to match nearby buildings.</i></p>
<p><i>Allow open spaces on lower floors for gathering areas, dining room, etc., while providing support for smaller living spaces overhead.</i></p>	<p><i>Hollow-core slabs can span long distances to eliminate columns on lower floors and provide support for walls on upper floors.</i></p>
<p><i>Control sound transmission between rooms and the exterior to maintain privacy.</i></p>	<p><i>Precast concrete wall panels, especially insulated panels, minimize noise between units.</i></p>
<p><i>Minimize impact noise and vibration between floors.</i></p>	<p><i>Hollow-core slabs' ability to absorb impact and vibration helps minimize disturbance to those on lower floors.</i></p>
<p><i>Ensure fire resistance.</i></p>	<p><i>Inherently noncombustible composition helps contain fire, providing more time for detection, evacuation, and suppression.</i></p>
<p><i>Minimize energy needs throughout the life of the building.</i></p>	<p><i>Insulated sandwich wall panels offer an energy-efficient façade that aids in controlling heating and cooling costs.</i></p>
<p><i>Minimize congestion and safety concerns on site and in the general vicinity during construction.</i></p>	<p><i>Precast concrete components can be brought to the site as needed for that day's erection, and staging areas can be arranged nearby. Fabrication of components off site ensures less traffic on the site and less congestion in the vicinity during the construction.</i></p>
<p><i>Meet the area's seismic requirements.</i></p>	<p><i>Precast concrete systems, using proven connection technology, allow precast concrete components to be used in all seismic zones.</i></p>
<p><i>Expedite construction to provide faster occupancy.</i></p>	<p><i>A total precast concrete system expedites construction, minimizes the number of component pieces by combining structural and architectural attributes into a single piece, and offers single-source responsibility from the precaster.</i></p> <p><i>Component casting begins when the shop drawings are complete, ensuring that erection begins as soon as the site is prepared.</i></p> <p><i>Year-round, all-weather construction ensures that schedules are met.</i></p>

assisted living

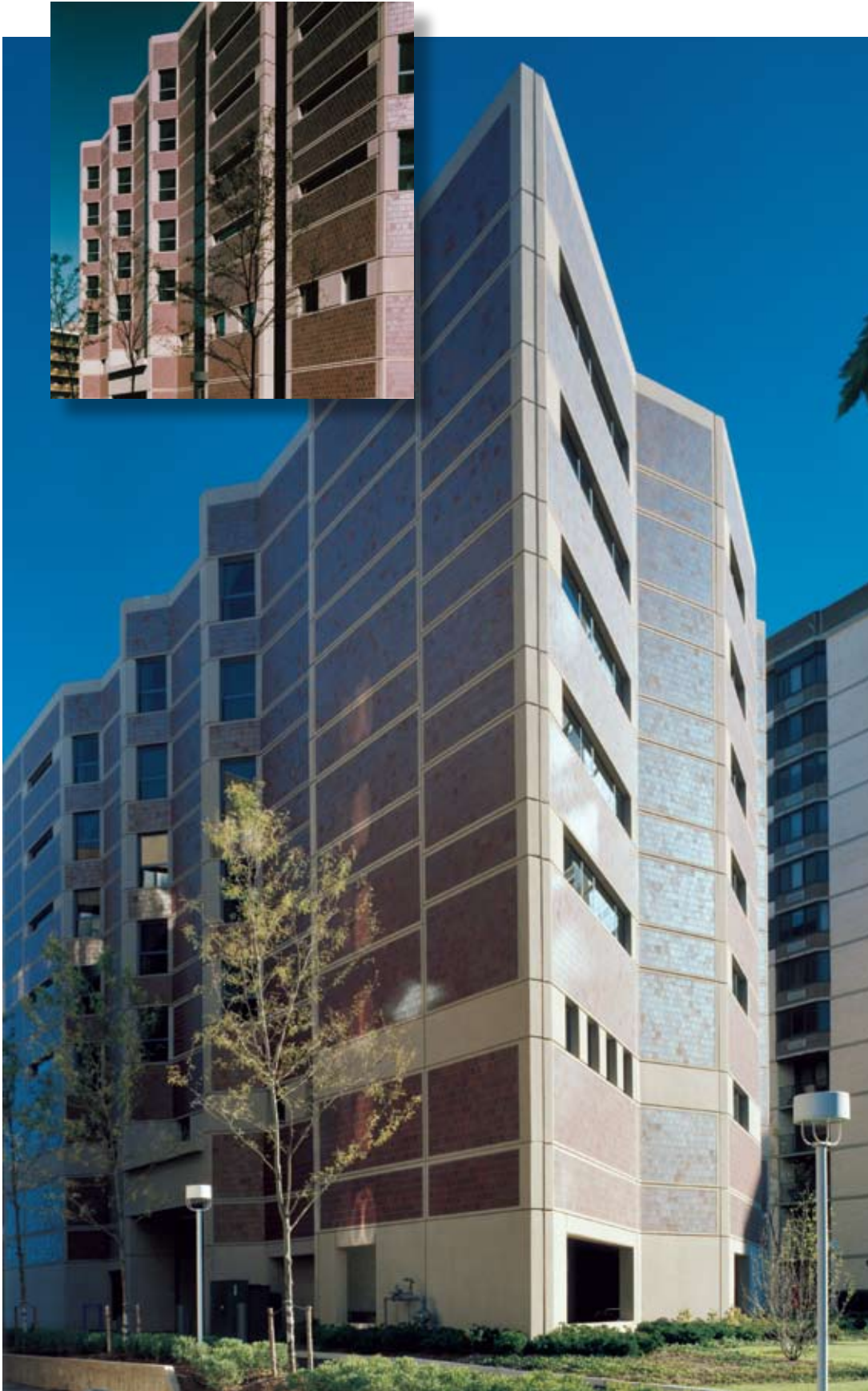
FACILITIES



Senior Quarters at Riverdale, Bronx, N.Y.; Architect: Architects Design Group.



Emerson House Residential Care Facility, Portland, Ore.; Architect: Chillless Nielsen Architects; Photo: Bob Boll Photography.



Prospect Heights Care Center, Hackensack, N.J.; Architect: Herbert Beckhard Frank Richlan & Associates; Photo: Norman McGrath.





Brighton Gardens, Winston-Salem, N.C.; Architect: Ray Troxell Associates Inc.



Roosevelt Place, Chicago, Ill.; Architect: Piekarz Associates PC; Photos: Prestress Engineering Corp.

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CHAPTER TWO
INDUSTRIAL

Industrial facilities are highly functional projects that need to be able to handle a high volume of delivery vehicles, provide expansive operational working spaces, and perform specialized activities that can challenge designers working to blend them together. Owners of these facilities are also aware of how important an attractive image can be in maintaining good relations with the local community and enhancing market value throughout the life of the building. Precast concrete can help meet these and other challenges for space requirements that can be specialized, focused, and demanding.





Peoria Production Shop, Peoria, Ill.; Architect: River City Construction LLC.

warehouse

FACILITIES

Design Challenges

Precast Concrete Solutions

Design a durable, attractive exterior that blends with surrounding buildings.	Architectural precast concrete panels use colors, textures, reveals, finishes, formliners, or thin-brick insets to match any needed design style.
Provide open interiors.	Hollow-core slabs and double tees can create long spans, allowing column-free areas for installing or rearranging equipment.
Create easy support options for HVAC and processing equipment.	Precast concrete panels can carry the structural load of the roof system, reducing costs and expediting construction while creating large, open interiors. This structural support can be used for installation of mechanical equipment.
Install efficient delivery bays for easy truck access.	Precast concrete panels can be cast at 12 ft widths or wider to allow installation of delivery doors in one panel, providing structural support and fast construction.
Minimize energy requirements.	Insulated sandwich wall panels offer an energy-efficient façade that aids in controlling heating and cooling costs.
Allow for potential horizontal expansion of the building if needed.	Non-loadbearing panels can be removed from one end of the building, with new panels (using the same type of concrete) added to the sides and the original panels reattached to add space.
Minimize congestion and safety concerns on site and in the general vicinity during construction.	Precast concrete components can be brought to the site as needed for that day's erection, and staging areas can be arranged nearby. Fabrication of components off site ensures less traffic on the site and less congestion in the vicinity during the construction.
Meet the area's seismic requirements.	Precast concrete systems, using proven connection technology, allow precast concrete components to be used in all seismic zones.
Expedite construction to provide faster return on investment.	<p>A total precast concrete system expedites construction, minimizes the number of component pieces by combining structural and architectural attributes into a single piece, and offers single-source responsibility from the precaster.</p> <p>Component casting begins when the shop drawings are complete, ensuring that erection begins as soon as the site is prepared.</p> <p>Year-round, all-weather construction ensures that schedules are met.</p>

warehouse

FACILITIES



Damark International, Brooklyn Park, Minn.; Photo: Koyama Photographic.



Fletcher Park, Indianapolis, Ind.; Architect: Ratio Architects Inc.; Photo: ©Mardan Photography.



Toppan Printing Company America Inc., Franklin Township, N.J.; Architect: Herbert Beckhard Frank Richlan & Associates; Photo: Otto Baitz.



Gannett Newspapers, Appleton, Wis.; Architect: McMahon Associates.



Quad Graphics, Wis.; Architect: Wheeler-Kearns Architects; Photo: William Kildow.



Peoria Production Shop, Peoria, Ill.; Architect: River City Construction LLC.



Centro de Distribucion Elektra Guadalajara, Mexico;
Architect: Springall + Lira S.A. de C.V.

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MK-15-98: Precast Concrete Wall Panels: Warehouse/Distribution Centers (6 pp.).

MK-20-98: Precast Panels for Industrial Buildings (6 pp.).



Federal Express, Hagerstown, Md.;
Architect: Coakley Williams Construction Co.

distribution

FACILITIES

Design Challenges

Precast Concrete Solutions

<p><i>Design a durable, attractive exterior that blends with surrounding buildings.</i></p>	<p><i>Architectural precast concrete panels use colors, textures, reveals, finishes, formliners, or thin-brick insets to match any needed design style.</i></p>
<p><i>Provide open interiors.</i></p>	<p><i>Hollow-core slabs and double tees can create long spans, allowing column-free areas for installing or rearranging equipment.</i></p>
<p><i>Create easy support options for HVAC and processing equipment.</i></p>	<p><i>Precast concrete panels can carry the structural load of the roof system, reducing costs and expediting construction while creating large, open interiors. Precast concrete roof systems can be used to support mechanical equipment.</i></p>
<p><i>Install efficient delivery bays for easy truck access.</i></p>	<p><i>Precast concrete panels can be cast at 12 ft widths or wider to allow installation of delivery doors in one panel, providing structural support and fast construction.</i></p>
<p><i>Minimize energy requirements.</i></p>	<p><i>Insulated sandwich wall panels offer an energy-efficient façade that aids in controlling heating and cooling costs.</i></p>
<p><i>Allow for economical future horizontal expansion of the building, if needed.</i></p>	<p><i>Non-loadbearing panels can be removed from one end of the building, with new panels (using the same type of concrete) added to the sides and the original panels reattached to add space.</i></p>
<p><i>Minimize congestion and safety concerns on site and in the general vicinity during construction.</i></p>	<p><i>Precast concrete components can be brought to the site as needed for that day's erection, and staging areas can be arranged nearby. Fabrication of components off site ensures less traffic on the site and less congestion in the vicinity during the construction.</i></p>
<p><i>Meet the area's seismic requirements.</i></p>	<p><i>Precast concrete systems, using proven connection technology, allow precast concrete components to be used in all seismic zones.</i></p>
<p><i>Expedite construction to provide faster return on investment.</i></p>	<p><i>A total precast concrete system speeds construction, minimizes the number of component pieces by combining structural and architectural attributes into a single piece, and offers single-source responsibility from the precaster.</i></p> <p><i>Component casting begins when the shop drawings are complete, ensuring that erection begins as soon as the site is prepared.</i></p> <p><i>Year-round, all-weather construction ensures that schedules are met.</i></p>

distribution

FACILITIES



United Parcel Service, Hodgkins, Ill.; Architect: McCluer Corp.



Department 56, Rogers, Minn.; Architect: Ryan Companies; Photo: Koyama Photographic.



Federal Express, Hagerstown, Md.; Architect: Coakley Williams Construction Co.



SuperValu Minneapolis Distribution Center, Hopkins, Minn.; Architect: Planmark Inc.; Photo: Koyama Photographic.





Federal Express, Crofton, Md.; Architect: Morgan Glick & Associates.



Lily Popcorn Co., Bethpage, N.Y.; Architect: Billow & Goldberg Associates.



Pepsi-Cola General Bottlers, Morton, Ill.; Architect: River City Design Group; Photo: Don Phelps, Photo Creations.

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MK-20-98: Precast Panels for Industrial Buildings (6 pp.).



Digital Monitoring Products Inc., Springfield, Mo.; Architect: Sapp Design Associates Architects P.C.

manufacturing

FACILITIES

Design Challenges

Precast Concrete Solutions

<i>Design a durable, attractive exterior that blends with surrounding buildings.</i>	<i>Architectural precast concrete panels use colors, textures, reveals, finishes, formliners, or thin-brick insets to match any needed design style.</i>
<i>Include design flexibility so fabrication or processing activities can be changed as needed.</i>	<i>Hollow-core slabs and double tees can create long spans, allowing column-free areas for installing or rearranging equipment.</i>
<i>Provide easy support options for HVAC and processing equipment.</i>	<i>Precast concrete panels can carry the structural load of the roof system, reducing costs and expediting construction while creating large, open interiors. Precast concrete roof systems can be used to support mechanical equipment.</i>
<i>Install efficient delivery bays for easy truck access.</i>	<i>Precast concrete panels can be cast at 12 ft widths or wider to allow installation of delivery doors in one panel, providing structural support and fast construction.</i>
<i>Minimize energy requirements.</i>	<i>Insulated sandwich wall panels offer an energy-efficient façade that aids in controlling heating and cooling costs.</i>
<i>Allow for economical future horizontal expansion of the building, if needed.</i>	<i>Non-loadbearing panels can be removed from one end of the building, with new panels (using the same type of concrete) added to the sides and the original panels reattached to add space.</i>
<i>Minimize congestion and safety concerns on site and in the general vicinity during construction.</i>	<i>Precast concrete components can be brought to the site as needed for that day's erection, and staging areas can be arranged nearby. Fabrication of components off site ensures less traffic on the site and less congestion in the vicinity during the construction.</i>
<i>Meet the area's seismic requirements.</i>	<i>Precast concrete systems, using proven connection technology, allow precast concrete components to be used in all seismic zones.</i>
<i>Expedite construction to provide faster return on investment.</i>	<p><i>A total precast concrete system expedites construction, minimizes the number of component pieces by combining structural and architectural attributes into a single piece, and offers single-source responsibility from the precaster.</i></p> <p><i>Component casting begins when the shop drawings are complete, ensuring that erection begins as soon as the site is prepared.</i></p> <p><i>Year-round, all-weather construction ensures that schedules are met.</i></p>

manufacturing

FACILITIES



Digital Monitoring Products Inc., Springfield, Mo.; Architect: Sapp Design Associates Architects P.C.



Phillip Morris Plant, Concord, N.C.; Architect: Herbert Beckhard Frank Richlan & Associates (HB+FR); Photos: ©Rick Alexander.



Poblocki & Sons Exterior and Interior Sign Systems, Wis.



Phillips Communications, Lancaster, Pa.; Architect: Greenfield Architects.



AT&T Corp., Chicago, Ill.; Architect: MFH Associates.

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"Precast Wall Separates, Spotlights Plant and Offices, Building Awards," *ASCENT*; Fall 2002, pp. 20-21.

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MK-15-98: Precast Concrete Wall Panels: Warehouse/Distribution Centers (6 pp.).

MK-20-98: Precast Panels for Industrial Buildings (6 pp.).



Gerry Baby Products, Thornton, Colo.;
Architect: Intergroup.

FOOD - processing FACILITIES

Design Challenges

Precast Concrete Solutions

<p><i>Meet government regulations for providing an environment in which dust and dirt cannot accumulate.</i></p>	<p><i>Precast concrete designs can ensure that the structure contains no horizontal surfaces where dust, dirt, or other contaminants can lodge. The most effective approach uses precast concrete panels as a loadbearing element to eliminate most columns and beams where dust could accumulate.</i></p>
<p><i>Provide completely smooth walls where no particles can lodge.</i></p>	<p><i>Durable precast concrete panels can be rubbed with a mortar after casting to fill pin-sized air voids before the final finish is applied. This ensures a solid surface that leaves no microscopic ledges to hold contaminants.</i></p>
<p><i>Create specialized spaces for technical processes and equipment.</i></p>	<p><i>Precast concrete components can provide the design flexibility and durability needed to allow for added HVAC infrastructure, such as larger clearances in shafts, ceiling spaces, plenums, and chases.</i></p>
<p><i>Provide controlled-atmosphere or freezer areas for storing food and produce prior to processing.</i></p>	<p><i>Precast concrete panels can provide the insulation required, while also supplying separation from surrounding surfaces that can induce humidity or groundwater to freeze and disrupt the structure.</i></p>
<p><i>Create a durable interior environment that can withstand regular cleaning with harsh chemicals.</i></p>	<p><i>Precast concrete insulated sandwich wall panels provide a durable, finished interior side that can withstand regular cleaning, as well as high humidities that would corrode metal. They can also be designed to achieve a maximum four-hour fire rating to help contain accidents.</i></p>
<p><i>Design a façade that blends storage spaces, processing plants, and office areas into one aesthetically pleasing design.</i></p>	<p><i>Precast concrete insulated sandwich wall panels provide an interior finished wall that blends these diverse functions, while offering aesthetics that complement them all. The exterior side can provide smooth, textured, or other types of finish, which can visually separate functions or blend them together. They can also include embedded logos and other corporate designs that project a professional image.</i></p>
<p><i>Allow for expansion potential of the facility as business grows.</i></p>	<p><i>Precast concrete panels can expand an existing building by adding new adjacent space or merging new space with the existing structure. The non-loadbearing panels on the end wall can be disconnected from the framing, and new panels and framing can be added on each side, with the end panels replaced.</i></p>
<p><i>Install efficient delivery bays for easy truck access.</i></p>	<p><i>Precast concrete panels can be cast at 12 ft widths or wider to allow installation of delivery doors in one panel, providing structural support and fast construction.</i></p>
<p><i>Minimize energy requirements.</i></p>	<p><i>Insulated sandwich wall panels offer an energy-efficient façade that aids in controlling heating and cooling costs.</i></p>
<p><i>Minimize congestion and safety concerns on site and in the general vicinity during construction.</i></p>	<p><i>Precast concrete components can be brought to the site as needed for that day's erection, and staging areas can be arranged nearby. Fabrication of components off site ensures less traffic on the site and less congestion in the vicinity during construction.</i></p>

FOOD- processing FACILITIES



Malt-O-Meal Co., Northfield, Minn.; Architect: Professional/Design Group.



Premium Standards Farms (PSF), Milan, Mo.; Architect: Rietz Consultants Ltd.



Hershey Food Pasta Group, Va.



Pepperidge Farm, Denver, Pa.; Photo: Loomis Shade Photography.





Fieldale Corp. Hatchery, Toccoa, Ga.; Photo: ©Hank Somma.



U.S. Durum Products Ltd., Lancaster, Pa.; Photo: J&D Graphics.



General Mills Inc., Albuquerque, N.M.; Architect: United Engineers & Constructors Inc.

RESOURCES:

Chapter 1. Section 1.2, "Applications of Architectural Precast Concrete," PCI MNL-122-07: *Architectural Precast Concrete, Third Edition*.

Chapter 1.2.1.3, "Warehouses and Industrial Buildings, PCI MNL-120-04: *PCI Design Handbook, Sixth Edition*.

CD/IGS-5-01: Industrial CD-ROM.

Other:

Ideas By Design, Vol. 1. No. 4, August 2001: Industrial Buildings (12 pp.).

MK-14-98: Precast Concrete Wall Panels: Sandwich Wall Panels (6 pp.).

MK-16-98: Precast Concrete Wall Panels: Food-Processing (6 pp.).

MK-20-98: Precast Panels for Industrial Buildings (6 pp.).

CHAPTER TWO

e MISCELLANEOUS

Precast concrete components can be used to create a wide range of unique and custom structures to meet owners' specific needs.

As part of their design, some building projects require structural spans to be used as bridges. Spanning highways, connecting to retail facilities, and providing access to higher levels of nearby structures are key applications of bridge technology to building construction. Precast concrete designs can provide a wide range of attractive, functional, and easily constructed spans.



Minnesota Library Access Center at the University of Minnesota, Minneapolis; Architect: Stageberg Beyer Sachs Inc.



Colonial Williamsburg Bridge To The Past, Williamsburg, Va.; Architect: Carlton Abbott & Partners PC.



Washington County Fair Park West Bend Multipurpose Building, West Bend, Wis.; Architect: BHS Architects; Photo: BHS Architects.



Le Veck Bridge, Los Angeles, Calif.; Architect: David Jay Flood Architect.

BICYCLE & pedestrian BRIDGES

Spans can be created by a variety of methods. For longer spans, cables can be strung between abutments at each end, with post-tensioned precast concrete panels resting atop the cables, similar to a suspension bridge. Graceful precast concrete arches, colored to match the surrounding landscape, can also be created, as well as balustrades and other decorative pieces.

Deck panels and spandrels can be combined to create quickly constructed and aesthetically pleasing designs that can connect portions of a campus, or allow access over a highway to retail spaces from parking or transportation hubs. The spandrels are cast with a continuous ledge on the lower interior surface, and the panels are laid on top. The spandrels' exterior sides can be inset with brick, or feature a variety of visually pleasing finishes.

Precast concrete manufacturers are aware of the latest techniques and state-of-the-art approaches to aid designers in achieving spans that provide access to buildings or between structures.

BICYCLE &
pedestrian
BRIDGES



Westminster Promenade Pedestrian Bridge, Westminister, Colo.



Padden Parkway Pedestrian Bridge, Vancouver, Wash.



Angels Flight™ Railway & Funicular Trestle, Los Angeles, Calif.



AirTrain Light Rail System, Queens, N.Y.



Nepperhan Avenue Pedestrian Bridge, Yonkers, N.Y.





Kennesaw State University Phase II Pedestrian Bridge, Kennesaw, Ga.; Architect: Niles Bolton Associates.

unique STRUCTURES

Contact your local precast manufacturer to determine how best to approach the challenges of unique structures and how precast concrete components can meet those individual requirements. These designs can include:

- Railroad ties,
- Soundwalls for freeways,
- Water tanks and reservoirs,
- Air-traffic control towers,
- Floating piers,
- Outdoor structures such as terraces and canopies.



unique STRUCTURES



Lincoln Heights Reservoirs, Spokane, Wash.



Riverside Plaza, Hartford, Conn.; Architect: Carol R. Johnson Associates and Goedes Brecher Qualls & Cunningham Inc.; Photos: Jerry Howard, Landscape Photography.



Maryland 216 Sound Barrier, Howard County, Md.; Designer/Engineer: JTE Civil Inc.; Photo: Creative Design Solutions.



The Clock Tower, Albion, Mich.; Architect: MacLachlan, Cornelius & Filoni Architects.



Metronome Building, New York City; Architect: Fredenburgh Wegierska-Mutin Architects Inc. and Kristin Jones and Andrew Ginzel, art wall designers; Photos: David Sunberg/ESTO.



Children's Museum of Indianapolis, Ind.; Architect: Browning Day Mullins Dierdorf Architects; Photos: High Concrete Group.



Commonwealth Edison Cooling Tower, Bryon, Ill.



Richard E. Lindner Athletics Center, University of Cincinnati, Ohio; Architect: Bernard Tschumi Architects; Design Architect: Glaserworks; Photo: Bernard Tschumi Architects.



Millennium Carillon, Naperville, Ill.; Architect: Charles Vincent George Design Group Inc.; Photo: Charles Vincent George Design Group Inc.



U.S. Navy Modular Hybrid Floating Pier, San Mateo/Alameda Counties, Calif.

RESOURCES:

Chapter 1, Section 1.2, "Applications of Architectural Precast Concrete," PCI MNL-122-07: *Architectural Precast Concrete, Third Edition*.
Chapter 1.2.1.4, "Other Building Structures," PCI MNL-120-04: *PCI Design Handbook, Sixth Edition*.

ASCENT:

"Metronome Art Wall, Building Awards," *ASCENT*; Fall 2002, p. 28.
"Millennium Carillon, Building Awards," *ASCENT*; Fall 2002, p. 26.
"Precast's Flexibility Aids Diverse, Specialized Projects," *ASCENT*; Summer 2001, pp. 28-30.
"U.S. Navy Modular Hybrid Floating Pier," *ASCENT*; Fall 2005, p. 20.



CHAPTER DESIGN CONSIDERATIONS

three

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Integration & Coordination with Other Building Systems _____	3B
Team Responsibilities _____	3C
Initial & Life-Cycle Costs _____	3D
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Health & Indoor Air Quality _____	3F
Acoustics _____	3G
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Precast concrete's high level of quality fabrication and its array of benefits help architects meet a variety of design challenges. These goals can range from projecting the appropriate image today to maintaining that appearance and retaining all functional activities for decades into the future. Maximizing the performance of the material requires an understanding of its capabilities and limitations related to each goal.

The aesthetic options available with architectural precast concrete components, especially wall panels, are considerable. They can mimic a wide variety of other masonry alternatives, including brick and stone, providing many options for duplicating existing architectural styles used with surrounding buildings. This holds true whether the styles are historic or contemporary.

In many cases, architectural finishes also can be provided for structural precast components, combining functions and saving material cost and construction time. Precast components also mesh well with other materials, including curtain walls, and they can accommodate any required penetrations. Special considerations will aid the installation of mechanical systems and vapor barriers, all of which can be accommodated easily.

Precast concrete's economy aids owners and designers in meeting their budgetary needs and helps make funds available that are typically needed for design consideration for other key elements. Its economy not only reduces the immediate in-ground cost but also continues to save operating expenses over the life of the building through extended durability and lower maintenance costs. Precast concrete can also aid in meeting sustainability goals set by the owner, including certification standards set by the Leadership in Energy & Environmental Design (LEED) program instituted by the U.S. Green Building Council (USGBC).

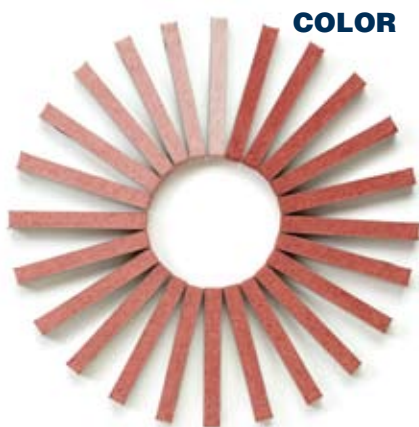
A variety of additional design challenges, such as maximizing fire resistance, heightening acoustic control, and providing safety provisions, can all be met by designing precast concrete components to the appropriate specifications. Architects who work closely with their local precaster during the design phase and throughout the development of the contract documents can ensure their projects make efficient use of the material's wide range of capabilities to provide optimum value and quality while minimizing construction cost.

Aesthetics

Precast concrete is a visually rich material that allows the architect to be innovative and attain design objectives that cannot be achieved with any other material. The architect's selection of color, form, and texture is critical to the aesthetic appearance of architectural precast concrete components. The choice of appropriate aggregates and textures, combined with well-conceived production and erection details, can achieve a wide variety of design objectives.

Design flexibility is possible in both color and texture of precast concrete by varying aggregate and matrix color, size of aggregate, finish processes, and depth of aggregate exposure. Combining color with texture accentuates the natural beauty of aggregates.

With the vast array of colors, textures, and finishes available, designers can use precast concrete to achieve almost any desired effect.



These swatches illustrate the different shades that can be created in architectural precast using a single pigment at many different concentrations. They represent addition rates of red pigment from 1/4% to 7% in a white cement base.

Color is a relative value, not an absolute and unvarying tone. It is affected by light, shadow, density, time, and other surrounding or nearby colors. Color selection should be made under lighting conditions similar to those under which the precast concrete will be used, such as the strong light and shadows of natural daylight. Surface texture influences color. The building's appearance is a function of the architect's use of light, shadow, texture, and color.

Cement combined with a coloring agent exerts the primary color influence on a smooth finish, because it coats the exposed concrete surface. As the concrete surface is progressively removed and aggregates are exposed, the panel color increasingly exhibits the fine and then the coarse aggregate colors. The color of the cement always has an effect on the general tone of the panel. Cement may be gray, white, or a mixture. All cements have inherent color and shading differences, depending on their source.

Pigments and pigmented admixtures are often added to the cement matrix to obtain colors that cannot be created through combinations of cement and fine aggregate alone. White portland cement will produce cleaner, brighter colors and where color is important should be used in preference to gray cement with pigments, especially for the light pastels such as buff, cream, pink, rose, and ivory.

Fine aggregates have a major effect on the color of white and light buff-colored concrete and can add color tones when the surface is given a shallow profile to increase the aggregate's exposure. Coarse aggregate colors become dominant as the surface of the concrete is removed to obtain a medium or deep aggregate exposure profile.

Some finishing processes change the appearance of aggregates. Sandblasting will give the aggregates a matte finish, while acid-etching may increase their brightness. Exposure by retardation of the surface cement normally leaves the aggregates unchanged.

Maintaining consistency of color throughout the production run requires attention to detail and proper specification. Eight key factors should be closely controlled when color consistency is critical:

1. Type and color of cement.
2. The quality and quantity of the coloring agent.
3. Proper batching and mixing techniques and the coloring agent's effect on the concrete's workability.
4. Quality (that is, freedom from impurities) of the fine and coarse aggregates.
5. Uniform quantities and gradation of the fine materials (capable of passing through a No. 50 sieve, including the cement) in the concrete mix.
6. Careful attention to curing and uniform duplication of curing cycles.
7. Constant water-cement ratio in the mix.
8. Consideration of the factors that can contribute to efflorescence. Its appearance on the concrete's surface can mask the true color and give the appearance of color fading. Should efflorescence occur, it can be washed off when its appearance on the panel is noticed.

The ease of obtaining uniformity in color is directly related to the ingredients supplying the color. Optimum uniformity is obtained by using white cement. Extreme color differences between aggregates and matrix should be avoided.

Color should be judged from a full-sized sample that has the proper cement matrix and has been finished in accordance with planned production techniques (see Reference 1).

TEXTURES



The Anadarko Tower located in The Woodlands, Tex., was clad with light and medium sandblast, textured precast panels composed of a single-face mix design. Some of the panels were supplemented with thermal finished Luna Pearl granite insets. The mix was composed of 100 percent white portland cement, coarse aggregates, fine aggregates, and pigment. Photo: Gensler.

Texture allows the naturalness of the concrete ingredients to be expressed, provides some scale to the mass of the building, expresses the creative aspect of the concrete, and improves the weathering characteristics of the element surface. A variety of textures can be achieved, ranging from a honed or polished surface to a deeply exposed, 3-in.-diameter, uncrushed aggregate surface.

The final appearance of any precast concrete finish will depend on the selection of aggregate color and size, matrix color, shape details or form, surface finish, and depth of aggregate exposure. Four major factors should be considered in choosing a texture:

1. The area of the surface. Coarse textures are difficult to use on small areas. Dividing large, flat areas by means of rustications tends to deemphasize any variations.
2. The viewing distance. From a greater distance, different textures will provide different tonal values. Determining the normal viewing distance in the final use will impact which textures and sizes of aggregates should be used.
3. The orientation of the building's wall elevation. The siting determines the amount and the direction of light on the surface and how the panel will weather.
4. Aggregate particle shape and surface characteristics. Both the shape and surface characteristics determine how the surface will weather and reflect light (see Reference 2.).

There are three key levels of exposure that are used in creating a finished appearance:

1. Light exposure involves removing only the surface skin of cement and sand. This sufficiently exposes the tips of the closest coarse aggregate.
2. Medium exposure requires further removal of cement and sand to cause the coarse aggregates to appear approximately equal in area to the matrix.
3. Deep exposure requires cement and sand to be removed from the surface so the coarse aggregates become the major surface feature (see Reference 3.).

FINISHES



The single concrete mix shown here has three different finishes. From left to right, they are acid etch, sandblast, and retarded. This multiple-finish technique offers an economical, yet effective, way to heighten aesthetic interest.

A wide range of surface finishes are available, achieved through a variety of processes. Before a specific finish is specified, sample panels should be created to ensure the finish achieves the desired aesthetic and functional goals.

Samples may be provided by competing producers initially in small, 12-in. squares. The selected producer should then provide three 4 ft² or 5 ft² samples to determine color range. The range of acceptable variations in color, texture, and uniformity should be determined when these mockup units are approved. Full-scale mockups should be specified by the architect to arrive at a final approval of the desired design (see Reference 4).



388 Market Street building in San Francisco, Calif., is clad with 1 1/4 in. (3 cm) granite anchored to precast concrete. Architect: Skidmore, Owings & Merrill; Photo: Skidmore, Owings & Merrill San Francisco.

The most common types of finishes available include:

- **Smooth as-cast finishes** show the natural look of the concrete without trying to simulate any other building product. Fine surface details and sharp arrises can be achieved. When a high level of color uniformity is required, this finish is strongly discouraged (see Reference 5).
- **Exposed-aggregate finishes**, via chemical retarders or water washing, are achieved with a non-abrasive process that effectively brings out the full color, texture, and beauty of the coarse aggregate. The aggregate is not damaged or changed by this exposure method (see Reference 6).
- **Formliners** provide an almost unlimited variety of patterns, shapes, and surface textures. The concrete is cast against liners made of a range of materials, including wood, steel, plaster, elastomeric, plastic, or foam plastic (see Reference 7).
- **Sand or abrasive blasting** provides all three degrees of exposure noted above. This process is suitable for exposure of either large or small aggregates. Uniformity is directly proportional to the depth of material removal (see Reference 8).



Examples of light, medium, and heavy sandblast textures.

- **Acid etching** dissolves the surface cement paste to reveal the sand, with only a small percentage of coarse aggregate being visible. It is most commonly used for light or light-to-medium exposure (see Reference 9).



Examples of light, medium, and heavy acid-washed textures.

- **Tooling, usually called bushhammering**, mechanically spalls or chips the concrete surface using any of a number of hand or power tools, producing an abraded aggregate texture. Each tool produces a distinctive surface effect and a unique shade of concrete color (see Reference 10).
- **Hammered-rib or fractured-fin designs** are created by casting ribs onto the surface of the panels and then using a hammer or bushhammer tool to randomly break the ribs and expose the aggregate. The effect is a bold, deeply textured surface (see Reference 11).

- **Sand embedment** creates a bold and massive appearance for the panel, using 1- to 8-in.-diameter stones or flagstones. The stones typically are placed in a sand bed at the bottom of the mold, and finishing reveals the stone face, resulting in the appearance of a mortar joint (see Reference 12).
- **Honing or polished finishes** are achieved by grinding the surface to produce smooth, exposed-aggregate appearances. Polished, exposed-aggregate concrete finishes compare favorably with polished natural stone façades, such as granite (see Reference 13).
- **Painting or staining** is used purely for decorative purposes, due to the high-strength, durable nature of precast concrete panels. There is a vast difference in paint types, brands, prices, and performance, and knowledge of composition and performance standards is necessary to obtain a satisfactory result. In some cases, the precast concrete surface can be so smooth that it makes adhesion difficult to obtain, so a decision on painting should be made prior to casting if possible (see Reference 14).



Panels on the Shriners Hospital for Crippled Children, Sacramento, Calif., are 6 in. thick and have a horizontal band of 1 1/4 in. granite attached with one anchor per 2 ft². Architects: Odell Associates; and Associate Architect: HDR.

Multiple mixtures and textures in the same unit provide design flexibility. Color and texture variations can be obtained by manipulating aggregates and matrix colors, size of aggregates, formliners, finishing processes, and depth of exposure. A rustication feature needs to be detailed to separate the different colors and/or finishes.

Combinations of various finishes on the same unit depend on the shape of the unit. Some finishes, such as acid etching, can't be easily applied to only one portion of a unit. The combination of a polished or honed surface and acid etching provides a surface that exposes a very high percentage of aggregate (see Reference 15).

FACING PRODUCTS AND ARCHITECTURAL TRIM UNITS

Clay product-faced precast concrete panels combine the pleasing visual appearance of traditional masonry products with the strength, versatility, and economy of precast concrete. Clay products that can be cast integrally with precast concrete panels include brick, ceramic tile, and terra cotta. The clay product can cover the entire exposed-panel surface or only a portion, serving as an accent band or contrasting section. Marble, glass, and ceramic mosaics can also be cast integrally (which is preferred) or applied to the hardened concrete (see Reference 16).

The combination of precast concrete and clay products has several advantages over site-laid-up masonry. By using precast concrete panelized construction, the need for on-site scaffolding and significant on-site labor is eliminated, which can be a significant cost savings over masonry construction.



Arizona red sandstone, 1 1/4 in. to 1 3/4 in. thick, was anchored to 4-in.-thick concrete panels for the Sacramento Municipal Utility District's Customer Service Center, Sacramento, Calif.; Architect: Williams + Paddon Architects & Planners/Inc.

Structural design, fabrication, handling, and erection aspects of clay product-faced precast concrete units are addressed similarly to those for other precast concrete wall panels except that special consideration must be given to the dimensional layout of the clay product and its embedment in the concrete. The physical properties of the clay products must be compatible with the properties of the concrete backup. The most significant property is the coefficient of thermal expansion, which causes volume change. It is best to select material with similar coefficients of expansion along with tight dimensional tolerances.

Reinforcement of the precast concrete backup should follow recommendations for precast concrete wall panels relative to design, cover, and placement. Uniform and even coursing without cutting any units vertically or horizontally except as necessary for running bond allow for economical production. To achieve this thin brick conforming to the PCI standard for embedded brick should be specified (see Reference 17).

Natural stone has been widely used in building construction due to its strength, durability, aesthetic effect, availability, and inherent low-maintenance costs. Stone veneers for precast concrete facings are usually thinner than those used for conventionally set stone, with the maximum size generally determined by the stone strength.

When purchasing stone, a qualified individual should be appointed to be responsible for coordination, which includes delivery and scheduling responsibility and ensuring color uniformity (see Reference 18).

Architectural trim units (cast stone) are manufactured to simulate natural cut stone. They are used in masonry work mostly as ornamentation and architectural trim for stone bands, sills, lintels, copings, balustrades, and door and window trimming. They replace natural cut stone or terracotta in these applications (see Reference 19).



One-in.-thick brick cladding on 5-in.-thick concrete panels was used on the first three floors of the Sacramento County System and Data Processing Building in Sacramento, Calif. Terracotta medallions were placed on spandrels and column covers. Architect: HDR Architecture Inc. formerly Ehrlich-Rominger; Photos: HDR Architecture Inc.

MATCHING PRECAST WITH CAST-IN-PLACE CONCRETE



Architectural precast panels for the new wing of the Joslyn Art Museum, Omaha, Neb., are clad in Georgia marble to match the original stone building constructed in 1931. Labor and material cost were reduced using this system compared to traditional stone cladding systems. Architect: Henningson, Durham & Richardson Inc.

Precast concrete panels are often used in conjunction with architectural cast-in-place concrete. Matching these finishes to create a monolithic look must be planned before construction starts to allow adjustment of mix design, placement technique, methods of consolidation, and finishing procedures. Samples and full-scale mockups should be prepared for both the precast and cast-in-place panels, and differences should be resolved prior to finalizing either finish.

When both products will be used in the same plane, the cast-in-place tolerances must be strictly enforced. Differences in curing methods between the two techniques, even with identical mixes, may cause color variation in the finish, particularly if the precast concrete uses accelerated, high-temperature curing. Different weathering patterns may result in dissimilar appearances due to different concrete densities (see Reference 20).

INTERIOR FINISHES



Architectural precast concrete panels both inside and out bring drama and quality to the recent 3 million-ft² expansion of McCormick Place in Chicago, Ill. Photo: Brian Gassel/TVS&Assoc.

The interior side of architectural precast concrete panels can also be given an aesthetic finish, eliminating the need to provide an additional finished wall, saving materials, time, and cost. Exposed interior surfaces should have finishes that are realistic in terms of exposure, production techniques, configuration of the precast concrete units, and quality requirements.

A variety of finishes for the back of a precast concrete panel can be provided. They include screed, light broom, float, trowel, stippled, or waterwashed or retarded exposed-aggregate finishes or sandblast finish. If the finish is to be painted, a stippled concrete finish normally will be the most economical. A trowelled finish is the most common interior finish, but it frequently darkens the surface in uneven patterns.

The treatment of joints and connections with regard to interior-finish requirements should be considered if panels are to remain exposed. Load-supporting connections at the top and bottom of the panel should be hidden above the ceiling panels and below the floor level, respectively. If they are exposed, they should be recessed (see Reference 21).

ACCEPTABILITY OF APPEARANCE

Contract documents should spell out who the accepting authority for the panel color, finish, and texture will be. This is typically the owner, architect, general contractor, or site inspector. One person must have final authority on all issues of appearance. Determining acceptable uniformity of color, finish, and texture is by visual examination, and is generally a matter of subjective, individual judgment and interpretation. The acceptable variations should be determined at the time the visual mockups or initial production units are approved. Suitable criteria for acceptability require that the finished concrete face surface should have no readily visible imperfections other than minimal color and texture variations from the approved samples or evidence of repairs when viewed in good, typical daylight illumination with the unaided, naked eye at a 20 ft or greater viewing distance.



Built in 1906, the architectural landmark 88 Kearney St. in San Francisco had its terra cotta removed and reassembled on precast panels for an all-new structure of taller height. Architect: Skidmore, Owings & Merrill; Photo: Skidmore, Owings & Merrill.

Appearance of the surface should not be evaluated when light is illuminating the surface from an extreme angle, as this tends to accentuate minor surface irregularities due to shadowing.

Building façades may be oriented such that sunlight just grazes the surface at a particular time of day. This causes otherwise imperceptible ripples, projections, and misalignments on the surface to cast long shadows and be grossly exaggerated in appearance. The shadows may last briefly. The actual time at which they appear varies with the season for a particular wall. Precast concrete, like any building surface, is subject to manufacturing and alignment tolerance so that the effect cannot be avoided.

Units should be assessed for appearance during dry weather. In climates with intermittent dry and wet conditions, drying-out periods may produce temporary mottled appearances.

Minor surface abnormalities and blemishes will occur on occasion, and precasters can adequately repair minor problems quickly. There are key finish defects and/or problems that are considered unacceptable in the fabrication of high-quality, PCI-certified architectural precast concrete (see Reference 22). These should be addressed as soon as they appear to ensure that the condition that caused the defects is corrected early in the production sequence. The unacceptable conditions for architectural concrete are:

- Ragged or irregular edges.
- Excessive air voids (“bug holes” or “blow holes”) in the exposed surface.
- Adjacent flat and return surfaces with noticeable differences in texture and/or color from the approved samples or mockups.
- Casting and/or aggregate segregation lines evident from different concrete placement lifts and consolidation.
- Visible form joints or irregular surfaces of or larger than those acceptable in the approved samples or mockups.
- Rust stains on exposed surfaces.
- Excessive variation of texture and/or color from the approved samples, within the unit, or compared with adjacent units.
- Blocking stains or acid stains evident on panel surface.
- Areas of backup concrete bleeding through the face concrete.
- Foreign material embedded in the face.
- Repairs visible at 20 ft or greater viewing distance.



The flagship retail store for Tommy Hilfiger used 180 GFRC panels and decorative architectural details to create a striking façade on the corner of Santa Monica Boulevard and Rodeo Drive in Beverly Hills, Calif. Architect: Allan Greenberg, Architect Washington, D.C. Photo: Derek Rath.

- Reinforcement shadow lines.
- Visible cracks at a 20 ft or greater viewing distance.

Precast concrete generally undergoes far less cracking than cast-in-place concrete. This resistance results in part from the high compressive and tensile strength of the precast concrete. A certain amount of cracking may occur without having any detrimental effect on the structural capacity of the member, and it is impractical to impose specifications that prohibit cracking. Cracks can be unsightly and create potential locations for concrete deterioration, so any cracking should be avoided and those cracks that do appear should be inspected to determine acceptability. Cracks may be repaired and effectively sealed by pressure-injecting a low-viscosity epoxy.

The best methods to minimize cracks are to provide proper reinforcement locations, prestressing when appropriate, and proper handling. Whether cracks are acceptable will depend on an evaluation of the cause of the cracking and the service condition requirements, structural significance, and aesthetics.

Erected panels not complying with the contract documents may require additional work. Trial repairs should be applied to the project mockup or small sample panels and allowed to cure, followed by a normal drying period. Acceptability criteria for repairs should be agreed on at an early stage of the project. A certain amount of repair is to be expected as a routine procedure. Repair and patching of precast concrete is an art that requires expert craftsmanship and careful selection and mixing of materials (see Reference 23).

Repairs should be done only when conditions exist that ensure the repaired area will conform to the balance of the work's appearance, structural adequacy, and durability. Slight initial color variations can be expected between the repaired area and the original surface due to the different age and curing conditions of the repair. Time will tend to blend the repair into the rest of the component to make it less noticeable.

GLASS FIBER–REINFORCED CONCRETE (GFRC)

Glass fiber–reinforced concrete, commonly known as GFRC, is a composite concrete product fabricated by many precast concrete manufacturers. It consists of a portland-cement-based composite that is reinforced with an absolute, minimum of 4% by weight of alkali-resistant glass fibers to total mix, which are randomly dispersed through the material. The fibers serve as reinforcement to enhance the concrete's flexural, tensile, and impact strength.

The manufacture of GFRC products requires a greater degree of craftsmanship than other precast concrete products. Many combinations of shapes, sizes, colors, and textures are possible with this product. Typically, the fibers in a GFRC component make up at least 4% by weight of the total mix, with a minimum design thickness of 1/2 in. for the piece. The alkali-resistant glass fibers are specially designed for use in these components, and no others should be used (see Reference 24).



GFRC with horizontal striations relate the Pleasanton Corporate Campus buildings to the hills, creating the texture and shadow pattern HOK/SF Inc. Architects were looking for. Photo: HOK/SF Inc.



Recalling Art Deco architecture, the Esquire Plaza office tower and mixed-use building in Sacramento, Calif., takes its design cue from the two existing theater façades incorporated in the building. Precast concrete panels on the lower levels and GFRP on the upper portion made the highly articulated façade possible at an affordable cost. Architect: HOK/SF; Photo: Ed Asmus Photography.



Located in downtown Chicago, Ill., the new residence hall for the School of the Art Institute is clad in GFRP panels, which emulate the look of the Windy City's historic buildings finished in terra cotta. The dormitory is composed of two connected buildings and a rear link. Architect: Booth Hansen Associates Inc., Chicago; Photo: ©Brian Fritz Photography.

GFRP is manufactured by hand-spraying a cement/sand slurry and glass fibers into molds of the desired shape and size. GFRP also can create highly detailed, ornamental pieces. Panels can be produced with or without a face mix of conventional concrete with decorative 1/4 in. maximum size aggregates. With a face mix, GFRP cladding panels, when given an architectural finish, are indistinguishable in exterior appearance from conventional concrete panels.

The variety of sculptural shapes made possible through the GFRP manufacturing process enables a wide range of creative architectural designs. The designer can choose from deep reveals to complex rectilinear and curvilinear shapes such as short radius curves, wide sweeping arcs, or 90-degree angles. The degree of such complex shaping has minimal effect on the cost of the panel due to GFRP's inherent design flexibility.

The low weight of GFRP panels decreases superimposed loads on the building's structural framing and foundation, providing potential savings in multistory construction and in areas with poor supporting soil. Its light weight also makes it ideal for use on low-rise frame buildings where heavier cladding systems would increase the size of framing members required.

Unless the panels have a functionally strengthening shape, GFRP properties dictate the use of stiffeners on panels of any appreciable size.

Stiffeners may be prefabricated, plant-attached steel studs or structural tubes, or integral ribs formed on the back of the panel by over-spraying hidden rib formers, such as expanded polystyrene strips or adding an upstanding single skin rib on the back of the panel. Either method stiffens the panel and provides a means for connection to the supporting structure. The steel panel frame is usually the more economical and preferred method for stiffening.

It is important when evaluating costs to realize that GFRP panels provide more than an exterior finish. The steel stud frame provides a surface for applying the interior finish, such as drywall, as well as the window frame. It also provides a cavity for installation of insulation, plus electrical, mechanical, and telephone conduits. This decreases the floor space needed for these items and eliminates trade overlap problems.

Panel design usually prevents stud or tube spacing from being coordinated with interior drywall modules. Therefore, it is recommended that if the studs are to receive interior drywall or similar treatment, drywall be mounted on shimmed, transverse furring channels rather than directly to the studs.

Windows should be attached directly to the head and sill tracks of the panel frame (or to a separate framing system) with only sealant contact to the GFRP.

Clay products, such as veneer-thickness brick, facing tile, and architectural terra-cotta, are not recommended due to volume change considerations. For more about this topic, see Reference 25.

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Integration & Coordination with Other Building Systems

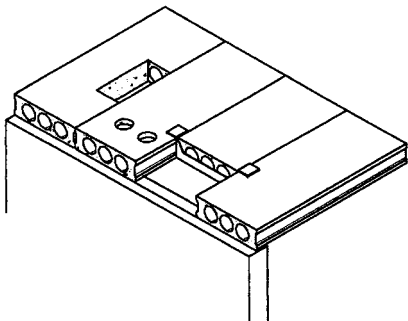
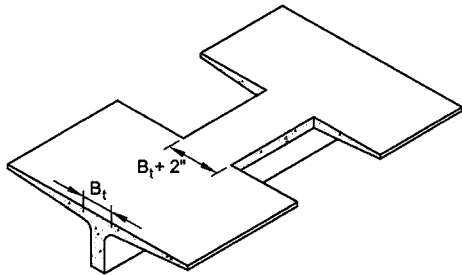
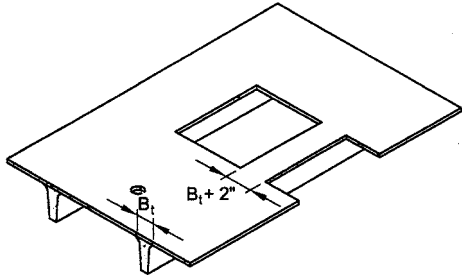
Precast concrete is used in a wide range of building types, and its integration with mechanical, plumbing, lighting, and other systems can be achieved easily if designers understand the specifics of each project and precast concrete's requirements. Because of increased environmental demands, the proportion of costs related to mechanical and electrical installations in the overall budget has increased substantially in recent years. Working closely with the precaster to satisfy all of the service requirements will ensure an economical solution that produces cost-efficient, functional, and aesthetically pleasing results.

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MECHANICAL

Spaces within stemmed precast concrete members, or the voids in hollow-core slabs, can be used for distribution ducts for heating, air-conditioning, and exhaust systems. In stemmed members, three sides of the duct are provided by the bottom of the flange and the sides of the stems. The bottom of the duct is completed by attaching a metal panel to the tee stems.



Large openings in floors and roofs are made during the manufacture of the units; small openings are field drilled. Some common types are shown here.

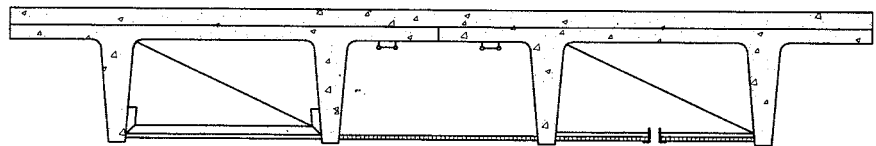
The ducts can be connected in several ways, including powder-activated fasteners, cast-in inserts, or reglets. Field-installed devices generally offer the best economy and ensure placement in the exact location required. Inserts should be cast-in only when they can be located during the design stage of the job, well in advance of casting the precast members.

If high-velocity air movement is desired, the enclosed space becomes a long plenum chamber with uniform pressure throughout its length. Diffusers are installed in the ceiling to distribute the air. Branches can consist of standard ducts installed along the column lines. Branch ducts of moderate size can also be accommodated by providing block-outs in the stems of tees or beams. These blockouts should be repeated in size and location to handle all conditions demanded by mechanical, electrical, or plumbing runs to remain economical, even if this results in some openings being slightly larger than required.

When ceilings are required, proper selection of precast concrete components can result in shallow ceiling spaces to accommodate required ducts, piping, and lighting fixtures.

Prestressed concrete box girders can serve a triple function as air conditioning distribution ducts, conduit for utility lines, and structural supporting members for the roof-deck units. Conditioned air can be distributed within the void area of the girders and then introduced into the building work areas through holes cast into the sides and bottom of the box girders. The system is balanced by plugging selected holes.

Vertical supply and return-air trunks can be carried in the exterior walls, with only small ducts needed to branch out into the ceiling space. In some cases, the exterior wall cavities are replaced with three- or four-sided precast concrete boxes stacked to provide vertical runs for the mechanical and electrical systems. These stacked boxes also can be used as columns or lateral-bracing elements (see Reference 1).



Metal panels attached at the bottoms of the stems create ducts, and diffuser panels provide a flush ceiling.



The three parking structures for the Shops at Willow Bend Mall in Plano, Tex., provide a light, bright interior. JPRA Architects Inc., Farmington Hills, Mich. Photo: J. Bendist Photographic/Dallas.

ELECTRICAL SYSTEMS

For many applications, designers can take advantage of prestressed concrete's reflective qualities and appearance by leaving the columns, beams, and ceiling structure exposed. The lighting system should parallel the stems of tee members to achieve uniform lighting free from distracting shadows.

A high level of illumination can be achieved at a minimum cost by using a reflective paint and proper spacing for high-output fluorescent lamps, which should be installed in a continuous strip. In special areas, lighting troffers can be enclosed with diffuser panels fastened to the bottom of the tee stems, providing a flush ceiling. By using reflective paints, the precast concrete lighting channels can be made as efficient as conventional fluorescent fixtures (see Reference 2).

The increasing use of networks for office machines, computers, and telephones and the continual adaptation of office space to new functions and staff needs have made adequate and flexible systems more critical in buildings to ensure this equipment can be handled efficiently. Since a cast-in-place topping is often placed on prestressed floor members, conduit runs and floor outlets can be easily buried within this topping. Burying conduits in toppings of parking structures, however, is not recommended because of the possibility for conduit corrosion.

Most systems can be included easily in a 2- to 4-in.-thick topping. When the system is placed in a structural-composite slab, the effect of ducts and conduits must be carefully examined and their locations coordinated with the placement of reinforcing steel. Voids in hollow-core slabs also can be used as electrical raceways. Spaces requiring large quantities of flexible wiring systems are typically addressed by specifying raised-access flooring.

Because of the high load-carrying capability of prestressed concrete members, high-voltage substations, with heavy transformers, can be located near the areas of consumption with little or no additional expense. For extra safety, distribution feeds can be run within the channels created by stemmed members. Such measures also aid the structure's economy by reducing the overall story height and minimizing maintenance expenses (see Reference 3).

BUILDING PENETRATIONS

Architectural precast concrete wall panels can be adapted to combine with preassembled window or door units. Door or window frames, properly braced to prevent bowing during concrete placement, can be cast into the panels, after which the glazing or doors can be installed, prior to or after delivery to the jobsite. If the glazing or doors are properly protected, they can also be cast into the panel at the plant.

Repetition of the design produces the most economy in a precast concrete panel, so windows and doors should be located in identical places for all panels whenever possible. However, virtually any design and window or door placement or combination of these units can be accommodated with precast concrete panels (see Reference 4).

Penetrations into precast concrete components are the most significant because they will allow energy transference that will reduce efficiency of HVAC equipment. A thorough analysis of air leakage is complex and involves parameters such as wall construction, building height, and orientation. An air barrier can stop outside air from entering the structure through the walls, windows, or roof, and it can prevent inside air from exfiltrating through the building envelope and any penetrations.

An air-barrier system must be virtually air-impermeable. Materials such as polyethylene, gypsum board, precast concrete panels, metal sheeting, or glass qualify as low air-permeable materials when joints are properly sealed. Materials that do not qualify include concrete block, acoustic insulation, open-cell polystyrene insulation, and fiberboard.

One relatively new approach to sealing joints involves using an interior foam backer rod and sealant along with a thermal-fusible membrane seal around the panel, which covers the gap between the structure and the panel. In the case of construction assemblies that do not lend themselves to sealing interior surfaces, the use of a separate vapor retarder must be considered (see Reference 5).

Fittings installed in outer walls, such as electrical boxes, should be completely sealed against moisture and air passage. They should be installed on the warm side of unbroken vapor retarders or air barriers that are completely sealed.



*Velocity Multifamily Residential Condominiums,
Hoboken, N.J.; Architect: Equus Design Group;
Photos: Oldcastle Precast Building Systems.*



VAPOR BARRIERS

Water-vapor diffusion occurs when water-vapor molecules diffuse through solid interior materials at a rate dependent on the permeability of the materials, the vapor pressure, and the temperature differentials. Generally, the cooler the outside temperature is, the greater the pressure is for the water vapor in the warm interior air to reach the cooler, drier, outside air.

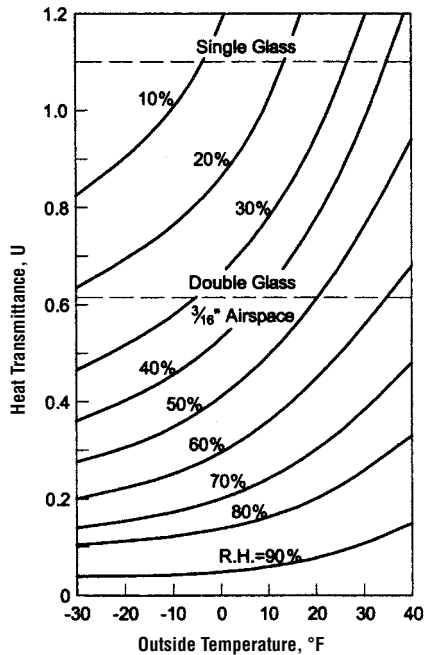
Concrete in general provides a relatively good vapor retarder, provided it remains crack free. Permeance is a function of the ratio of the concrete's water and cementitious materials. A low ratio, such as those used in most precast concrete members, results in concrete with low permeance. Where climatic conditions require insulation, a vapor retarder is generally necessary to prevent condensation. A closed-cell insulation will serve as its own vapor retarder.

The function of a vapor retarder made of low-permeability material is to stop (actually, to retard) the passage of moisture as it diffuses through the assembly of wall materials. In temperate climates, vapor retarders should be applied on or near the warm side (inner surface) of assemblies. Vapor retarders can be structural or take the form of thin sheets or coatings. They can be positioned part way into the insulation, but they should be placed no farther inside than the point at which the dew-point temperature is reached to avoid condensation.

In climates with high humidities and high temperatures, especially where air-conditioning is virtually continuous, the ingress of moisture may be minimized by a vapor-retarder system in the building envelope near the outer surface. For air-conditioned buildings in hot and humid climates without extended cold periods, it may be more economical to use only adequate air-infiltration retarding systems rather than vapor retarders, since the interior temperature is rarely below the outside dew point.

High thermal-conductance paths reaching inward from or near the colder surfaces may cause condensation within the construction. High conductance paths may occur at junctions of floors and walls, walls and ceilings, and walls and roofs. They may also occur around wall or roof openings, at perimeters of slabs on the ground, and at connections.

When a material such as plaster or gypsum board has a permeance that is too high for the intended use, one or two coats of paint frequently will suffice to lower the permeance to an acceptable level, or a vapor barrier can be used directly behind such products. Polyethylene sheet, aluminum foil, and roofing materials are common applications. Proprietary vapor barriers, usually combinations of foil and polyethylene or asphalt, are typically used in freezer and cold-storage construction (see Reference 6).



Relative humidity at which visible condensation occurs on inside surface. Inside temperature, 70 °F.

MODULAR UNITS

Precast concrete provides an ideal material with which to create entire structures, particularly housing units, that require identical spaces that can be completed quickly. These designs work well because so many of the mechanical systems and other services can be installed in the units prior to delivery to the site, requiring only a final hookup after the unit is erected in its final location. This approach limits the amount of on-site labor that is required, saving time and adding safety. School classrooms, housing units, and prison cells all benefit from this type of fast, replicated unit and the advance installation of plumbing, electrical, mechanical, and even finishing systems.

For housing or school applications, electrical conduit and boxes can be cast into the precast wall panels, which requires coordination with the electrical contractor. The metal or plastic conduit is usually pre-bent to the desired shape and delivered to the casting bed already connected to the electrical boxes. Telephone and communication accessories have also been cast-in using the same procedure.

Plumbing units are often connected and assembled prior to delivery for kitchen or bathroom modules. To eliminate a double floor, the module can be plant-built on the structural member or the walls of the unit can be designed for all fixtures to be wall-hung. Some core modules also feature HVAC components, which are packaged in one unit. These modules can be accommodated in prestressed structural systems by placing them directly on the prestressed members with shimming and grouting (see Reference 7).

Prisons maximize the use of these modules by creating multiple-cell units. They generally consist of cell walls, chase walls, and a floor and/or ceiling. All components of each cell are installed at the plant. These components include windows, beds, mirrors, desks, air vents, light fixtures, sinks, water closets, and associated chase plumbing and wiring. Erection at the site is rapidly completed and field work is greatly reduced. The result is a safe, functional, and economical prison facility in the shortest construction time (see Reference 8).

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Photos: Tindall Corporation/Correctional Division.

Team Responsibilities

Design and construction of a high-quality structure is a complex process requiring teamwork among all of the professionals involved. The project's success relies on defining the scope of work and the responsibilities of the involved parties by means of contract documents. To that end, the scope of the precast concrete work and the responsibilities of each party should be established early in the project's development to maintain the schedule.

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One of the basic principles of the construction industry is that responsibility and authority must go hand in hand. Another principle is that every party should be responsible for its own work. These principles are sometimes violated in practice, leading to adversarial situations that can damage a project's success.

The complexity of structures today makes it essential to have design input from subcontractors, whether the project will follow a conventional design-bid build, design-build, or alternative construction formats. This input can take three forms:

- Value-engineering proposals
- Response to performance requirements
- Suggestions for design alternatives

Gaining the precaster's aid and insight during the conceptual stage can ensure that the design provides the most cost-efficient, aesthetically pleasing, and functional plan possible. The precast concrete manufacturer can consider many aspects, including transportation and erection, that may otherwise be overlooked and become costly after the fact (see Reference 1).

(For more on the benefits provided by early input by the precaster, see Chapter 1D, "Construction Issues.")

THE DESIGN PROCESS

The design considerations for the precast concrete components of a project consist of three stages:

- 1. Conceptual design.** The general ideas of what the owner wants to accomplish in function, image, budget, and other factors can be discussed with the precaster. This will often aid the project's completion even if the original intent was not to use precast concrete, especially if stone or masonry was desired.
- 2. Preliminary design.** This planning stage gains from precaster input on the general layout, overall dimensions, typical details, and other specifics. This input can be relatively simple, such as with the layout of a hollow-core flooring plan, or complex if the design will feature a total-precast concrete structural system and intricate finishes on architectural precast concrete components.
- 3. Final design.** The specific details of the components, such as strand patterns, connections, embedded items, and other elements, are decided at this point, and shop drawings are produced.

Because of the range of input that can be provided at each stage, the precaster typically participates in the design process with the project-management team, especially to provide input on costing. The capacity to participate varies with each precaster and with each job.

In general, the precaster can provide the following information:

- Design properties unique to his or her product, such as section properties, normal concrete strengths, and strand patterns (if needed by the structural engineer).
- Detailed specifications for the manufacture of the components using proprietary equipment.
- The detailed design of the specific components as agreed in the preliminary design phase.
- Detailed layout drawings locating each component type in the structure.
- Support and joint details.
- Product drawings showing details, including dimensions and the location of lifting and connection hardware.
- The erection procedure.

In some cases with fast-track projects, some precast concrete components go to the shop-drawing stage before the final specifics of the design are completed. Because precast concrete components combine customization with a highly controlled manufacturing process, fabrication in some cases can go forward on this accelerated basis to meet a tight deadline that cannot wait for all of the contract drawings to be completed first. This ability can keep a project on schedule when the use of other materials would not have been able to improve the timeframe (see Reference 2).

RESPONSIBILITIES OF THE ARCHITECT

The architect has responsibility and authority for all aspects of the precast concrete design. This generally requires that a registered professional engineer or architect accepts responsibility as the engineer of record for ensuring that these requirements are met. The engineer of record seals the contract documents, which constitute the structural design. They are customarily submitted to regulatory authorities for a building permit.

The engineer of record will also approve shop drawings and may have other ongoing responsibilities during construction.

The architect may specify in the contract documents that design services for portions of the work are to be provided by the precaster and must be performed by a licensed engineer employed or hired by the precaster. The division of responsibility between the engineer of record and the precaster's structural specialty engineer must be worked out in advance.

The contract and the design documents should state clearly the scope of both the precast concrete design and review responsibilities, as well as the responsibilities of others providing design services.

The contract drawings prepared by the architect should provide the overall geometry of the structure, member, or panel sizes (including permissible alternative sizes) and typical connection locations and concepts. This detail allows everyone to estimate based on the same information. These drawings and the specifications become a part of the contract documents used by contractors to construct the structure (see Reference 3).

The contract documents provided by the architect should include:

- **Reveals or design articulation**, letting the precaster determine panel sizes suitable to their handling and erection capabilities.
- **General performance criteria**, including concrete strength requirements for loading, deflection requirements, temperature considerations, and any tolerance or clearance requirements for proper interfacing with other parts of the structure.
- **The order of priority** in which the project contract, specifications, or drawings prevail in the event of conflict.
- **All aesthetic, functional, and structural requirements** that impact the precast concrete fabrication.

To delineate responsibility for all interfaces of precast concrete components with other materials, the architect also should define:

- **Precast concrete components** to be designed by the precaster, stating who takes responsibility for conditions at interfaces with other parts of the structure.
- **Details or concepts of supports, connections, and clearances** that are part of the structure designed by the architect and that will interface with the precast concrete components.
- **Permissible load transfer points** with generic connection types indicated so the precaster does not make assumptions during bidding.

The architect and engineer of record should review submitted designs, calculations, and shop drawings to ensure they conform to design criteria, loading requirements, and design concepts as specified in the contract documents. This review does not relieve the precaster and the precast concrete engineer of their design responsibilities (see Reference 4).

The format and extent of information supplied by the architect will impact the precaster's responsibility. The accompanying chart indicates three ways in which contract information can be supplied by the architect and the activities for which the precaster is thereby responsible.

DESIGN RESPONSIBILITIES

Contract Information Supplied by Design Team	Responsibility of the Precaster
OPTION I	
<p>Provide complete drawings and specifications detailing all aesthetic, functional, and structural requirements including design criteria, plus dimensions.</p>	<p>The precaster should make shop drawings (erection and production drawings), as required, with details as shown by the designer. Modifications may be suggested that, in precaster's estimation, would improve the economics, structural soundness, or performance of the precast concrete installation. The precaster should obtain specific approval for such modifications. Full responsibility for the precast concrete design, including such modifications, remains with the designer. Alternative proposals from a precaster should match the required quality and remain within the parameters established for the project. It is particularly advisable to give favorable consideration to such proposals if the modifications are suggested so as to conform to the precaster's normal and proven procedures.</p>
OPTION II	
<p>Detail all aesthetic and functional requirements but specify only the required structural performance of the precast concrete units. Specified performance should include all limiting combinations of loads together with their points of application. This information should be supplied in such a way that all details of the unit can be designed without reference to the behavior of other parts of the structure. The division of responsibility for the design should be clearly stated in the contract documents.</p>	<p>The precaster has two alternatives:</p> <ul style="list-style-type: none"> (a) Submit erection and shape drawings with all necessary details and design information for the approval and ultimate responsibility of the designer. (b) Submit erection and shape drawings and design information for approval and assume responsibility for the structural design; that is, the individual units, but not their effect on the building. Precasters accepting this practice may either stamp (seal) drawings themselves or commission engineering firms to perform the design and stamp the drawings. <p>The choice between the alternatives (a) and (b) should be decided between the designer and the precaster prior to bidding with either approach clearly stated in the specifications for proper allocation of design responsibility.</p> <p>Experience has shown that divided design responsibility can create contractual problems. It is essential that the allocation of design responsibility is understood and clearly expressed in the contract documents.</p>
OPTION III	
<p>Cover general aesthetic and performance requirements only and provide sufficient detail to define the scope of the precast concrete work.</p>	<p>The precaster should participate in the preliminary design stage and the development of the final details and specifications for the precast concrete units and should work with the design team to provide an efficient design. The precaster provides the engineering design of the precast concrete units and their connections to the structure and should work with the design team to coordinate the interfacing work. The precaster should submit shop design information for approval and drawings at various stages of completion for coordination with other work.</p>

Source: Table 4.1.1: Design Responsibilities; Chapter 4, Section 4.1.2, "Responsibilities of the Architect," PCI MNL-122-07: Architectural Precast Concrete, Third Edition.

KEY ARCHITECTURAL DESIGN ISSUES

The architect should make sure that the contract documents address the issues that affect a precaster's bid. The drawings should provide a clear interpretation of the configurations and dimensions of individual units and their relationship to the structure and to other materials. Contract documents that lack detail may extend shop-drawing time and could lead to confusion over the scope of work and impact schedule.

The contract documents should supply the following data:

- Elevations, sections, and dimensions necessary to define the sizes and shapes (profiles) of each type of precast concrete component.
- Locations of joints real (functional) and false (aesthetic).
- Required materials, color, and finish treatment for all surfaces with a clear indication of which surfaces are to be exposed to view when in place.
- Corner details.
- Details for jointing and interfacing with other materials (coordinated with the general contractor) including windows, roofing, and other wall systems.
- Openings for services and equipment with their approximate size and location.
- Details for special or unusual conditions, including fire-endurance requirements.
- Governing building codes, design loads, and deflection limitations.
- Specified dimensional tolerances for the precast concrete and the supporting structure, location tolerances for the contractor's hardware, clearance requirements and erection tolerances for the precast concrete.
- Support locations for gravity and lateral loads.
- Building location and site access.
- Delineation of any unusual erection sequence requirements.



Logan International Airport Central Parking Garage Expansion, Boston; Architect; TAMS/Fennick/McCredie Architecture Ltd.; Photo: Blakeslee Prestress Inc. (top right), ©PhotoDisc (bottom right).

The precaster will use this information from the contract drawings and documents to generate shop (erection) drawings and design calculations. The shop drawings should detail elevations showing panel sizes, surface features and panel relationships. Detail sheets should show panel cross-sections, special edge conditions and feature details, and they should specify connections showing mechanisms and locations of load transfers to the supporting structure.

Greater economy and flexibility will be achieved by allowing the precaster to suggest configurations and select which joints are false and which are real in the panelization. The architect should then review all shop drawings to ensure they conform to the contract documents.

Small mockups are encouraged, as they help verify the appearance of the completed façade and help clarify actual field-construction techniques and material interface issues. When the units have returns, the same size return should appear in the mockup panels. It is the architect's responsibility to determine the standards of acceptability for surface finish, color range, and remedial procedures for defects and damage.

After the project is erected and detailed, the architect should immediately prepare a punch list setting forth, in accurate detail, any items that are not in accordance with the contract documents so the proper corrective action can be taken. All repairs should conform to the architect's requirements for matching the original finish and should be structurally sound.

When advised by the precaster that the listed items have been completed, the general contractor, construction manager, architect, and engineer should check the corrections as needed. After the precast concrete components have been accepted, subsequent responsibility and liability for their condition rests with the general contractor (GC)/construction manager (CM). (For more on these responsibilities, see Reference 5.)

THE BID PROCESS

When selection of the precaster cannot be negotiated or controlled by the owner or architect but is governed by an open-bid situation, these steps should be followed:

- 1. Verification of architects concepts and systems.** A review of the proposed precast concrete assumptions during the early design development stage of the architectural contract documents should be arranged with at least one local precaster. Items to be reviewed include:
 - Panelization, form families, piece sizes, weights, and reveals.
 - Potential shipping and erection issues.
 - Architectural concepts for structural supports or connections for the precast concrete so that the architect can communicate to the engineer of record about any support requirements.

- Desired aesthetic issues relative to mixture(s) and finish(es) and the sample process.
- The architect's intent for any interfaces with adjacent systems, such as windows, roofing, or building entrances.
- Mockups or other special testing requirements.

2. The prebid conference. A meeting with all precasters planning to bid on the project should be held at least three weeks prior to the bid date. Items to be discussed include:

- Specifications and any special provisions.
- Design responsibilities and lines of communication.
- The architect's approved finish samples with information on the mixture design, where applicable.
- Prebid submittal requirements, such as proposal drawings and finish samples.
- Project schedule, shop-drawing submittal requirements, and architectural-review turnaround times.
- Panelization.
- Mockups, if applicable.
- Potential problems, discrepancies, or both found in the contract documents.
- How and where the project's precast concrete will be structurally attached to the building frame.
- Interfacing with other trades.
- Responsibility for designing, providing and installing embedded items, connection hardware attached to the structural steel, bracing, and other structural items.
- Hardware and reinforcement finishes.
- Special erection needs, such as access, crane limitations, and sequences, as well as logistics.
- Responsibility for caulking.

3. The post-bid scope review. A final meeting allows the architect and general contractor to review the precaster's proposal and confirm the company's ability to satisfactorily produce the project and conform to the design concepts and finish requirements. This review should include:

- Proposal drawings that express the architectural precast concrete panelization and structural attachment concepts.
- Finish samples.
- The history of the precaster's company and confirmation of the plant's PCI certification.
- A list of comparable projects, references, and financial capability.
- Key schedule items such as mockup panels, shop drawings and design submittals, mold production, production start and duration, and erection start and duration.
- Qualifications to the bid that can be listed and reviewed.

If the project allows a negotiated precast concrete contract, and the precaster is brought on board during the initial stages of development, prebid and bid submittal information can be minimized.

4. Construction coordination. This meeting should be held at the jobsite after the precast concrete and erection contracts have been awarded. The general contractor should conduct frequent jobsite meetings to coordinate precast concrete design and erection with the work of other trades and general building construction. These meetings should include the subcontractors whose work is impacted by the precast concrete design and erection.

The coordinating meetings should consider a variety of details, including:

- Loading, delivery sequence, and schedules.
- Types of transportation.
- Routes of ingress and egress for delivery trucks and erection cranes.
- Handling techniques and devices.
- Connections.
- Erection methods and sequences.
- The effects of temporary bracing on other trades.
- Offsite storage and protection.

Additional questions about site access, street use, sidewalk permits, oversized loads, lighting, or unusual working hours should be addressed at this time. (For more on the prebid process, see Reference 6.)

THE PRECASTER'S RESPONSIBILITIES

The precaster will perform component design of the members when this task is required by the contract. The precaster normally accepts responsibility for design of the connections when the forces acting on the connections are defined by the engineer. Precast concrete reinforcement is determined by code and industry-standard design, unless otherwise defined by the contract documents.

The precaster's responsibilities include:

- Value engineering to improve construction economics, structural efficiency, and precast concrete performance.
- Panelization (panel sizing and joints), which is typically designed first.
- Connection details.
- Detailed shop drawings and design calculations, showing all design criteria, identifying all materials and illustrating panel interfaces with each other, the structure, and adjacent materials.
- Designing panel and connection hardware for the specified loads.
- Selecting, designing, and locating hardware for the specified loads and panel reinforcement.
- Items associated with the precaster's methods of handling, storing, shipping, and erecting the precast concrete components.
- If necessary, creation of an erection and bracing sequence, developed in conjunction with the erector, engineer, and general contractor, to maintain the stability of the structure during erection.

The extent of additional design responsibility vested with the precaster should be clearly defined in the project documents prepared by the architect.

Quality control for product manufacturing is supplied by the precaster according to provisions contained in a comprehensive quality system manual developed by the precaster, in addition to requirements contained in PCI MNL-117, *Manual for Quality Control for Plants and Production of Architectural Precast Concrete Products*. Quality assurance is provided through the precaster's participation in the PCI Plant Certification Program. Additional inspection at the owner's expense may be required by specification through the owner's quality-assurance agency (see Reference 7).

VALUE ENGINEERING AND DESIGN-BUILD APPLICATIONS

Owners may allow, or even encourage, considerations of alternative construction schemes on a project. In such cases, the design drawings frequently are not as definitive as in fully developed designs. When such alternatives use precast concrete as the primary structural system, the precast engineer or another qualified consulting engineer may be designated as the engineer of record.

If a fully developed design is included in the contract documents, a contractor proposing an alternative for some part of the structure should consider the effect of the alternative on all other parts of the structure and provide all necessary design changes.

Owners also may directly seek proposals from general contractors who are willing to prepare design-build proposals. The general contractor may employ a professional engineer or subcontract the design to a firm that serves as the engineer of record. Typically, the precaster serves as a subcontractor of the general contractor, and he or she accepts responsibility for component design of the produced member.

Local regulatory authorities may approve design documents for starting construction without final design of the precast concrete members. In some cases, the design can be performed and submitted at a later time, often in conjunction with preparation of shop drawings. The engineer of record may require that a registered engineer seal the documents that depict the precast design.

REFERENCES:

1. Chapter 4, Section 4.1, "Design & Construction Responsibility," PCI MNL-122-07: *Architectural Precast Concrete, Third Edition*.
2. Chapter 2, "Design Approach," MNL-126-98: *Manual for the Design of Hollow-Core Slabs, Second Edition*.
3. Chapter 10.4.3, "Design Practices," MNL-120-04: *PCI Design Handbook, Sixth Edition*.
4. Chapter 4, Section 4.1.2, "Responsibilities of the Architect," PCI MNL-122-07: *Architectural Precast Concrete, Third Edition*.
5. Chapter 4, Section 4.1.2, "Responsibilities of the Architect," PCI MNL-122-07: *Architectural Precast Concrete, Third Edition*.
6. Chapter 4, Section 4.1.4, "Responsibilities of the General Contractor/Construction Manager," PCI MNL-122-07: *Architectural Precast Concrete, Third Edition*.
7. Chapter 4, Section 4.1.5, "Responsibilities of the Precaster (Manufacturer)," PCI MNL-122-07: *Architectural Precast Concrete, Third Edition*.
8. Chapter 10.4.3, "Design Practices," MNL-120-04: *PCI Design Handbook, Sixth Edition*.

PCI is keenly aware of the competitiveness in the marketplace for building systems. Along with high quality, it is essential that a structure have structural integrity and performs as intended. Because the construction process involves many parties, it is essential that work assignments and responsibilities be clearly defined in the contractual arrangements, whatever form they take (see Reference 8).

RESOURCES:

- DN-13-03: *Designer's Notebook: Specification Guidance*.
- PCI MNL-117: *Manual for Quality Control for Plants and Production of Architectural Precast Concrete Products*.
- PCI MNL-120-04: *PCI Design Handbook, Sixth Edition*.
- PCI MNL-122-07: *Architectural Precast Concrete, Third Edition*.
- PCI MNL-126-98: *Manual for the Design of Hollow-Core Slabs, Second Edition*.

Initial & Life-Cycle Costs



Joe Serna Jr. California EPA Headquarters;
Sacramento, Calif.; Architect: A.C. Martin Partners;
Photo: Walters and Wolf Precast.

A variety of cost calculations is required on every project to determine what design approaches will reap the most advantages for the owner and allow budgets to be allocated most efficiently. Initial, in-ground costs are the most obvious expenses, but hidden and longer-term costs are becoming more significant as owners and designers study the budget impact of various specifications.

The primary philosophy that has come to the fore looks at the project holistically, understanding that every system and decision impacts others. The goal is to ensure that all products and systems work together to enhance each other without creating redundancy or inefficiencies.

Added insulation and other energy efficiencies, for instance, may allow the installation of smaller HVAC equipment than would be needed otherwise. Siting the building certain ways and using more glass may allow fewer light fixtures to be installed. Using products that can enclose the building quickly avoids winter slow downs and gets crews inside quicker, bringing the project online faster so revenues can be generated quicker.

Maintenance needs throughout the building's life must also be considered. These expenses come from the operating budget rather than the construction budget, and so they often were overlooked in the past when designing the building. Today, owners and designers are acknowledging that all budgets must be considered, and labor and material costs that keep a building operating efficiently through its life are part of the equation at the design phase.

Durability, such that a building does not need to have its exterior refurbished or possibly replaced in 20 years, has also become more of a consideration. The entire life-cycle costs of a project are being calculated, and each material choice must justify its value today, tomorrow, and many years from now.

IN-GROUND COSTS

Initial or in-ground costs are the most obvious and most significant when determining budgets and where to allocate funds for the construction of a building. Precast concrete components provide a variety of savings to a project in ways that are not always considered when looking at upfront costing versus other materials, including masonry and curtain wall. These savings include:

SPEED. Precast concrete components provide a variety of ways to speed the construction process, from design through fabrication and erection. These efficiencies can shave as much as one-third of the time needed for construction, meeting tight deadlines and generating revenues quicker. Time can be saved through:

- **The design process.** It takes less time to design a precast concrete building than one built of other materials, due to the lessened detail required in precast concrete's panelized system and the ability to quickly replicate components on each floor or wing.
- **The fabrication process.** Precast concrete components can be fabricated while permitting and foundation work progress, so they are ready to begin erection as soon as foundations are complete. As a single-source supplier for a large portion of the structural system, precasters help maintain the critical-path scheduling.
- **The erection process.** Foundations can be placed one day and precast concrete loadbearing or non-loadbearing panels can be erected as soon as the foundations have cured sufficiently. Wall panels, double tees, and hollow-core planking also erect quickly, often cutting weeks or months from the schedule. This speed allows construction to get into the dry quicker. The fast enclosure also lessens concern for weather or material damage during erection, reducing the contractor's risks and costs.
- **The finishing process.** Precast concrete insulated sandwich panels create a finished interior wall that avoids the time and cost of furring and drywalling. Architectural panels can have a variety of colors and textures cast into them, including several in one panel, eliminating the need to field-set trim pieces or paint the façade after the structure is built. (For more on this aspect, see Reference 1.)



NBSC Headquarters Building, Greenville, S.C.;
Architect: Neal + Prince & Partners; Photos: Metromont
Corporation.



Day 1 — Foundation ready.



Day 7 — Building begins taking shape.

DESIGN ECONOMY. The custom, sculptured designs that are possible with precast concrete may be achieved within a limited budget by selecting economical aggregates and textures combined with repetitive units and effective production and erection details. The key factors in designing economically with architectural precast are:

- **Repetition.** By reusing the same dimensions for components, the same molds can be used, minimizing the total number needed and the changes between casting. Efficiency is created by making it possible for similar, if not identical, shapes to be produced from the same basic (master) mold and by minimizing the time required to disassemble a mold and reassemble it for the next piece. Mold costs range from hundreds to thousands of dollars per mold, depending on size, complexity, and materials used.

Effect of Repetition on Panel, Square-Foot Cost

Number of Reuses	Panel Size (square feet)	Mold Cost	Cost per Square Foot
1	200	\$5,000	\$25.00
10	200	\$5,000	\$2.50
20	200	\$5,000	\$1.25
30	200	\$5,000	\$0.83

Source: PCI MNL-122-07: Architectural Precast Concrete, Third Edition. Art. 2.2.2 Mold Costs.

Note: This table reflects a typical cladding application of precast concrete architectural panels. The same or a similar process can be used for a total-precast concrete structure.



Day 15 — Interior shear walls.



Day 25 — Shear structure.



Day 44 — Structurally and architecturally dry.

- **Average piece size.** Precast concrete pricing is primarily determined by the size of the pieces and piece repetition. Pricing depends more on the number of pieces than the size of the project. A 100-piece project of large panels can be less expensive per square foot than a 1000-piece project of much smaller panels on the same size building. Labor functions drive pricing more than material cost, and each new piece, particularly different shapes or sizes, drives up the amount of labor needed to create and erect a component. It is most economical to cover a larger portion of the building's exterior with fewer precast concrete panels.

During a project's preliminary design, a precast concrete project can be budget "guesstimated" on a square-foot basis. Although this provides a good starting point, it is not recommended that designers rely on this method alone. A square-foot take-off can differ depending on the precaster, general contractor, and architects involved and on the procedures used. Work-scope criteria typically isn't known, and it impacts the final budget. Erection access and crane requirements also are not defined, and back-forming and other details cannot be predicted (see Reference 2).

**Effect of Panel Size on Erection Cost, per Square Foot
(based on a minimum erection time of one month)**

Panel Size (Square Feet)	Erection Cost per Piece, \$/Square Foot			
	\$500	\$1,000	\$1,500	\$2,000
50	10.00	20.00	30.00	40.00
100	5.00	10.00	15.00	20.00
150	3.33	6.67	10.00	13.33
200	2.50	5.00	7.50	10.00
250	2.00	4.00	6.00	8.00
300	1.67	3.33	5.00	6.67

Source: PCI MNL-122-07: Architectural Precast Concrete, Third Edition. Art. 2.2.4 Panel Size/Panelization.

Note: This table reflects a typical cladding application of precast concrete architectural panels. The same or a similar process can be used for a total-precast structure.

Material Efficiency. Precast concrete saves money by replicating the look of more expensive materials, such as natural stone (granite, marble, limestone, sandstone, or slate). Veneers of these materials also can be cast into the face of the precast concrete components, saving the expense of full-thickness pieces. Brick-faced precast concrete also eliminates labor costs and speeds up construction.

Precast concrete components can save money by using single components to serve several functions. Hollow-core planking and double tees, for instance, can be used as a combined ceiling/flooring unit, saving material costs and speeding construction further due to less labor. This is enhanced with total-precast concrete systems, which can combine architectural and structural functions into one piece (see Reference 3).

In parking structures, precast concrete spandrel panels are used as a vehicle-impact restraint in addition to providing a perimeter design feature. This eliminates the need for an upturned cast-in-place concrete beam or cable system (see Reference 4).

Construction Efficiency. Because precast components are fabricated under factory-controlled conditions at a plant, harsh winter weather does not impact the production schedule or product quality. This approach means they can be erected through the winter months to meet a tight schedule, cutting overhead costs, and opening the building for occupancy faster.

Producing the components in a plant also ensures tight tolerances, which will facilitate erection and require fewer field adjustments that other methods may need to complete the structure.

Precast concrete panels inset with thin bricks or cast using formliners to resemble stone require only one trade, eliminating costly and time-consuming masonry as well as other trades from the site. (For more on this aspect, see Reference 5.)

REFERENCES:

1. MK-34-03: *Precast Concrete Makes the Grade For K-12 School Facilities*, p. 4: "Meeting Deadlines."
2. Chapter 2, Section 2.2, "Design Economy," MNL-122-07: *PCI Architectural Precast Concrete Manual, Third Edition*.
3. MK-34-03: *Precast Concrete Makes the Grade For K-12 School Facilities*, p. 2, "Total Precast Concrete Systems Meet Schools' Total Lifetime Needs."
4. DN-11-02: Designer's Notebook: *Design Economy*.
5. MK-34-03: *Precast Concrete Makes the Grade For K-12 School Facilities*, p. 3: "Cost Effectiveness."
6. MK-34-03: *Precast Concrete Makes The Grade For K-12 School Facilities*, p.3: "Cost Effectiveness."

Hidden Costs. Precast concrete's speed of construction can reduce the construction time frame by several months. This results in less time to carry financial bonds, lower contractor overhead costs and risk, elimination of expenses for nonprecast-related equipment, and reduced subcontractor costs by giving more responsibility to a single-source supplier (see Reference 6).

RESOURCES:

- CD/IGS-8-02: Commercial Building CD-ROM.
- DN-11-02: Designer's Notebook: *Design Economy*.
- DN-12-02: Designer's Notebook: *Benefits & Advantages*.
- MK-21-98: *Parking Structures: Team Solutions Timeline*.
- MK-22-98: *The Precast Prestressed Advantages for Owners and Developers*.
- MK-35-03: *Precast Concrete Panels: Tilt-up Doesn't Measure Up*.

MAINTENANCE COSTS

Generally, precast concrete components, even architectural precast concrete panels exposed to weather, require little maintenance. A regular inspection and routine recaulking of cladding panels every 15 to 20 years are all that may typically be required. Panels can be washed with strong chemicals and cleaners without losing their color, and UV rays will not cause them to fade, as will happen with paint.

Parking structures, more than any other building type, require routine maintenance. Unlike other buildings, the structural components are exposed directly to weather and other environmental conditions. Extreme temperature changes, rain, snow, deicing salts, road grime, and dampness directly influence the durability of parking structures and have the potential to create performance problems. The severity of these problems will depend on the structure's location, environmental conditions, and maintenance schedule.

Based on national surveys, precast concrete parking structures offer superior resistance to deterioration. Components produced by PCI-certified plants in particular offer a controlled environment where durable concrete with specialty curing can be created that cannot be achieved in the field. However, without proper maintenance, any structure's life will be compromised.

Besides increasing service life and reducing long-term structural repairs, a comprehensive maintenance program for a parking structure will produce a cleaner, safer, and more user-friendly atmosphere that encourages repeat business and discourages littering and loitering. It is essential that a maintenance program be a major part of the operation of all parking structures. A routine maintenance program should be set up immediately upon turnover of the parking structure, and the precaster can help in preparing a schedule of activities (see Reference 1).



*Hull Street Parking Structure, Athens, Ga.;
Architect: Smallwood, Reynolds, Stewart,
Stewart & Associates Inc.;
Photo: Jim Roof.*

In general, there are three types of maintenance:

- 1. Housekeeping.** This includes general cleaning, floor washing, cleaning of debris from expansion joints, touchup of painted surfaces, upkeep of landscaping, repainting stripes and graphics, cleaning lighting fixtures, removing graffiti, etc. (see Reference 2).
- 2. Prevention Maintenance.** This focuses on periodic checkup, cleaning, and restoration of all components, including structural, architectural, and mechanical elements, as well as equipment maintenance and safety systems. Such activities will prevent premature deterioration of the structure and unexpected failure of mechanical components (see Reference 3).
- 3. Structural Repairs.** Even the best maintained parking structure may occasionally require some structural repairs. Repairs may be needed to fix scaling, spalling, cracking, or delamination. In addition, flange connections should be checked for weld failures or corrosion damage. An experienced engineer should examine these conditions to determine the best course of action (see Reference 4).

Having an engineer experienced in this type of construction perform a periodic structural audit will ensure that any conditions are caught before they become a major expense. Performing such an audit every three to four years with experienced personnel using the proper testing equipment is recommended. The first audit should take place immediately after construction is completed so a basis for future audits is established (see Reference 5).

REFERENCES:

1. Chapter 1.0, "Introduction," MNL-136-04: *Maintenance Manual for Precast Parking Structures*.
2. Chapter 2.1, "Housekeeping," MNL-136-04: *Maintenance Manual for Precast Parking Structures*.
3. Chapter 2.3, "Prevention Maintenance," MNL-136-04: *Maintenance Manual for Precast Parking Structures*.
4. Chapter 2.4, "Structural Repairs," MNL-136-04: *Maintenance Manual for Precast Parking Structures*.
5. Chapter 2.5, "Periodic Structural Audit," MNL-136-04: *Maintenance Manual for Precast Parking Structures*.

RESOURCES:

- CD/IGS-8-02: Commercial Building CD-ROM.
DN-11-02: *Designer's Notebook: Design Economy*.
DN-12-02: *Designer's Notebook: Benefits & Advantages*.
MK-21-98: *Parking Structures: Team Solutions Timeline*.
MK-22-98: *The Precast Prestressed Advantages for Owners and Developers*.
MK-35-03: *Precast Concrete Panels: Tilt-up Doesn't Measure Up*.



Union Plaza Transit Terminal and Parking Garage, El Paso, Tex. The use of an all-precast concrete structure, including double tees, beams, columns, and shear walls speeded construction and maximized interior layout space.

LIFE-CYCLE COSTS

Determining life-cycle costs, or all of the expenditures incurred over the lifetime of a particular structure, has gained a higher profile as owners and architects realize the impact of long-term expense on the operating cost of a building and its effect on the structure's overall return on investment. The focus on sustainable design in particular has made owners and designers examine the long-term benefits and costs of various decisions.

Performing a life-cycle analysis, however, requires a variety of assumptions and complexities. Many types of life-cycle analyses can be created, and the best one to meet the owner's needs will vary based on the project, the owner, and the goals.

Economic versus Environmental

A life-cycle analysis can be done in terms of the economic or environmental life-cycle cost impact. Although the two approaches are different, they each consider the impacts of the building design over the life of the building, an essential part of sustainable design.

When the energy and resource impacts of sustainable design are considered over the life of the building, a sustainable design often becomes cost-effective. Conversely, when the energy-consuming impacts of a low, first-cost design are considered over the life of the building, the building may not be as attractive of an investment (see Reference 1).

A life-cycle cost analysis is a powerful tool used to make economically sound decisions for selection of materials. Costs at any given time are discounted back to a fixed date, based on assumed rates of inflation and the time-value of money. A life-cycle cost is given in terms of dollars and represents the construction cost plus the present value of future utility, maintenance, and replacement costs over the life of the building.

Using the widely accepted life-cycle cost analysis, it is possible to compare, in a fair way, the economics of alternatives that may have different cash-flow factors but provide a similar standard of service. The result is financial information for decision making, which can be used to balance capital costs and future repair or maintenance costs.

Quite often, those designs with the least first cost for new construction will require higher costs during the building life. Because they avoid a high first cost, they require more maintenance over time and thus have a higher life-cycle cost. As a very durable material, precast concrete may have somewhat higher initial costs but lower life-cycle costs because they require little maintenance after they are fabricated and erected.

The Building Life-Cycle Cost software from the National Institute of Standards and Technology (NIST) provides economic analysis of capital investments, en-

ergy and operating costs of buildings, systems, and components. The software includes the means to evaluate costs and benefits of energy conservation. It complies with ASTM standards related to building economics and Federal Energy Management Program requirements.

Accepted methods of performing life-cycle cost analyses of buildings assume a 20-year life, with the building maintaining 80% of its residual value at the end of this period. However, buildings actually last hundreds of years if they are not torn down due to functional obsolescence.

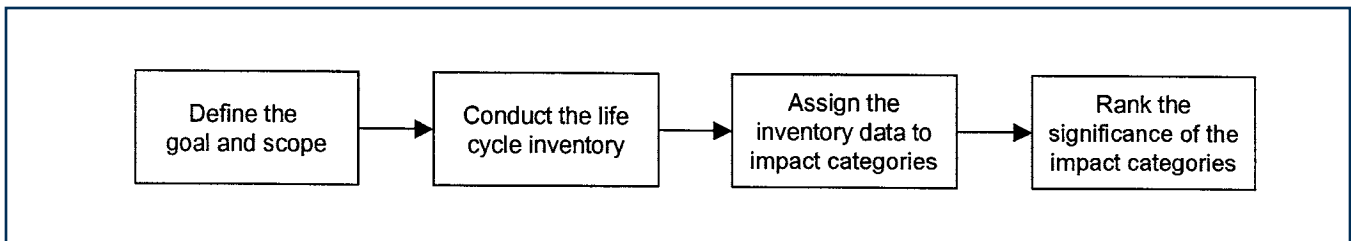
Sustainability practitioners advocate that the building's foundation and shell should be designed to last for 200 to 300 years. The building's long-term flexibility can be increased by allowing extra capacity in the columns for extra floors and floor loads as well as extra capacity in roofs for roof-top gardens.

Speculative-building developers often design for a return on investment in seven years and generally do not buy into the life-cycle cost approach. Similarly, minimum code requirements for energy-conserving measures in the building shell are generally calculated for five years, meaning initial insulation levels should pay for themselves in that time. Since it is difficult and costly to add more insulation to the building shell after it has been constructed, the 5-year payback for insulation is not consistent with a 100-year building use.

Advanced building-design guidelines from the New Buildings Institute (www.NewBuildings.org) and others specify insulation levels for those who want to build cost-effective buildings above minimum code level. Alternatively, thermal mass and insulation can be included in the life-cycle cost analysis to determine cost-effective levels. However, this requires whole-building energy analyses, to determine annual costs to heat and cool the building. Economic levels of insulation depend on the climate, location, and building type. (See Reference 2.)

Creating a Life-Cycle Assessment

A life-cycle assessment (LCA) is an environmental assessment of the life cycle of a product. An LCA looks at all aspects of a product life cycle, from the first stages of harvesting and extracting raw materials from nature to transforming and processing these raw materials into a product, using the product and ultimately recycling or disposing of it back to nature. An LCA consists of four phases:



A life-cycle assessment of a building is necessary to evaluate the environmental impact of a building over its life. It includes impacts due to:

- Extraction of materials and fuel used for energy.
- Manufacture of building components.
- Transportation of materials and components.
- Assembly and construction.
- Operation, including energy consumption, maintenance, repair, and renovations.
- Demolition, disposal, recycling, and reuse of the building at the end of its functional or useful life.

A full set of impacts includes land use, resource use, climate change, health effects, acidification, and toxicity.

A life-cycle assessment involves a time-consuming manipulation of large quantities of data. A model such as Simapro provides data for common building materials and options for selecting LCA impacts. The Portland Cement Association (www.cement.org) publishes reports with life-cycle inventory data on cement and concrete. All models require a separate analysis of annual heating, cooling, and other occupant loads using a program such as DOE2.1e.

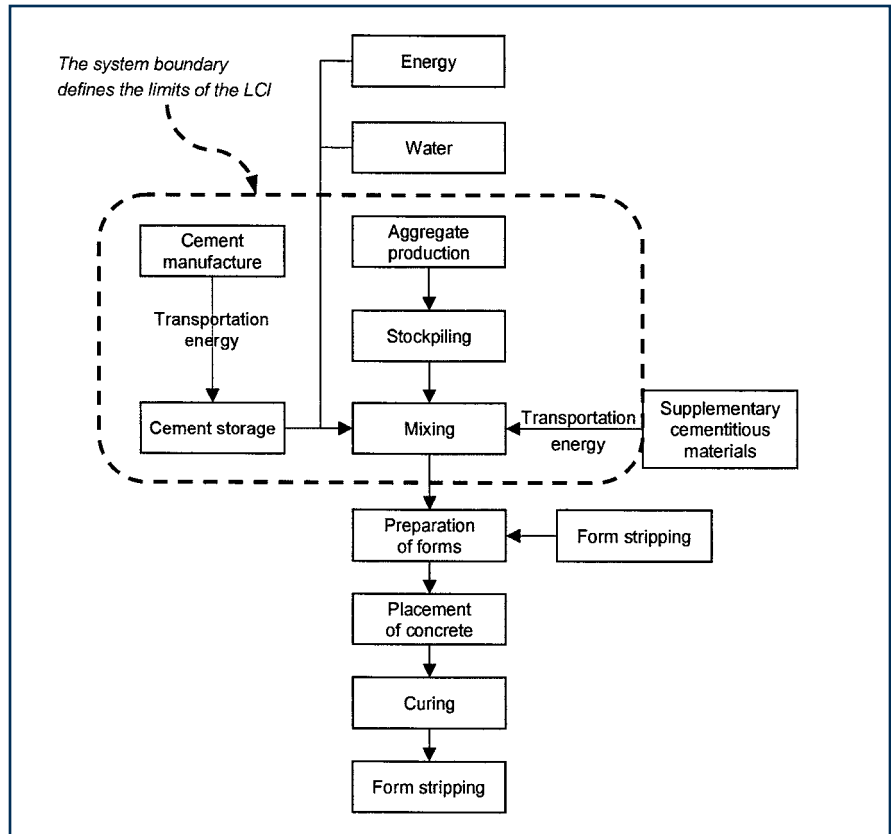
Creating an LCI

A life-cycle inventory (LCI) is the first stage of a life-cycle assessment. An LCI is an accounting of all the individual environmental flows to and from a product throughout its life cycle. It consists of the materials and energy needed to make and use a product and the emissions to air, land, and water associated with making and using that product.

Several organizations have proposed how an LCA should be conducted. Organizations such as the International Organization for Standardization (ISO, www.iso.org), the Society of Environmental Toxicology and Chemistry (SETAC, www.setac.org), and the United States Environmental Protection Agency (www.epa.gov) have documented standard procedures for conducting an LCA. These procedures are generally consistent with each other. What these standards have in common is that they are scientific, explained in detail, and repeatable.

The usefulness of an LCA or LCI depends on where the boundaries of a product are drawn. A common approach is to consider all of the environmental flows from cradle-to-grave. A system boundary for a precast concrete operation would look like the diagram on the next page.

Note that the boundary does not include upstream profiles of fuel, electricity, water, or supplementary cementitious materials. It also does not include form preparation, placing the concrete in the formwork, curing, and stripping. A complete precast concrete LCI would include these steps.



An upstream profile can be considered as a separate LCI that is itself an ingredient to a product. For example, the upstream profile of cement is essentially an LCI of cement, which can be imported into an LCI of concrete. The LCI of concrete can then be imported into an LCI of a product, such as an office building.

To obtain the most useful information from an LCI, precast concrete should be considered in the context of its end use. For example, in a building, the environmental impact of the building materials is usually dwarfed by the environmental impacts associated with building operations such as heating, ventilating, cooling, and lighting.

Life-cycle inventories of materials generally do not consider embodied energy and emissions associated with construction of manufacturing-plant equipment and buildings, nor the heating and cooling of such buildings. This is generally acceptable if their materials, embodied energy, and associated emissions account for less than 1% of those in the process being studied. Guidelines established by the Society of Environmental Toxicology and Chemistry indicate that inputs to a process do not need to be included in an LCI if:

- They are less than 1% of the total mass of the processed materials or product.
- They do not contribute significantly to a toxic emission.
- They do not have a significant associated energy consumption.

(For more on this aspect, see Reference 3.)

Precast Concrete LCI

The data gathered in an LCI is voluminous by nature and does not lend itself well to concise summaries; that is the function of the LCA. The data in typical LCI reports often are grouped into three broad categories: materials, energy, and emissions. These LCI data do not include the upstream profiles of supplementary cementitious materials (such as fly ash, silica fume, etc.) or energy sources (such as fuel and electricity).

The embodied energy of concrete increases in direct proportion to its cement content. Therefore, the embodied energy of concrete is sensitive to the cement content of the mix and to the assumptions about LCI energy data in cement manufacturing.

Replacing cement with supplementary cementitious materials, such as slag cement or silica fume, has the effect of lowering the embodied energy of the concrete. Fly ash, slag cement, and silica fume do not contribute to the energy and emissions embodied in the concrete (except for the small energy contributions due to slag granulation/grinding, which is included). These products are recovered materials from industrial processes (also called post-industrial recycled materials) and, if not used in concrete, would use up valuable landfill space.

For instance, with a 20% replacement of fly ash for portland cement in a 3000-psi (20 MPa) mixture, embodied energy changes from 1.2 to 1.1 MBtu/yd³ (1.7 to 1.5 GJ/m³), a 10% reduction. With a 50% slag-cement replacement for portland cement in a 5,000-psi (35 MPa) mixture, embodied energy changes from 2.3 to 1.5 GJ/m³ (1.7 to 1.1 MBtu/yd³), a 34% reduction.

REFERENCES:

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RESOURCES:

MNL-122-07: *PCI Architectural Precast Concrete Manual, Third Edition*.

Fly ash or slag cement replacement of portland cement also can significantly reduce embodied emissions. For instance, a 20% substitution of fly ash for portland cement in a 3000-psi (20 MPa) mixture results in a 17% reduction in carbon dioxide emissions. A 45% carbon-dioxide-emissions reduction is achievable with 50% substitution of slag for portland cement in a 7500-psi (50 MPa) precast concrete mixture.

Embodied energy of reinforcing steel used in concrete is relatively small because it represents only about 1% of the weight in a unit of concrete, and it is manufactured mostly from recycled scrap metal. Reinforcing steel has over 90% recycled content, according to the Concrete Reinforcing Steel Institute (www.crsi.org) The process for manufacturing reinforcing bar from recycled steel uses significant energy and should be considered if the reinforcing bar content is more than 1% of the weight of the concrete.

It is assumed that, at a typical site and in a precast concrete plant, concrete-production formwork is reused a number of times through the repetitious nature of work, so its contribution to an LCI or LCA is negligible. Steel and wood formwork is generally recycled at the end of its useful life (see Reference 4).



Sustainability & LEED Considerations

Precast concrete components can aid designers in achieving sustainable designs and in meeting standardized requirements for environmentally friendly designs. Sustainability has become a watchword for owners and architects when designing new buildings, intermingled with terms such as “environmental friendliness” and “green building.”

In general, sustainability is considered to mean development that meets present needs without compromising the ability to meet the needs of future generations. The goal is to use building materials and energy resources in ways that will minimize their depletion or not restrict their ability to be used by future generations.

Today's approach extends beyond the ability to renew or recycle resources to examine the embodied energy required to make use of that material. This accounting practice encompasses all the energy necessary to manufacture, deliver, and install the product, including fuel to extract materials, finish them, and transport them to the site. Even so, the concept also balances environmental impact with cost-effectiveness.

While other building materials may have to alter their configurations or properties to be applicable to sustainable structures, precast concrete's inherent composition allows it to naturally achieve sustainability. It contributes by incorporating integrated design, using materials efficiently, and reducing construction waste, site disturbance, and noise.

The information in this chapter, which discusses sustainable concepts as they apply to precast concrete, is condensed and edited from Chapter 5, Section 5.4, “Sustainability,” in PCI's *Architectural Precast Concrete Manual, Third Edition* (MNL-122-07). Additional resources pertaining to precast's role in designing a sustainable building can be found at the end of the chapter.

INTEGRATED DESIGN

Precast concrete components play a key role in maximizing benefits from integrated-design strategies. Integrated design, also called the holistic or whole-building approach, focuses on all of the building's materials, systems, and design from the perspective of all project team members and tenants.

Decisions are based on the combination of energy efficiency, cost, durability (or service life), space flexibility, environmental impact, and quality of life. Choices in one area impact other areas, requiring all systems to be considered together to maximize efficiency and minimize redundancies or interference.

Integrated design requires coordinating the architectural, structural, and mechanical designs early in the schematic-design phases to evaluate system interactions and decide which beneficial interactions are essential for project success. For example, a well-insulated building with minimal windows facing east and west requires less heating and air-conditioning. That reduction, in turn, could result in fewer ducts or the elimination of registers along the building's perimeter.

Integrated design consists of eight key components. Requests for proposals and contracts should clearly describe sustainability requirements and project documentation. The eight components are:

1. Emphasize the integrated process.
2. Consider the building as a whole—often interactive, often multi-functional.
3. Focus on the life cycle.
4. Have disciplines work together as a team from the start.
5. Conduct relevant assessments to help determine requirements and set goals.
6. Develop tailored solutions that yield multiple benefits while meeting requirements and goals.
7. Evaluate solutions.
8. Ensure requirements and goals are met.



The U.S. Department of Transportation facility in Lakewood, Colo., used an all-precast concrete structure to help it achieve LEED Silver Certification. Design Architect: Oz Architecture; Architect/engineer: Opus Architects & Engineers Inc.; Photo: Oz Architecture.

Some of the primary ways that precast concrete components can help include:

- Precast concrete walls act as thermal storage to delay and reduce peak thermal loads.
- Precast concrete walls used with insulation provide energy benefits that exceed the benefits of mass or insulation used alone in most climates.
- Precast concrete sandwich wall panels used as an interior surface can save material by eliminating the need for framing and drywall.
- Hollow-core panels used as ducts can save material and energy by eliminating ductwork and charging the thermal mass of the panel.
- Precast concrete walls can be designed to be disassembled for building-function changes, saving material and extending the service life of the panels.
- Precast concrete's durability creates a long life cycle and low maintenance, which creates less need for replacement and maintenance during the building's life.
- As a plant-cast product manufactured under tight quality controls, precast concrete eliminates any construction waste and minimizes transportation and disposal costs.

In addition, a major tenet of an integrated-design strategy embracing sustainable concepts is to focus on three ways to minimize the material used in the project:

1. Reduce the amount of material used and the toxicity of waste

materials. Precast concrete can be designed to optimize or lessen the amount of concrete used. Industrial wastes such as fly ash, slag cement, and silica fume can be incorporated into the mix, reducing the amount of cement. As a manufactured product created under controlled conditions in the plant, precast concrete generates low amounts of waste, and the waste generated has low toxicity. It is generally assumed that 2% of the concrete at the plant is waste, but because it is generated at the plant, 95% of the waste is used beneficially elsewhere.

2. Reuse and repair products. Precast concrete panels can be reused when buildings are expanded. Concrete pieces from demolished structures also can be reused, such as protection for shorelines. Because the precast process is self-contained, formwork and finishing materials are reused. Wood or fiberglass forms can generally be used 40 to 50 times without major maintenance, while concrete and steel forms have practically unlimited service lives.

3. Recycle and use products with recycled content. Concrete can be recycled as fill or road base. Wood and steel forms are recycled when they become worn or obsolete. Virtually all reinforcing steel is made from recycled steel. Many cement plants burn waste-derived fuels such as spent solvents, used oils, and tires.

LEED Rating System

Precast concrete can help buildings in a variety of ways to achieve the standards created by the LEED building-rating system. LEED is a voluntary, consensus-based national standard for developing high-performance, sustainable buildings. Administered by the U.S. Green Building Council, LEED-NC applies to new construction and major renovation projects and covers commercial and institutional projects as well as high-rise residential new construction and major renovation projects.

The system uses points to create a framework for assessing building performance and meeting sustainability goals. Points are awarded when a specific intent is met, and a building is LEED certified if it obtains at least 26 points. Additional silver, gold, and platinum levels of ratings are awarded for at least 33, 39, and 52 points, respectively. The points are grouped into five categories:

1. Sustainable Sites
2. Water Efficiency
3. Energy & Atmosphere
4. Materials & Resources
5. Indoor Environmental Quality

Appropriate use of precast concrete components can help a building earn up to 27 points, one more than is required for LEED certification. Precast concrete can help meet minimum energy requirements, optimize energy performance, and increase the life of a building. The constituents of concrete can be made from recycled materials, and concrete itself can also be recycled. The materials are usually available locally.

These attributes of concrete, recognized in the LEED rating system, can help lessen a building's impact on the natural environment. Points applicable to precast concrete are summarized in the accompanying table. The USGBC website (www.usgbc.org) contains a downloadable "letter template" that greatly simplifies documentation requirements

Total-precast concrete structure aids office design by offering "green" qualities, including close proximity, energy efficiency, reliability, and minimal construction waste.



CH2M Hill World Headquarters, Englewood, Colo.; Architect: Barber Architecture, Denver, Colo.; Photos: Rocky Mountain Prestress.

LEED* Project Checklist: Precast Concrete Potential Points

LEED CATEGORY	CREDIT OR PREREQUISITE	POINTS AVAILABLE
Sustainable Sites	Credit 5.1: Site Development, Protect or Restore Habitat	1
Sustainable Sites	Credit 5.2: Site Development, Maximize Open Space	1
Sustainable Sites	Credit 7.1: Heat Island Effect, Non-Roof	1
Energy and Atmosphere	Prerequisite 2: Minimum Energy Performance	—
Energy and Atmosphere	Credit 1: Optimize Energy Performance	1-10
Materials and Resources	Credit 1.1: Building Reuse, Maintain 75% of Existing Shell	1
Materials and Resources	Credit 1.2: Building Reuse, Maintain 95% of Existing Shell	1
Materials and Resources	Credit 2.1: Construction Waste Management, divert 50% by weight or volume	1
Materials and Resources	Credit 2.2: Construction Waste Management, divert 75% by weight or volume	1
Materials and Resources	Credit 4.1: Recycled Content, the post-consumer recycled content plus one-half of the pre-consumer content constitutes at least 10% (based on cost) of the total value of the materials in the project	1
Materials and Resources	Credit 4.2: Recycled Content, the post-consumer recycled content plus one-half of the pre-consumer content constitutes at least 20% (based on cost) of the total value of the materials in the project	1
Materials and Resources	Credit 5.1: Local/Regional Materials, Use a minimum of 10% (based on cost) of the total materials value	1
Materials and Resources	Credit 5.2: Local/Regional Materials, Use a minimum of 20% (based on cost) of the total materials value	1
Indoor Environmental Quality	Credit 3.1: Construction Indoor Air Quality Management Plan, during construction	1
Innovation and Design Process	Credit 1.1: Use of high volume supplementary cementitious materials. Apply for other credits demonstrating exceptional performance	1 [†]
Innovation and Design Process	Credits 1.2: Apply for other credits demonstrating exceptional performance	1 [†]
Innovation and Design Process	Credits 1.3: Apply for other credits demonstrating exceptional performance	1 [†]
Innovation and Design Process	Credits 1.4: Apply for other credits demonstrating exceptional performance	1 [†]
Innovation and Design Process	Credit 2.1: LEED Accredited Professional	1
PROJECT TOTALS		23

*LEED: Leadership in Energy and Environmental Design.

[†] Up to 4 additional points can be earned, must be submitted and approved (not included in total).

Note: Scoring System: Certified, 26-32 points; Silver, 33-38 points; Gold, 39-51 points; and Platinum, 52-69 points.



PRECAST CONCRETE ATTRIBUTES APPLIED TO LEED CERTIFICATION

The attributes and capabilities of precast concrete that help meet LEED certification vary by the intent of each category. The key applications center on the following attributes:

Durability

Durability of the original structure represents a key factor in building reuse. Precast concrete panels provide a long service life due to their durable and low-maintenance concrete surfaces. A precast concrete shell can be left in place when the building interior is renovated. Yearly maintenance should include inspection and, if necessary, repair of joint material.

Modular and sandwich-panel construction with precast concrete exterior and interior walls provides long-term durability inside and out. Precast concrete construction creates the opportunity to refurbish the building if its use or function changes rather than tearing it down to start anew.

These characteristics of precast concrete make it sustainable in two ways:

1. It avoids contributing solid waste to landfills.
2. It reduces the depletion of natural resources and production of air and water pollution caused by new construction.

Mitigating the Urban Heat-Island Effect

Precast concrete provides reflective surfaces that minimize the urban heat-island effect. Cities and urban areas are 3 °F to 8 °F warmer than surrounding areas due to buildings and pavements taking the place of vegetation. Trees provide shade that reduce temperatures at the surface and also create transpiration and evaporation that cool the surfaces and air surrounding them.

Urban heat islands result primarily from solar radiation being absorbed by horizontal surfaces such as roofs, pavements, parking lots, driveways, and walkways. Vertical surfaces, such as the sides of buildings, also contribute. The ability of a material to reflect solar heat is called albedo, and the higher the material's albedo, the better it reflects. High albedo can reduce the heat-island effect, save energy by reducing the demand for air conditioning, and improve air quality.

Concrete has a relatively high albedo. Traditional portland-cement concrete generally has an albedo or solar reflectance of approximately 0.4. The solar reflectance of new concrete is greater when the surface reflectance of the sand and cementitious materials in the concrete are greater. Surface finishing techniques also have an effect, with smoother surfaces generally having a higher albedo. Lighter or white colors also increase solar reflectance.



Typical Albedos for Selected Building Products

Material	Albedo Range
Asphalt	.05-.20
Roofing tile	.10-.35
Stone	.20-.35
New concrete	.35-.40
Colored metal roofs	.55-.66
Cool roofs (with reflective membrane)	.85
Snow	.75-.95

Source: U.S. Environmental Protection Agency (www.epa.gov) and ESPERE-ENC (Environmental Science Published for Everybody Round the Earth-Educational Network on Climate)

Moisture in concrete helps to cool the surface by evaporation, too. Concrete, when placed, has a moisture content of 100% relative humidity. The concrete surface gradually dries over a period of one to two years, until it reaches equilibrium with its surroundings. Concrete surfaces exposed to rain and snow will continue to become wet and dry. This moisture helps cool the concrete by evaporation whenever the temperature and relative humidity of the air are greater than that just beneath the concrete surface.

The thermal mass of concrete delays the time it takes for a surface to heat up, but it also delays the time to cool off. For example, a white roof will get warm faster than concrete during the day, but will also cool off faster at night. Concrete surfaces are often warmer than air temperatures in the evening hours.

Concrete's albedo and thermal mass will help mitigate heat-island effects during the day but may contribute to the nocturnal heat island effect. Designers should try to use concrete to mitigate heat islands while keeping evening temperatures as cool as possible.

Precast Concrete Production

The production of precast concrete has many environmental benefits, including:

- Less material is required because precise mixture proportions and tighter tolerances are achieved.
- Optimal insulation levels can be incorporated into precast concrete sandwich wall panels.
- Waste materials are more likely to be recycled because concrete production is in one location.
- Gray water is often recycled into future mixtures.

- Hardened concrete is recycled (about 5% to 20% of aggregate in precast concrete can be recycled concrete).
- Steel forms and other materials are reused.
- Less dust and waste are created at the construction site because only needed precast concrete elements are delivered.
- There is no debris from formwork and associated fasteners.
- Fewer trucks and less time are required for construction because concrete is made offsite, which is particularly beneficial in urban areas where minimal traffic disruption is critical.
- Precast concrete units are normally large components, so greater portions of the building are completed with each activity.
- Less noise is generated at the construction site because concrete is made offsite.
- Less concrete generally is used in precast buildings compared with other concrete buildings because of the optimization of materials. A properly designed precast concrete system will result in smaller structural members, longer spans, and less material used onsite. This creates economic and environmental savings.

Precast concrete components can provide the building structure as well as the interior and exterior finishes. Structurally efficient columns, beams, and slabs can be left exposed with natural finishes. Interior and exterior concrete walls offer a wide range of profile, texture, and color options that require little or no additional treatment to achieve aesthetically pleasing results.

Constituent Materials

Concrete contributes to a sustainable environment because it does not use scarce resources. It consists of only a few ingredients, primarily cement, water, large and small aggregates, and admixtures, all of which are abundant locally.

Portland cement is made by heating common minerals (primarily crushed limestone, clay, iron ore, and sand) to a white-hot mixture to form clinker. This intermediate product is ground with a small amount of gypsum to form a fine, gray powder. To trigger the necessary chemical reactions in the kiln, these raw materials must reach a temperature of about 2700 °F, the temperature of molten iron. Although portland cement is energy intensive, the U.S. cement industry has reduced energy usage per ton of cement by 35% since 1972.

Aggregates, which comprise about 85% of concrete, generally consist of materials that require low levels of energy to produce, comprising local, naturally occurring sand and stone. Limestone and clay needed to manufacture cement also are prevalent. Limestone and aggregate quarries often are reused. While quarrying is intense, it is closely contained and temporary.

Three types of industrial by-products, or pozzolans, are used to replace portland cement in concrete to reduce the energy and CO₂ impacts of cement in concrete. If not used in concrete, these pozzolans would use valuable landfill space. These admixtures are:

1. **Fly ash**, a by-product of the combustion of pulverized coal in electric power generating plants. It can replace up to 25% of the cement used in precast concrete.
2. **Slag cement**, made from iron blast-furnace slag. It can replace up to 60% of the cement used in precast concrete.
3. **Silica fume**, a by-product from the electric arc furnace used in the production of silicon or ferrosilicon alloy. It can replace up to 7% of the cement used in precast concrete.

Because the cementitious content of concrete accounts for only about 15% of the material's total, these pozzolans typically comprise only 2% to 5% of the overall concrete material in buildings. However, their use can have a significant effect on the environmental impact of concrete: When slag cement replaces 50% of the portland cement in a 7500-psi concrete, greenhouse-gas emissions per cubic yard of concrete are reduced by 45%.

The environmental attributes of concrete can be further improved by using aggregates derived from industrial waste or using recycled concrete as aggregates. Blast-furnace slag is a lightweight aggregate with a long history of use in the concrete industry. Recycled concrete also can be used as aggregate in new concrete, particularly the coarse portion.

Admixtures provide enhancing qualities in concrete but are used in such small quantities that they do not adversely affect the environment. Likewise, color pigments used to provide decorative colors in precast concrete generally do not contribute to environmental calculations, although some may contain trace amounts of heavy-metals.

The use of local materials reduces the transportation needs for heavy building materials, along with the associated energy and emissions. Most precast concrete plants are within 200 miles of a building site. The cement, aggregates, and reinforcing steel used to fabricate precast concrete components, along with the raw materials used to manufacture cement, are usually obtained or extracted from sources within 200 miles of the precast concrete plant.

Precast concrete elements are usually shipped efficiently because of their large, often repetitive sizes and the ability to plan their shipment during the normal course of the project.

Energy Conservation

Energy conservation is a key tenet of sustainability. About 90% of the energy used during a building's life is attributed to heating, cooling, and other utilities. The remaining 10% is attributed to manufacturing materials, construction, maintenance, replacement of components, and demolition.

Precast concrete's inherent capabilities to provide energy efficiency rely on the high thermal mass of the material, which benefits exterior wall applications. Precast concrete walls provide benefits because they:

- Delay or reduce peak loads.
- Reduce total loads in many climates and locations.
- Work well regardless of the placement of mass.

Precast's thermal mass works best in commercial applications by delaying the peak summer load, which generally occurs around 3:00 p.m. The high mass also can be applied to smaller residential applications. The approach works most efficiently when mass is exposed on the inside surface.

Precast concrete's high thermal mass may help shift the peak hour of electric demand for air conditioning to a later hour and help reduce time-of-use charges. Nighttime ventilation can be used to cool thermal mass that has been warmed during the day. Local outdoor humidity levels influence the effectiveness of nighttime ventilation strategies. These strategies can help to reduce the overall load in many climates.

Mass works well on the inside surfaces by absorbing the heat gains generated by people and equipment indoors. Interior mass from interior walls, floors, and ceilings will help moderate room temperatures and reduce peak energy use.

Thermal mass is most effective in locations and seasons where the daily outdoor temperature rises above and falls below the building's balance-point temperature. The balance-point temperature is the outdoor temperature below which heating will be required. It is less than room temperature, generally between 50 °F and 60 °F, at the point where internal heat gains approximately equal the heat losses through the building envelope. In many climates, buildings with thermal mass have lower energy consumption than non-massive buildings with walls of similar thermal resistance; heating and cooling needs can be met with smaller equipment sizes.

Light-colored precast concrete will reduce energy costs associated with indoor and outdoor lighting. The more reflective surfaces will reduce the amount of fixtures and lighting required.

To maximize the effectiveness of the insulation used with precast concrete panels, thermal bridges (disruptions of insulation between two layers of concrete) should be minimized or avoided. Fiberglass or epoxy-coated, carbon fiber composite fasteners or thermal breaks offer the best approach, as they will minimize thermal bridges. Concrete thermal bridges may occur at the bottom and the top of concrete panels. Metal thermal bridges may occur as fasteners that penetrate insulation to connect concrete layers.

Concrete contains low to negligible volatile organic compounds (VOC). These compounds degrade indoor air quality when they off gas from new products such as interior finishings, carpet, and furniture. Manufactured wood products such as laminate, particleboard, hardboard siding, and treated wood can also lead to off gassing. In addition, VOCs combine with other chemicals in the air to form ground-level ozone.

Polished concrete floors do not require carpeting. Exposed concrete walls do not require finishing materials. The VOCs in concrete construction can be reduced further by using low-VOC materials for form-release agents, curing compounds, damp-proofing materials, wall and floor coatings and primers, membranes, sealers, and water repellants.

Precast concrete components can further help meet LEED standards for indoor air quality because they are delivered to the site in modules that do not require fabrication, processing, or cutting at the construction site, thereby reducing dust and airborne contaminants on site. Concrete is not damaged by moisture and does not provide nutrients for mold growth.

Precast concrete panels can be reused when buildings are expanded, and precast concrete can be recycled as road base or fill at the end of its useful life. Concrete pieces from demolished structures can be reused to protect shorelines. Most concrete from demolition in urban areas is recycled and not placed in landfills.

The concrete industry has LEED-experienced professionals available to assist teams with concrete applications and help maximize points for concrete. An additional point is available if a principal participant of the project team is a LEED-accredited professional.

RESOURCES:

DN-15 *Designer's Notebook: Energy Conservation & Condensation Control.*

ASCENT:

"Best Justice Facility: Fresno Courthouse & Federal Building," *ASCENT*, Fall 2006, p. 30.

"DOT Project Shows LEEDership," *ASCENT*, Winter 2006, pp. 32-35.

"Precast Helps Attain LEED Certification," *ASCENT*, Winter 2005, pp. 18-23.

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"Analytical Investigation of Thermal Performance of Precast Concrete Three-Wythe Sandwich Wall Panels," *PCI Journal*, July-August 2004, pp. 88-101.

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Health & Indoor Air Quality

Building users have growing concerns about having a healthy environment in which to work, shop, play, and live. The damage that can be wrought by mold and the lack of fresh air within a structure continues to gain awareness, making designers place more emphasis on controlling these factors in their structures. Mold damage has ruined countless projects and has been directly or indirectly linked to severe illness and harm to individuals.

A side aspect to this problem for designers is that mold problems have clogged the court system with more than \$300 million annually in litigation as well as produced a 300% increase each year in the number of lawsuits filed nationwide. Remediating mold growth also requires expensive treatments that disrupt the building's operation and pose burdens on operating budgets.

Proper design and production techniques can help prevent mold proliferation as well as reduce moisture damage and water migration. The proper design of building envelopes with the correct construction materials is a key way to reduce the presence and potential damage from mold (see Reference 1).

*Orville L. Freeman Office Building and Laboratory,
St. Paul, Minn.; Architect: HGA.*



Mold requires four conditions to thrive: mold spores, organic matter for food, moisture, and optimal temperatures (40 to 100 °F).

There is no way to eliminate all mold in the interior environment, as it exists throughout the natural world. Treatment of materials with chemicals may reduce the potential for mold but can not eradicate it. The careful attention to the building envelope, the choice of materials, and control of moisture penetration can reduce harmful mold's success in establishing itself and growing.

Precast concrete aids in controlling mold growth for a number of reasons:

- **It is not an organic material.** While concrete can accumulate dirt and debris, which can breed mold, its durability allows it to be cleaned in place rather than removed for remediation, as must happen with many other organic construction materials.
- **Its production is controlled away from moisture.** Unless properly designed and constructed, the building site can permit excessive moisture in either surface, underground water, outside humid air, or rain into openings like doors, windows, ventilation ducts, or shafts that pull outside air in the buildings. Precast concrete is produced in a controlled and protected environment in a process that resists moisture intrusion. By delivering the components to the site as needed, they are exposed to the environment for a shorter period of time (see Reference 2).
- **Precast concrete's speed provides interior protection quicker.** The use of precast concrete systems to construct building envelopes also allows the structure to be completed faster, leaving it exposed to humidity and moisture for a shorter time period. This is particularly vital for the installation of the HVAC system, which is one of the more common entrance paths for mold formation. During the "exposed" phase of the construction process, mold spores can come to rest on building materials and components, whether installed or simply stored. If water is added from any natural or other source, the spores may be able to begin to grow.
- **It can be cleaned easily.** Concrete can be cleaned of mold and dust spores, making them ideal substrates for controlling mold growth. The cleaning can be accomplished on precast concrete components by pressure washing, which rids the surface of any food source for mold that may have lodged there. In addition, the site's natural ventilation will normally dry out concrete and steel, eliminating moisture as a source of growth (see Reference 3).
- **Precast concrete provides fewer entry points.** Because of its panelized construction, fewer points of potential moisture penetration exist with precast concrete panels. This helps control moisture and eliminate the possibility for mold growth in water that penetrates the walls. Maintenance needs for precast concrete panels are also minimal, with panels only requiring caulking every 15 to 20 years to maintain their reliability. This limits the need to budget for repairs in annual maintenance budgets and reduces the potential for lapses to allow problems to develop.

- **It ensures mold growth isn't exacerbated by changes in the interior environment.** Because precast concrete panels eliminate worries about moisture penetration, administrators can reduce HVAC usage when a building, especially seasonal structures such as schools, are unoccupied for long periods and not worry that they are risking mold growth or creating bad indoor air quality (see Reference 4).

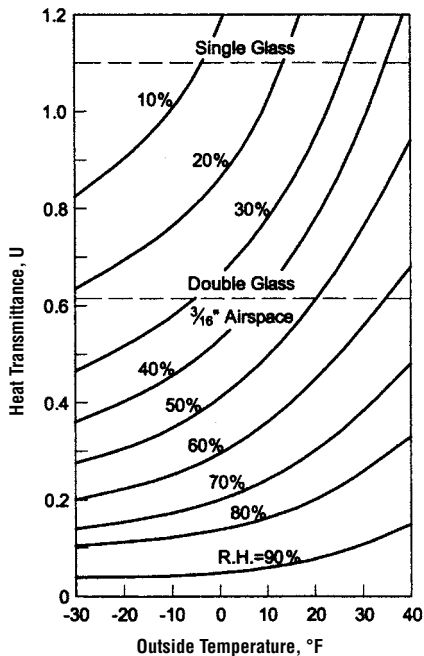
AIR, VAPOR BARRIERS REQUIRED

Controlling condensation in a building with a precast concrete façade, as with any material, requires an air barrier and a vapor barrier, although they often consist of a single material that can provide both functions. The principle function of the air barrier is to stop outside air from entering the building through the walls, windows, or roof, and inside air from exfiltrating through the building envelope to the outside environment.

The principal function of a vapor retarder made of low-permeability materials is to stop or retard the passage of moisture as it diffuses through the assembly of materials in a wall. Vapor-diffusion control is easy to achieve and is primarily a function of the water-vapor diffusion resistance of the chosen materials and their position within the building-envelope assembly. The vapor retarder should be clearly identified by the designer and be clearly identifiable by the general contractor (see Reference 5).

Precast concrete construction supports the scientific community's maxim to prevent or inhibit mold formation rather than attempt remediation of fungi in indoor environments.

In addition, precast concrete panels have no outgassing that can cause deteriorated air quality. This has become a critical component in recent years as the need to enhance energy efficiency has tightened the "breathability" of buildings, preventing air from infiltrating and exfiltrating, which retains existing particulates in the air. Precast concrete will not add to this outgassing that comes from volatile organic compounds and new materials brought into the structure (see Reference 6).



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2. "Mold White Paper," produced for the Precast/Prestressed Concrete Institute; April 2005, p. 2.
3. "Mold White Paper," produced for the Precast/Prestressed Concrete Institute; April 2005, p. 3.
4. MK-34-03: Precast Concrete Makes the Grade For K-12 School Facilities (12 pp.).
5. Chapter 5, Section 5.3.6, "Condensation Control," MNL-122-07: *PCI Architectural Precast Concrete Manual, Third Edition*.
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RESOURCES:

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- Chapter 9.1.7.1, "Air Barriers," PCI MNL-120-04: *PCI Design Handbook, Sixth Edition*.
- Chapter 9.1.7.2, "Vapor Retarders," PCI MNL-120-04: *PCI Design Handbook, Sixth Edition*.
- "Mold White Paper," produced for the Precast/Prestressed Concrete Institute; April 2005, p. 4.
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Acoustics

Inhabited spaces should be acoustically designed to provide a satisfactory environment in which desired sounds are heard clearly and unwanted sounds are isolated or absorbed. Under most conditions, the architect or engineer can determine the acoustical needs of the space and then design the building to satisfy those needs.

Good acoustical design uses absorptive and reflective surfaces, sound barriers, and vibration isolators. Sound is isolated from rooms where it is not wanted by selected wall and floor-ceiling constructions. Vibration generated by mechanical equipment must be isolated from the structural frame of the building.

The Juanita K. Hammons Hall for the Performing Arts, Springfield, Mo.; Architect: Pelham-Phillips-Hagerman; and Butler, Rosenbury & Partners (joint venture); Photos: Pelham-Phillips-Hagerman.



For buildings that require more sophisticated acoustical analysis, such as churches, concert halls, or auditoriums, it may be desirable to review the needs with an acoustical design consultant (see Reference 1).

The ability of a barrier to reduce the intensity of airborne sound is commonly designated by its Sounds Transmission Class (STC). Precast concrete walls, floors, and roofs usually do not need additional treatment to provide adequate sound insulation (see Reference 2).

Even when airborne sounds are adequately controlled, there can be severe impact noise problems. Footsteps, dropped objects, slammed doors, and plumbing generate impact noise. For performance specifications, the Impact Insulation Class (IIC) is used to measure this sound. In general, thickness or unit weight of concrete does not greatly affect the transmission of impact sounds. Structural concrete floors, combined with resilient materials such as carpeting, effectively control impact sound (see Reference 3).

Often, acoustical control is specified as to the minimum insulation values of the dividing partition system. Local building codes, lending institutions and the Department of Housing & Urban Development (HUD) list both airborne, STC and IIC values for different living environments:

HUD Recommendations for STC and IIC

Location	STC	IIC
Between living units	45	45
Between living units and public spaces	50	50

Source: Table 9.2.7.1, MNL-120-04: PCI Design Handbook, Sixth Edition

Other community ordinances can be more specific, listing the sound-insulation criteria with relation to particular ambient environments. Once objectives are established, the designer should refer to available data and select the system that best meets the requirements. In general, concrete systems have superior properties and can, with minimal effort, comply with these criteria (see Reference 4).

SOUND ABSORPTION VS. SOUND INSULATION

Designers must recognize that the basic mechanisms of sound absorption and sound insulation are quite different. Designing for sound insulation is usually considerably more complicated than designing for sound absorption. The former involves reductions of sound levels, which are of greater orders of magnitude than can be achieved by absorption. These large reductions of sound level from space to space can be achieved only by continuous, impervious barriers. It also may be necessary to introduce resilient layers of discontinuities into the barrier.

Sound-absorbing materials and sound-insulating materials are used for different purposes. For instance, an 8-in. concrete wall will not provide much sound absorption, while a porous, lightweight material that may be applied for sound absorption to room surfaces will not provide high sound insulation (see Reference 5).

SOUND-TRANSMISSION LOSS AND SOUND ABSORPTION

Sound-transmission loss measurements are made at 16 frequencies at one-third octave intervals covering the range from 125 to 4000 Hz. Airborne sound reaching a wall, floor, or ceiling produces vibrations in the wall that are radiated with reduced intensity on the other side. Airborne sound-transmission loss in wall assemblies is a function of their weight, stiffness, and vibration-damping characteristics.

Weight is concrete's best asset when it is used as a sound insulator. For sections of similar design but different weights, the STC increases approximately 6 units for each doubling of weight. This is shown in Fig. 1, which describes sound transmission class as a function of weight based on experimental data.

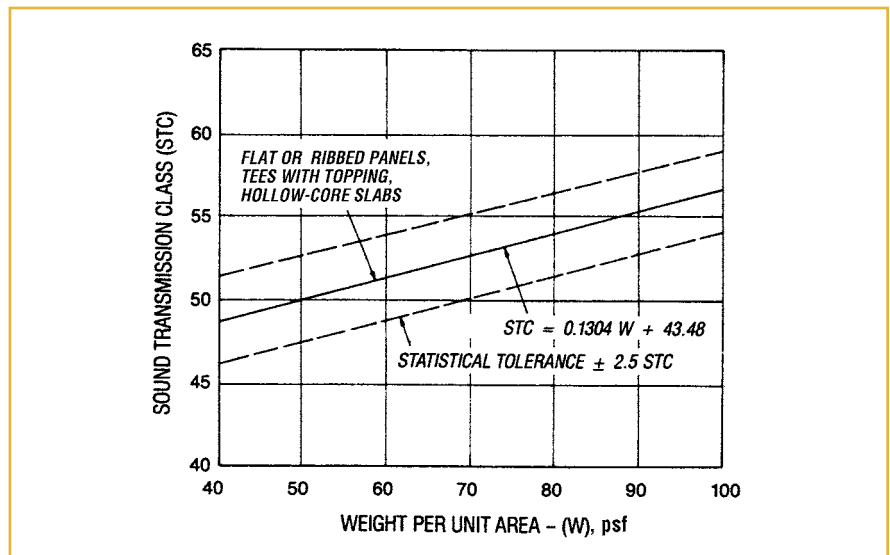


Fig. 1: Sound transmission class as a function of weight of floor or wall.

Precast concrete walls usually do not need additional treatments to provide adequate sound insulation. If desired, greater sound insulation can be obtained by using resiliently attached layers of gypsum board or other building materials. The increased transmission loss occurs because the energy flow path is increased to include a dissipative air column and additional mass (see Reference 6).

A dense, nonporous concrete surface typically absorbs 1% to 2% of incidental sound. Where additional sound absorption is desired, a coating of acoustical material can be spray applied, acoustical tile can be applied with adhesive, or an acoustical ceiling can be suspended. Most of the spray-applied, fire-retardant materials used to increase the fire resistance of precast concrete and other floor-ceiling systems can also be used to absorb sound (see Reference 7).

COMPOSITE WALL CONSIDERATIONS

Windows and doors are often the weak link in an otherwise effective sound barrier. Minimal effects on sound-transmission loss will be achieved in most cases by proper selection of glass. The control of sound transmission through windows requires large cavities between layers (multiple glazing), heavy layers (thicker glass), and a reduction of the structural connection between layers (separate frames and sashes for inner and outer layers).

These penetrations should be designed to be as airtight as possible. Fixed windows usually provide much better sound-transmission control than operable windows. The sound-transmission loss through a door depends on the material and construction of the door as well as on the effectiveness of the seal between the door and its frame.

There is a mass law dependence of STC on weight (psf) for both wood and steel doors. The approximate relationships are:

- For steel doors: $STC = 15 + 27 \log W$
- For wood doors: $STC = 12 + 32 \log W$

In these relationships, W = weight of the door, psf. These relationships are purely empirical, and a large deviation can be expected for any given door.

For best results, the distances between adjacent door and window openings should be maximized, staggered when possible, and held to a minimum area. Minimizing openings allows the wall to retain the acoustical properties of the precast concrete. The design characteristics of the door or window systems must be analyzed prior to writing the project specification.

Such qualities as frame design, door construction, and glazing thickness are vital performance criteria. Installation procedures must be exact and care must be given to the framing of each opening. Gaskets, weatherstripping, and raised thresholds serve as both thermal and acoustical seals and are recommended (see Reference 8).



Alberta Lea High School, Alberta Lea, Minn.; Photo: ©Don F. Wong.

LEAKS AND FLANKING

A building section's performance with an otherwise adequate STC can be seriously reduced by a relatively small hole (or any other path) that allows sound to bypass the acoustical barrier. All noise that reaches a space by paths other than through the primary barrier is called flanking noise.

Common flanking paths are openings around doors or windows, electrical outlets, telephone and television connections, and pipe and duct penetrations. Suspended ceilings in rooms where walls do not extend from the ceiling to the roof or floor above also allow sound to travel to adjacent rooms by flanking.

Anticipation and prevention of leaks begins at the design stage. Flanking paths or gaps at the perimeters of interior precast concrete walls and floors are generally sealed during construction with grout or drypack. All openings around penetrations through walls or floors should be as small as possible and must be sealed airtight. The higher the required STC of the barrier, the greater the importance of sealing all openings.

Perimeter leakage commonly occurs at the intersection between an exterior cladding panel and a floor slab. It is of vital importance to seal this gap to retain the acoustical integrity of the system and provide the required fire stop between floors. One way to seal the gap is to place a mineral-wool blanket covered by sealant between the floor slab and the exterior wall.

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7. Chapter 5, Section 5.5.5, "Acoustical Properties: Absorption of Sound," MNL-122-07: *PCI Architectural Precast Concrete Manual, Second Edition*.
8. Chapter 5, Section 5.5.7, "Acoustical Properties: Composite Wall Considerations," MNL-122-07: *PCI Architectural Precast Concrete Manual, Third Edition*.
9. Chapter 5, Section 5.5.8, "Acoustical Properties: Leaks and Flanking," MNL-122-07: *PCI Architectural Precast Concrete Manual, Third Edition*.

Flanking paths can be minimized in three ways:

1. Interrupt the continuous flow of energy with dissimilar materials, such as with expansion or control joints or air gaps.
2. Increase the resistance to energy flow with floating floor systems, full-height or double partitions, and suspended ceilings.
3. Use primary barriers that are less subject to the creation of flanking paths. Although not easily quantified, an inverse relationship exists between the performance of an element as a primary barrier and its propensity to transmit flanking sound. The probability of existing flanking paths in a concrete structure is much less than in one of steel or wood framing.

If the acoustical design is balanced, the maximum amount of acoustical energy reaching a space via flanking should not equal the energy transmitted through the primary barriers. In exterior walls, the proper application of sealant and backup materials in the joints between units will not allow sound to flank the wall (see Reference 9).

RESOURCES:

- MNL-120-04: *PCI Design Handbook, Sixth Edition*.
MNL-122-07: *PCI Architectural Precast Concrete Manual, Third Edition*.

Safety & Security

Providing a safe and secure structure for owners and users provides key challenges for designers. Integrating these critical functional aspects while meeting aesthetic goals and programmatic needs requires designers to remain up to date on new techniques and systems that can minimize the intrusion of security and safety elements in the overall plan. As security worries rise and Mother Nature continues to show her power, these concerns become key drivers for more clients.

Precast concrete designs can offer protection against fires, earthquakes, hurricanes, tornados, and explosive blasts when design and detailing are correctly applied. The requirements for achieving these goals must be taken into account as early in the design process as possible to maximize the effectiveness of precast concrete's capabilities against each of these issues.



Photo: ©PhotoDisc

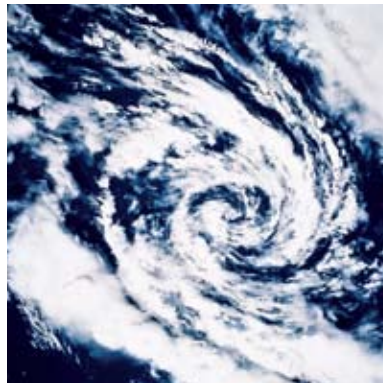


Photo: ©PhotoDisc



FIRE RESISTANCE

A key goal for the design team and the client is to protect the building from the multiple risks and losses caused by fire. A common misconception is that fire destroys by flames, which can be suppressed by sprinklers. In practice, this oversimplification can leave both property and human life vulnerable during a fire.

Among the goals that must be achieved when designing for fire safety are the following:

- **Contain high heat**, which can melt or ignite materials or kill in one breath.
- **Contain smoke that can blind**, choke, and ruin building components and contents. Smoke is often generated by the sprinkler suppression process, and it is unavoidable.
- **Contain toxic gas**, which is given off when plastics, synthetics, and chemicals burn. They can be deadly at any temperature.
- **Confine the fire event** to its place of origin and prevent it from spreading.
- **Reduce the fuel content** of the building by using non-combustible building materials whenever possible.
- **Avoid the potential for structural collapse** during the fire by protecting all structural framing elements that support the building.
- **Create a passive fire-protection strategy** for the building that will enable it to survive should arson, low water pressure, or a delayed fire-department response occur.
- **Divide the building** into several noncombustible compartments that will help achieve solutions for all the aforementioned hazards. This is the most important aspect of all.
- **Recognize that building codes** provide the minimum protection allowable and may not be enough to achieve the fire protection the building and its occupants will need. Each risk exposure requires a defense.



Photo: ©PhotoDisc.

Precast concrete provides noncombustible construction that can help contain a fire within minimal boundaries. As a separation wall, precast concrete helps to prevent a fire from spreading throughout a building or jumping between structures. During wildfires, precast concrete walls help provide protection to human life and the occupant's possessions. As an exterior wall, concrete that endures a fire can often be reused when the building is retrofitted.

The fire endurance of concrete can be determined by its thickness and type of aggregate. The American Society for Testing & Materials (ASTM) E119 lists procedures for determining fire endurance of building materials. Another good resource is PCI's *MNL 124-89: Manual on Design for Fire Resistance of Precast, Prestressed Concrete*.

Fire endurance is defined as the period of resistance to a standard fire exposure as defined by ASTM E119 that lapses before an "end point" is reached. Three end points are critical:

- 1. Structural end point.** Loadbearing components must sustain the applied loading for the duration of the required fire endurance. Collapse prior to that is an obvious end point.
- 2. Heat-transmission end point.** When the temperature increase of the unexposed surface of floors, roofs, or walls reaches an average temperature of 250 °F or a maximum of 325 °F at any one point.
- 3. Flame-passage end point.** Holes, cracks, or fissures allowing flames or gases hot enough to ignite cotton waste to pass through must not form.

Structural End Points

Concrete generally fails by heat transmission long before structural failure, whereas other construction materials fail by heat transmission when collapse is imminent.

Heat-Transmission End Points

For single-course precast concrete slabs or wall panels, a two-hour fire endurance means that thermocouples, measuring the passage of heat through the thickness of the wall, are recording an average temperature rise of 250 °F or a maximum temperature reading of 325 °F (see Reference 1).

Slabs or wall panels faced with protective materials can provide added endurance. The accompanying table shows the fire endurance of concrete slabs with $\frac{5}{8}$ -in. gypsum wallboard (Type X) for two cases:

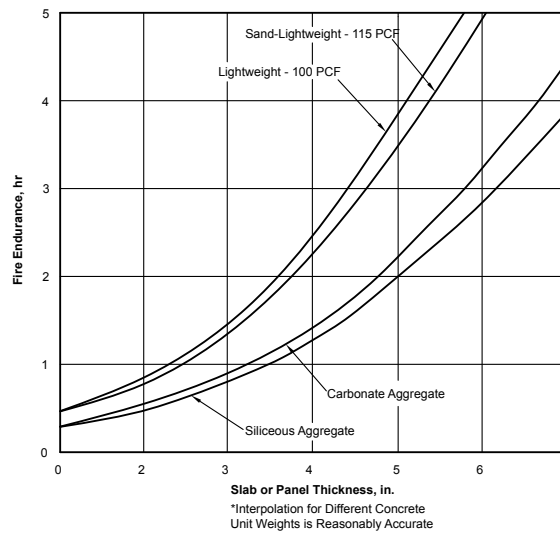
1. A 6-in. air space between the wallboard and slab.
2. No space between the wallboard and slab.

The specified materials and techniques for attaching wallboard should be similar to those used in the test on which the data are based (see Reference 2).

Thickness (in.) of Concrete Panel for Fire Endurance of	With no air space		With 6 in. air space	
	2 hr	3 hr	2 hr	3 hr
Aggregate				
Sand-lightweight	2.5	3.6	2.0	2.5
Carbonate	2.8	4.0	2.0	2.7
Siliceous	2.9	4.2	2.0	2.8

Thickness of concrete slabs or wall panels faced with 5/8 in. Type X gypsum wallboard to provide fire endurances of 2 and 3 hours.

Heat transmission through a ribbed or corrugated panel is influenced by the thinnest portion of the panel and by the panel's "equivalent thickness." This term is defined as the net cross-sectional area of the panel divided by the width of the cross section. In calculating the net cross-sectional area of the panel, portions of ribs that project beyond twice the minimum thickness should be ignored (see Reference 3).



Fire endurance (heat transmission) of concrete slabs or panels

Multi-course assemblies, such as floors and roofs, often consist of concrete base slabs with overlays or undercoatings of other types of concrete or insulating materials. In addition, roofs generally have built-up roofing. If the fire endurance of the individual courses is known, the fire endurance of the composite assembly can be estimated (see Reference 4).

Precast concrete insulated sandwich wall panels must conform to IBC requirements. Those regulations state that where noncombustible construction is specified, combustible elements in walls are limited to thermal and sound insulation having a flame-spread index of 25 or less.

When the insulation is sandwiched between two layers of noncombustible material such as concrete, the maximum flame-spread index allowed is 100, except that it shall not exceed 75 for foam-plastic insulation. When insulation is not installed in this manner, it is required to have a flame spread of not more than 25. Data on flame-spread classifications are available from insulation manufacturers.

Cellular plastics melt and are consumed at about 400 to 600 °F. Thus, additional thickness or changes in composition probably have only a minor effect on the fire endurance of sandwich panels. The danger of toxic fumes caused by burning cellular plastic is practically eliminated when the material is completely encased within concrete sandwich panels. Until more definitive data are provided, PCI recommends that 5 minutes be considered as the value for R for any layer of cellular plastic 1 in. or greater (see Reference 5), where R is the fire endurance rating of an assembly.

Flame-Passage End Points

Joints between panels should be detailed so that passage of flame or hot gases is prevented, and transmission of heat does not exceed the limits specified in ASTM E119. Concrete wall panels expand when heated, so the joints tend to close during fire exposure.

Noncombustible materials that are flexible, such as ceramic-fiber blankets, provide thermal, flame, and smoke barriers. When used with caulking, they can provide the necessary weather tightness while permitting normal volume-change movements. Joints that do not move can be filled with mortar.

Where no openings are permitted, the fire endurance required for the wall should be provided at the joints. Joints between adjacent precast floor or roof elements may be ignored in calculating the slab thickness provided that a concrete topping at least 1½ in. thick is used.

Where no concrete topping is used, joints should be grouted to a depth of at least one-third the slab thickness at the joint, or the joints should be made fire-resistive in a manner acceptable to the authority having jurisdiction. No joint treatment is required for parking structures constructed with pretopped double tees (see Reference 6).

Codes and Economics

An important aspect of dealing with fire endurance is to understand what the benefits are to the owner of a building in the proper selection of materials incorporated in the structure. These benefits fall into two areas: codes and economics. While code requirements must be met, designers typically have many options in the specification of materials and assemblies that meet these regulations.

Economic benefits associated with increased fire endurance should be considered at the time decisions are made on the structural system. Proper consideration of fire-resistive construction through a life-cycle cost analysis will show the owner the amount of economic benefits that will accrue through the use of different types of construction. These benefits can include lower insurance rates, larger allowable gross area, fewer stairwells and exits, increased value for loan purposes, longer mortgage terms, and better resale value (see Reference 7).

Several key areas of code compliance allow owners and designers to provide effective fire protection at an economical cost. The three key areas are:

- 1. Minimum standards.** A fire rating is not the same as fire safety. The IBC includes a variety of compromises. Code trends generally emphasize sprinkler installations by providing trade-offs that encourage their use. These active systems offer valuable protection, but they also include trade-offs such as more liberal fire-separation areas and other changes that decrease required wall and floor performance.
- 2. Building materials.** Wood and steel generally perform poorly in fires. Both must be treated, coated, or covered to meet fire requirements, which increases construction costs. Wood is a natural fuel source and steel begins to fail at 1200 °F. Concrete begins to melt at 2200 °F.
- 3. Sprinklers.** Automatic sprinklers are a desirable, active fire-suppression system and can help control fire spread. But they should not replace passive fire-suppression systems that are designed to inherently protect a building without any mechanical activation required. Relying on active-suppression systems alone can produce an inadequate response during a fire emergency.



A design approach that stresses compartmentalization offers a more fundamental method to protect lives and property. Compartmentalization uses passive, noncombustible floors and walls, such as those made of precast concrete, to construct sections of the building as separate modules that confine fire to a specific area. Once constructed into the building, these passive protectors will protect the building throughout its life.

Noncombustible compartmentalization, combined with an inherently fire-resistant/tolerant structural frame, provide the best combination of economics and protection that owners and users seek. When this passive design combines with other safety measures, including sprinklers and early-warning detection systems, a balanced design approach is achieved (see Reference 8).

A variety of precast concrete components can be used in creating a complete passive-design system for a building. Foremost among these are:

- **Hollow-core slabs**, which serve as combined floor/ceiling systems and can also be used as wall panels in either vertical or horizontal configurations.
- **Wall panels**, which offer high fire ratings and work with other components to create a noncombustible envelope. Insulated sandwich wall panels can also be used.
- **Double tees**, which can be used similar to hollow-core planks for roofs, ceilings, floors, or wall panels.
- **Columns and beams**, which create a framework that will resist intense heat and will not add fuel to a fire.

A total-precast concrete system provides an effective design for minimizing fire damage and containing the effects within the smallest space possible for the longest time.

The information above will provide for a structure with acceptable criteria for fire resistance. The designer and owner should also consider the following factors when designing for fire:

- Contain high heat, which can melt or ignite combustible materials.
- Contain smoke that can blind, choke, and ruin building contents. Smoke is often generated by a sprinkler suppression process which may be unavoidable.
- Contain toxic gases that are given off by plastics, synthetics and chemicals when they burn.
- Confine the fire event to its place of origin by using precast concrete components to create compartments.
- Reduce the fuel content of the building by using noncombustible material whenever possible.
- Create several noncombustible compartments in the building
- Understand that the local minimum code requirements may not be adequate to achieve the fire protection that your building and its occupants should have.



A 2005 study sponsored by the Fire Safe Construction Advisory Council compared construction costs among five building systems and found that a compartmentalized construction approach using concrete-based methods costs generally less than 5% of the overall construction cost. The group noted that this amount was less than the contingency budget typically recommended for the owner to carry for unanticipated expenditures during the project.





The project evaluated the impact of building a fire-resistant, multifamily, residential structure using five separate building techniques, to meet requirements of the 2003 IBC. The five systems comprised:

- Conventional wood framing with a wood-floor system using Type 5A or 5B construction;
- Light-gage steel framing with a cast-in-place concrete floor system on a metal form deck;
- Loadbearing concrete masonry construction with a precast concrete plank floor system or a cast-in-place concrete floor system;
- Precast concrete walls with a precast concrete floor system; and
- Insulated concrete form (ICF) walls or interior bearing walls made with concrete masonry units (CMU) with a precast concrete plank floor system or a cast-in-place concrete floor system.

In each case, except the conventional wood-frame system, it was assumed that the partition walls within the building would be constructed using metal studs finished with gypsum board.

The studied building was a four-story structure encompassing 25,000 ft² of space per floor. Two models were created, one with single-bedroom layouts and another with a mix of one- and two-bedroom layouts to address the variety of construction configurations commonly found in the multifamily dwelling marketplace. The team chose three specific locations in which to locate their projects (Framingham, Mass.; Harrisburg, Pa.; and Towson, Md.) to provide diversity in labor and material costs.

The study's consensus was that the costs associated with using a compartmentalized construction method that took advantage of precast concrete's benefits required less than 2% more of the total construction cost.

In addition, although precast concrete's initial in-ground cost was higher, the design did not fully play to the advantages that a total-precast concrete design would offer, as the designers created a layout that could be standardized for use by all material options. Those general parameters would not be necessary if a design intended to use precast concrete from the beginning, and the difference in costs would be lower.

The costing parameters were also unable to take into consideration the schedule advantages that precast concrete's fast erection would provide. Additional advantages, including longer span capability to reduce columns, can provide sufficient cost effectiveness to eliminate the cost differential.

The use of concrete materials can also provide long-term benefits, the report noted. Materials like concrete masonry, precast concrete, and cast-in-place concrete offer advantages beyond their inherent fire performance, such as

resistance to mold growth and damage from vandalism, as well as minimal damage caused by water and fire in the event of a fire. Those attributes can require reduced cleanup costs and quicker reoccupation of the structure (see Reference 9).



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MNL-122-07: *PCI Architectural Precast Concrete Manual, Third Edition*.
MNL-124-05: *Design for Fire Resistance of Precast Prestressed Concrete, Third Edition*.
MNL-126-98: *Manual for the Design of Hollow-Core Slabs, Second Edition*.

PCI JOURNAL:

"Are We Protected From Fire in Buildings?" *PCI Journal*, January-February 2005, pp. 118-123.

EARTHQUAKE RESISTANCE

Precast concrete can be designed to resist seismic events, and recent advancements in connection approaches provide additional design options.

Earthquakes in Guam, the United States (Richter scale 8.1); Manila, the Philippines (Richter scale 7.2); and Kobe, Japan (Richter scale 6.9), have subjected precast concrete buildings, using both architectural cladding and structural components, to some of nature's deadliest forces. During the 1994 Northridge, Calif., earthquake (Richter scale 6.8), in which damage was estimated at \$20 billion, most engineered structures within the affected region performed well, including structures with precast concrete components.

In particular, significant damage was not observed in precast concrete cladding due to either inadequacies of those components or inadequacies of their connections to the building's structural systems, nor was damage observed in the precast concrete components used for the first floor or first-floor support of residential housing. Parking structures with large plan areas, regardless of structural system, did not perform as well as other types of buildings (see Reference 1).

The key reason designers have gravitated toward precast concrete components is because they can span long distances between attachments to the main structure. Design methods and details have been developed to accommodate these applications in seismic areas.

Earthquakes generate horizontal and vertical ground movement. When the seismic waves pass beneath a structure, the foundation tends to move with the ground, while the superstructure remains in position. The lag between foundation and superstructure movement causes distortions and develops forces in the structure. As the ground moves, distortions and forces are produced throughout the height of the structure, varying with the ground acceleration and the resonance of the building.

Ductility Needs

The current philosophy for the design of earthquake-resistant structures permits minor damage for moderate earthquakes and major damage for severe earthquakes, provided complete collapse is prevented. The design details often require large, inelastic deformations to occur to dissipate energy and shed inertial forces. This is achieved by providing member and connection ductility.

While this ductility helps resist total collapse, the resulting distortions may lead to significant damage to mechanical, electrical, and architectural elements. Seismic damage can be minimized by setting limitations on structural deflections, usually considered as interstory drift.

The response of a structure to the ground motion of an earthquake depends on the structural system's dampening characteristics and on the distribution of its mass. With mathematical idealization, a designer can determine the probable response of the structure to an imposed earthquake.



The Paramount's use of a precast hybrid, moment-resisting frame as part of its structural system is that it creates a restoring force provided by its elastic, post-tensioned strands that rights the building following a seismic event. Architect of Record: Kwan Henmi, Architecture/Planning; Photo: David Wakely Photography.

New Code Requirements

A number of changes have been made to existing codes in recent years based on new research and observations. These include:

- Recognition of jointed-panel construction as an alternative to emulation of monolithic construction.
- Achieving ductile structural behavior by using “strong” connections that remain elastic while nonlinear action (plastic hinging) occurs in the member away from the connection.
- Modification of drift computation and limiting drift.
- Deformation compatibility of structural elements and attached nonstructural elements.
- Additional soil-type classifications.
- Special considerations for building sites located near seismic faults.
- Special considerations for structures possessing redundancy.

(See Reference 2.)

PCI has worked in several of these areas to help create new design solutions that provide more effective responses to seismic events. A 10-year study by the Precast Seismic Structural Systems (PRESSSS) Research Program produced three new approaches that have been or are in the process of being codified. These three systems are:

1. A hybrid post-tensioned precast frame, which was codified in 1999.

Developed by the National Institute of Standards & Technology (NIST), this method has the precast concrete beams connected to multistory columns by unbonded, post-tensioned strands that run through a duct in the center of the beam and through the columns. Mild steel reinforcement is placed in ducts at the top and bottom of the beam, which is sleeved through the column and grouted.

The reinforcement yields alternately in tension and compression and provides energy dissipation, while the post-tensioning strands essentially act as “rubber bands” that help right the structure after the seismic event ends. There are no column corbels, with the vertical shear resistance provided by the post-tensioning strand. The post-tensioning steel balances the mild steel reinforcement so the frame re-centers after flexing during a seismic event (see Reference 3).

2. A pretensioned precast frame, which is applied at locations where the most economical connection method features one-story columns with multispan beams. The multispan beams are cast with partially debonded pretensioning strand set on the columns. The column's reinforcing steel extends through the sleeves inside the beams. Reinforcing-bar splices ensure continuity above the



A moment-frame beam form illustrates the center PVC duct that holds the prestressing tendons and the six corrugated tubes for the mild steel bars used in the hybrid system.



Rigorous tests performed on an experimental structure proved the success of the PRESSS program's connection technology.

beam. As the frame displaces laterally, the debonded strand remains elastic. While the system dissipates relatively less energy than other systems, it re-centers the structure after a major seismic event (see Reference 4).

Although this frame has performed satisfactorily in tests, it would not be allowed to act as the sole seismic-force-resisting system in regions of high seismic risk or for structures assigned to high seismic-performance or design categories under Section 21.6.3 of ACI 318.

Such frames can be designed to satisfy all requirements for use as intermediate moment frames. These frames should also be acceptable for intermediate moment frames when designed using the same factors as those specified in the governing building code for cast-in-place concrete construction.

Analyses are still being done to verify the applicability of this system to various high seismic events. In the interim, the satisfactory performance of the frames in the PRESSS tests can be used to seek building-department approval for these designs in moderate seismic-risk zones and for structures assigned to intermediate seismic performance or design categories (see Reference 5).

3. A shear-wall system. The PRESSS shear-wall design used an innovative approach for anchoring and connecting jointed walls to lengthen the structural period and reduce the design-based shear forces. Gravity loads were mobilized to partially resist overturning from the lateral ground motions. The system also considered the behavior of the jointed shear-wall system when the wall lifts off and rocks, along with its effect on design forces. An important level of hysteretic damping was added to the wall system through the connection devices located at the vertical joint between the wall panels.

U-shaped flexure plates were used for vertical joint-connection devices where damping was achieved with flexural yielding of the plates. Unbonded post-tensioning forces re-centered the wall system when the load was removed, so there would be minimal residual drift after a design-level earthquake. Re-centering was ensured by relating the elastic capacity of the post-tensioning system to the yield strength of the panel-to-panel connection.

The shear wall is expected to displace laterally to approximately 2% of story drift under a design-level earthquake. This is consistent with the drift limits specified by existing standards. Should the designer desire smaller design-story drift or less energy dissipation, the balance of post-tensioning and energy-dissipating connections could be altered (see Reference 6).

This shear-wall design and test has led to the adoption of an allowance for nonemulative design of special precast concrete shear walls to be accepted for the 2003 edition of the National Earthquake Hazard Reduction Program (NEHRP) Provisions (see Reference 7).

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1. "Achieving Sustainability with Precast Concrete," *PCI Journal*, January-February 2006, pp. 42-61.
2. Chapter 3.2.4, "Earthquake Loads," MNL-120-04: *PCI Design Handbook, Sixth Edition*.
3. "Precast Seismic Innovations Aid Designs Across Nation," *ASCENT*, Winter 2000, pp. 16-23.
4. "Precast Seismic Innovations Aid Designs Across Nation," *ASCENT*, Winter 2000, pp. 16-23.
5. "Codification of Precast Seismic Structural Systems: An Update," *PCI Journal*, May-June 2006, pp. 46-49.
6. "Precast Seismic Innovations Aid Designs Across Nation," *ASCENT*, Winter 2000, pp. 16-23.
7. "Codification of Precast Seismic Structural Systems: An Update," *PCI Journal*, May-June 2006, pp. 46-49.

Contract Document Requirements

Many precast concrete buildings are designed by a team including the engineer of record, the precast manufacturer's engineer, and possibly a specialty engineer retained by the manufacturer. It is the engineer of record's responsibility to provide pertinent information on the contract documents so that others providing the seismic design of the structure use the correct information for the location of the project. The 2006 International Building Code indicates what these requirements are in Section 1603.

RESOURCES:

IBC-1-01: Impact of the Seismic Design Provisions of the International Building Code.
MNL-120-04: *PCI Design Handbook, Sixth Edition*.
MNL-122-07: *PCI Architectural Precast Concrete Manual, Third Edition*.
MNL-123-88: *Design and Typical Details of Connections for Precast and Prestressed Concrete, Second Edition*.

ASCENT:

"Apartment Skyscraper Shows Precast's Seismic Capabilities," *ASCENT*, Summer 2000, pp. 40-43.
"Newly Proven Seismic Connections Impact Designers and Owners," *ASCENT*, Spring 2000, pp. 38-40.
"The Paramount, Special Awards," *ASCENT*, Fall, 2002, p. 7.
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"Behavior of Connections and Floor Diaphragms in Seismic-Resisting Precast Concrete Buildings," *PCI Journal*, March-April 2005, pp. 56-75.
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"Ductile Connections in Precast Concrete Moment Resisting Frames," *PCI Journal*, May-June 2006, pp. 66-77.
"Hybrid Post-Tensioned Precast Concrete Walls for Use in Seismic Regions," *PCI Journal*, September-October 2002, pp. 36-59.
"A Hybrid Reinforced Precast Frame for Seismic Regions," *PCI Journal*, March-April pp. 20-33.
"Requirements for the Use of PRESS Moment-Resisting Frame Systems," *PCI Journal*, March-April 2004, pp. 98-103.
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"Seismic Design Methodology for Precast Concrete Diaphragms Part 1: Design Framework," *PCI Journal*, September-October 2005, pp. 68-83.
"Seismic Design Methodology for Precast Concrete Diaphragms Part 2: Research Program," *PCI Journal*, November-December 2005, pp. 14-31.
"Seismic Design Provisions in U.S. Codes and Standards: A Look Back and Ahead," *PCI Journal*, January-February 2002, pp. 94-99.
"Seismic Design Recommendations for Precast Concrete Diaphragms in Long Floor Span Construction," *PCI Journal*, November-December 2003, pp. 46-64.
"Seismic Tests of Beam-to-Column Connections in a Precast Concrete Frame," *PCI Journal*, May-June 2002, pp. 70-89.
"Structural and Economic Benefits of Precast/Prestressed Concrete Construction," *PCI Journal*, July-August 2001, pp. 34-43.
"Trends in the Seismic Design Provisions of U.S. Building Codes," *PCI Journal*, September-October 2001, pp. 98-103.
"Untopped Precast Concrete Diaphragms in High-Seismic Applications," *PCI Journal*, November-December 2002, pp. 94-99.

WIND RESISTANCE (TORNADOS AND HURRICANES)

In most areas of the United States using IBC 2003, the earthquake loading will be more critical than wind. But wind loads should be checked, and more emphasis today is being put on designing structures to withstand tornado and hurricane impacts, certainly in coastal areas where they are being addressed through supplemental codes and other local requirements.

Precast concrete structural systems and architectural panels provide significant benefits in meeting wind-resistance needs. A calculation for determining proper windloads for precast concrete structures can be found in MNL-120-04: *PCI Design Handbook, Sixth Edition* (see Reference 1).

Tornados

Single-family homes provide the greatest danger of destruction during a tornado. In regions of the country where tornados can wreak havoc on single-family homes, precast concrete designs can provide a durable, wind-resistant structure. Several key elements are desired in designing a home to resist tornado damage. These include:



Eight-four unit assisted-living facility built to withstand an F-4 tornado. Photo: Dukane Precast Inc.

- Connections that securely tie the house together from roof to foundation, providing protection for winds up to 130 mph.
- Impact-resistant roof materials that better withstand high winds and fire.
- Windows and doors with higher wind- and water-design pressure ratings and a garage door capable of withstanding impact from large objects.
- Construction materials and siting work that eliminate the threat of flood or wildfire.

A number of designers and precasters have worked together to create precast concrete housing designs across the country. These designs not only protect homes from wind damage but also cut energy costs, are constructed quickly and provide a range of aesthetic designs that can blend with any neighborhood (see Reference 2).

A variety of precast concrete components are used to create tornado-resistant housing. These include foundation walls, loadbearing precast concrete wall panels with an architectural finish, and hollow-core plank for floors and roofing. Precast concrete's inorganic and noncombustible composition ensure the housing will not generate mold or mildew following torrential rains, nor will they catch on fire should sparks ignite flammables.

Hollow-core plank is a key component in housing. Typically, one thickness is used as the lower level's ceiling and the upper level's floor. It is also used as the roofing substructure, again serving as the ceiling of the lower level at the same time. The long spans available with hollow-core planks are particularly useful for opening up interiors while providing a safe room for protection from high winds.

Precast concrete panels offer several different uses in housing designed to withstand tornados, including façades and foundation walls. Insulated panels, typically 10 by 16 ft in size, are used as foundation walls, with an insulating board on their back (interior) side. The walls offer more than twice the strength of concrete-block walls (5000 psi compared to 2000-2400 psi) and minimize seams through which moisture can penetrate.

Precast concrete homes provide significantly more protection from wind-borne debris than other building materials, according to tests conducted by the Portland Cement Association. The group tested various walls with the impact of a 2x4 wood stud traveling at 100 mph, the equivalent of wind-borne debris during a tornado with 250-mph winds. About 90% of tornados have wind speeds of less 150 mph, the group says. Of all materials tested, only the concrete design stopped the debris from penetrating the wall. All others suffered penetration (see Reference 2).

The actual cannon used. Spectators even got to touch the 2 x 4 to confirm the authenticity. In the distance are the panels ready to be tested with the safety wall behind.
Photos: Susan Leader.



In test one, the 2 x 4 went through this vinyl sided, wood-frame wall panel like a hot knife through butter. Notice the entry, and the exit holes. Not only are they clean holes, but it didn't even slow the projectile down.

Note as well the significant hole in the safety wall behind the panel in the photo to the right.





Test two shot the 2 x 4 through a brick wall with wood frame. Surprisingly, it's not all that much safer than siding. What you don't see are the pieces of brick that went flying through the back side of the panel. This wall introduced even more projectiles into the house.



Test three smashed a 2 x 4 through a brick home with steel framing. This damage is still rather significant, but in this test the projectile did not travel through the wall. Looking at the back side shows it would take only slightly more force to push all the way through.



Now for the real test: hurl a 2 x 4 at a precast wall panel at 112 mph. The result: no damage visible, not even a chip.

Wall Type:	Test Wall Description:	Speed of Debris:	Results:
Wood frame:	⁵ / ₈ -in. gypsum board interior finish, 2x4 wood studs at 16 in. o.c., 3 ¹ / ₂ -in. batt insulation, ³ / ₄ -in. plywood sheathing, vinyl-sided exterior finish	109 mph	The debris missile perforated completely through the wall assembly. Little damage to missile.
	⁵ / ₈ -in. gypsum board interior finish, 2x4 wood studs at 16 inches o.c., 3 ¹ / ₂ -in. batt insulation, ³ / ₄ -in. plywood sheathing, 4-in. brick veneer with 1-in. air space	69.4 mph	The debris missile perforated completely through the brick veneer and the interior finish. Minor damage to missile.
Steel frame:	⁵ / ₈ -in. gypsum board interior finish, steel studs at 16 in. o.c., 3 ¹ / ₂ in. batt insulation, ³ / ₄ -in. plywood sheathing, vinyl-sided exterior finish	103.5 mph	The debris missile perforated completely through the wall assembly. Little damage to missile.
	⁵ / ₈ -in. gypsum board interior finish, 2x4 wood studs at 16 in. o.c., 3 ¹ / ₂ -in. batt insulation, ⁵ / ₈ -in. gypsum board sheathing, synthetic stucco exterior finish	50.9 mph	The debris missile perforated completely through the wall assembly. No damage to missile.
Concrete:	6-in.-thick reinforced concrete wall, #4 vertical reinforcing bars, 12 in. o.c, no finishes	109 mph	No cracking, front-face scabbing, or back-face spalling of concrete seen.
	6-in.-thick reinforced concrete wall, #4 vertical reinforcing bars, 24 in. o.c, no finishes	102.4 mph	No cracking, front-face scabbing, or back-face spalling of concrete seen.
ICF:	Block ICF foam forms, 6-in.-thick flat concrete wall, #4 vertical reinforcing bars, 12 in. o.c., vinyl siding (tested twice with similar results)	103.8 mph	Debris penetrated vinyl siding and foam form. No cracking, front-face scabbing, or back-face spalling of concrete wall seen.
	Block ICF foam forms, 6-in.-thick flat concrete wall, #4 vertical reinforcing bars, 24 in. o.c., 3-in. brick veneer with ties spaced 1 in. each way	99 mph	Debris penetrated and cracked brick veneer. Foam form dented. No cracking, front-face scabbing, or back-face spalling of concrete wall seen.
	Panel ICF foam forms, 4-in.-thick flat concrete wall, #4 vertical reinforcing bars, 24 in. o.c., vinyl siding	96.7 mph	Debris penetrated vinyl siding and foam form. No cracking, front-face scabbing, or back-face spalling of concrete wall seen.
	Block ICF foam forms, variable thickness "waffle" concrete wall, 6 in. maximum thickness, and 2 in. minimum thickness, #4 vertical reinforcing bars in each 6-in. vertical core at 24 in. o.c, synthetic stucco finish (tested twice with similar results)	100.2 mph	Debris penetrated synthetic stucco finish and foam form. Impact of wall at 2-in.- thick section. No cracking, front-face scabbing, or back-face spalling of concrete wall seen.

*Note: All concrete tested had 3000-psi compressive strength with a maximum aggregate size of 3/4 in. with a 6-in. slump.
Source: Portland Cement Association*

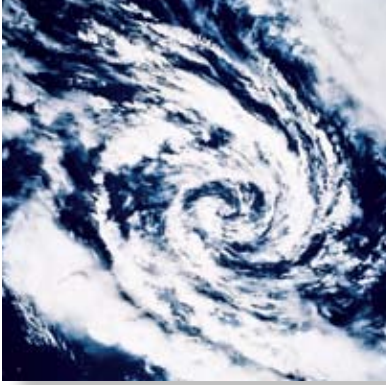
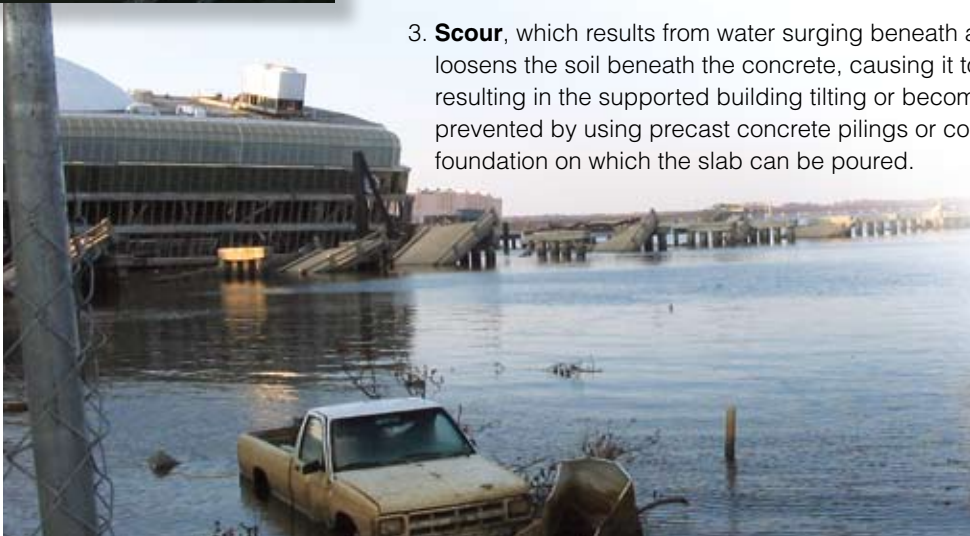


Photo: ©PhotoDisc.

Much of the damage done to precast concrete parking structures along the Gulf Coast by Hurricane Katrina was caused by the high storm surge, which flooded the structures and caused double tees to be pushed off their supports. Otherwise, the material performed well. (Three photos below).



Hurricanes

The devastating impact of recent hurricanes, notably Katrina and Rita, have put a spotlight on designing to withstand the highest levels of these forces, which are more complex than those associated with tornados. Hurricanes produce not only high winds but also forces associated with the impact from high waves and immense amounts of water overwhelming a structure.

Precast concrete components can help to withstand these forces if designers take into account all of the actions involved and how the components must react to them. The factors that designers must consider include:

1. **High winds**, which can be dealt with similarly to those in tornados and do not pose a substantial risk for buildings built of precast concrete. Examination of projects exposed to the high winds of Hurricane Katrina indicated that wind loads for precast concrete buildings were well accounted for. Wind-borne debris creates the largest problem and results in only chipping or cracking in some instances at the high end of the wind speeds.

To be certain of withstanding wind loads in these high-risk areas, designers should overcompensate for potential problems. Designing for a 200-mph wind and using reinforcement to meet that level of force should protect the structure under any situation. Modifying designs to reduce surface area will also help to ensure that wind loads do not create a problem.

2. **Surge**, in which large amounts of water rush over the land and up to buildings. Often, this water carries with it loose debris that can be substantial in nature and can act as a battering ram against a building. In some cases, if the surge is high enough, the debris can impact the building at a height that was not designed to withstand such force. This can cause damage to the stems on double tees, particularly on parking structures. Creating a precast concrete soffit or other protective shield that prevents large debris from surging through the structure at such a height can mitigate this concern.
3. **Scour**, which results from water surging beneath a slab on grade. This action loosens the soil beneath the concrete, causing it to deteriorate or break up, resulting in the supported building tilting or becoming unstable. This can be prevented by using precast concrete pilings or columns to create a stable soil foundation on which the slab can be poured.

REFERENCES:

1. Chapter 3.2.2, "Wind Loads," MNL-120-04: *PCI Design Handbook, Sixth Edition*.
2. "Designing for Hurricane Zones," *ASCENT*, Summer 2006, pp. 20-25.
3. "Achieving Sustainability with Precast Concrete," *PCI Journal*, January-February 2006, pp.42-61.

RESOURCES:

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ASCENT:

"All-Precast Concrete Residences Benefits Developers, Homeowners," *ASCENT*, Summer 2002, pp. 28-30.

"Archer Courts Townhouses, Building Awards," *ASCENT*, Fall 2005, p. 32

"Designing for Hurricane Zones," *ASCENT*, Summer 2006, pp. 20-25.

"Precast Lofts Help Build Chicago Neighborhood," *ASCENT*, Summer 2003, pp. 16-19.

"Precast Design Adds Safety To Residences," *ASCENT*, Spring 2005, pp. 18-22.

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PCI JOURNAL:

"NU Precast Concrete House Provides Spacious and Energy-Efficient Solution for Residential Construction," *PCI Journal*, May-June 2005, pp. 26-39.

"Project Study: Archer Courts Townhouses, Chicago, Illinois," *PCI Journal*, November-December 2005, pp. 96-101.

"University Village Mid-Rise Condominiums, Chicago, Illinois," *PCI Journal*, May-June 2005, pp. 108-111.

4. **Buoyancy**, in which the water levels rise above the first floor of a structure, such as a parking structure, where the levels are supported by double tees. Designs typically do not account for tees being lifted from their position. Connections must account for this possibility in the areas of the highest concern.

5. **Structure orientation**, which should provide the smallest exposure to the likely direction of a hurricane in areas most likely to be hit. Interiors also should take the concept of surging water into account. For instance, in parking structures, ramps should be faced away from the ocean to allow water to flow through the structure rather than be blocked by it. Creating fewer obstacles for the likely path that water will follow during a hurricane will minimize damage.

Salt-water damage, in the form of corrosion or deterioration of the components after water recedes, should not create a long-term problem. In many instances, precast concrete components produced for these marine environments already include additives that hinder the potential for corrosion.

Home Designs

Designing homes for wind loads can follow the same concepts as expressed for tornado designs, and these concepts are available throughout the country from precasters. Meeting the needs for protecting against surging water requires additional consideration.

With surges in New Orleans, La., of 12 ft or more, one design option is to use precast concrete piles or columns to create a first-level garage on top of which the living space can be created, using precast concrete panels to create the shell.

The home still can have wood and drywall interior framing, although if the surge or other water damage reaches the interior, all these materials may have to be completely removed to remediate mold. Even then, the shell and structural integrity remain intact, eliminating the need to start from scratch (see Reference 2).

Concrete is not damaged by water. In fact, concrete that does not dry out continues to gain strength in the presence of moisture. Concrete submerged in water absorbs small amounts of water over long periods of time, and the water does not damage the concrete. In flood-damaged areas, concrete buildings are often salvageable.

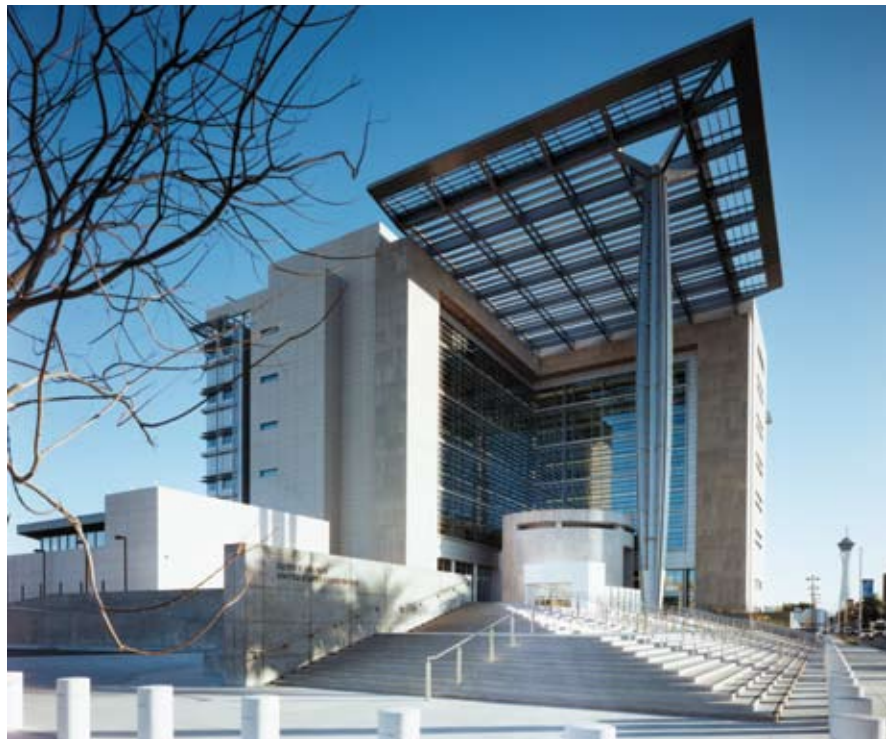
Concrete will only contribute to moisture problems in buildings if it is enclosed in a system that does not let it breathe or dry out, and moisture is trapped between the concrete and other building materials. For instance, vinyl wallcoverings in hot and humid climates will act as a vapor retarder, allowing moisture to become trapped between the concrete and wall covering. For this reason, impermeable wallcoverings (vinyl wallpaper) should not be used (see Reference 3).

EXTERNAL BLAST RESISTANCE

In today's environment of enhanced risk, some facilities require protective design and the management of risk. There are many design options available to reduce the risk to any building. Economically feasible design for antiterrorism/force protection (AT/FP) requires an integrated approach encompassing many aspects of the development, including siting, operation programming of interior spaces, and the use of active and passive security measures using provisions of both technology and human involvement.

The objective of blast-resistant design is to provide an acceptable level of safety to building occupants in the event of an explosion. Considerable damage is usually acceptable as long as components remain attached to the building and the building does not experience a progressive collapse.

Planning must include all involved members of the design team (owners, architects, structural engineers, and blast consultants). They must agree upon the blast forces to be withstood as well as the risk and vulnerability assessment to the occupants and the protection levels that can be achieved within budget.



Lloyd D. George Federal Courthouse, Las Vegas, Nev.; Architect: Langdon Wilson; Photo: Langdon Wilson.

The first major federal courthouse built after the 1995 blast in Oklahoma City contains features intended to avoid a catastrophic collapse in the event of a terrorist attack. The precast concrete panels were designed to be more ductile than conventional panels so they could absorb as much of a bomb blast as possible without destroying the connections that tie them to the main structure. Note: Bollards used to increase the standoff distance.

Probability Considerations

An awareness of a blast threat from the beginning of design helps to make decisions early about what the priorities should be for the facility. Including protective measures as part of the discussion regarding trade-offs early in the process helps to clarify the issues.

The willingness to pay the additional cost for protection against blast hazards is a function of the “probability of regrets” in the event that a sizable incident occurs. In some situations, with some buildings, the small probability of an incident may not be compelling enough to institute the design enhancements.

This logic will likely lead to a selection process in which buildings stratify into two groups: those that incorporate no measures at all or only minimal provisions and those that incorporate high levels of protection. It also leads to the conclusion that it may not be appropriate to consider any but the most minimal measures for most buildings.

Key Considerations

Unlike seismic and wind loads, blast loads have an extremely short duration (i.e., milliseconds). Often, the large mass associated with the overall building response provides enough inertia so the building’s framing does not need to be strengthened to resist blast loads. The lateral force-resisting system on smaller one- and two-story buildings generally needs to be designed to resist blast loads. Conventional foundation systems are almost always adequate to resist the short-duration reaction loads from building response to blast loads.

Quantifying blast events into overpressures and time durations is a science of its own. Blast engineers should be consulted when explosion scenarios are to be considered in the building’s design.

A key consideration will be designing the building’s façade, which is the structure’s first defense against an exterior explosion. How the façade responds to this loading will significantly affect the structure’s behavior. The need for comprehensive protection of occupants within the structure will likely cause window sizes to decrease in height and width and increase in thickness. Attachments likewise will become more substantial.

Architectural precast concrete can be designed to mitigate the effects of an explosion and thereby satisfy requirements of the General Services Administration (GSA) and the Department of Defense (DOD). Protecting the entire façade, however, will impose a great cost regardless of the material used. To provide the best protection for occupants, designers should plan for the building and its cladding to remain standing or attached long enough to protect occupants from injury or death resulting from flying debris and to evacuate everyone safely (see Reference 1).

The shape of the building can affect the overall damage. A U- or an L-shaped building can trap the shock wave, which may increase blast pressure locally because of the complex reflections created. Large or gradual re-entrant corners have less effect than small or sharp re-entrant corners. In general, convex rather than concave shapes are preferred. The reflected pressure on the surface of a circular building is less intense than on a flat building (see Reference 2).

Currently, no specific standards or guidelines exist for blast design from either the American Concrete Institute (ACI) or the PCI.

All building components requiring blast resistance should meet the criteria required for GSA or DOD facilities. They should be designed using established methods and approaches for determining dynamic loads and dynamic structural response. Design and analysis approaches should be consistent with the following manuals:

- U.S. Departments of the Army, Navy and Air Force, “Structures to Resist the Effects of Accidental Explosions,” Revision 1 (Department of the Army Technical Manual TM 5-1300, Department of the Navy Publication NAVFAC P-397, Department of the Air Force Manual AFM 88-22).
- DAHSCWEMAN, “Technical Manual – Design and Analysis of Hardened Structures to Conventional Weapon Effects; PSADS (Protective Structures Automated Design System), Version 1.0.” (It incorporates Army TM 5-855-1, Air Force AF JMAN32-1055, Navy NAVFAC P-1080, and Defense Special Weapons Agency DAHSCWEMAN-97).
- Unified Facilities Criteria, “Design and Analysis of Hardened Structures to Conventional Weapons Effects,” U.S. Department of Defense, UFC 3-340-01, June 2002.
- Hyde, D. “ConWep – Application of TM5-855-1,” U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss., August 1992.
- U.S. Department of the Army, Security Engineering, TM 5-853 and Air Force AFMAN 32-1071, Volumes 1-4, Washington, DC, Departments of the Army and Air Force, 1994.
- Air Force Engineering & Services Center, “Protective Construction Design Manual,” ESL-TR-87-57, Prepared for Engineering & Services Laboratory, Tyndall Air Force Base, Fla., November 1989.
- U.S. Department of Energy, “A Manual for the Prediction of Blast & Fragment Loadings on Structures,” Revision 1, DOE/TIC 11268, Washington, DC, Headquarters U.S. Department of Energy, July 1992.
- Unified Facilities Criteria, DOD Minimum Antiterrorism Standards for Buildings, UFC 4-010-01, U.S. Department of Defense, July 2002.
- Interim Antiterrorism/Force Protection Construction Standards – Guidance on Structural Requirements (Draft), U.S. Department of Defense, March 5, 2001.

Designing for blast resistance requires a comprehensive knowledge of explosive effects and fortification sciences, as described in DAHSCWEMAN (1998), in Technical Manual (TM) 5-855-1 (U.S. Department of the Army 1998), and in the Tri-Service Manual (TM-5-1300, U.S. Department of the Army, Navy, and Air Force 1990). The electronic version of the DAHSCWEMAN manual will greatly assist in applying blast-design concepts.

The report “Design for Physical Security—State of the Practice Report,” prepared by the Structural Engineering Institute Task Committee, American Society of Civil Engineers (1999), addresses the design of structures to resist the effects of terrorist bombings and provides guidance for engineers (see Reference 3).

Creating Standoff Distance

Basic protection is produced by creating a minimum guaranteed distance between the blast source and the target structure. The setback zone restricts vehicular access by using dense components such as perimeter anti-ram bollards, large planters, low-level walls, or fountains. Creating this standoff distance helps minimize the design requirements for protecting the building cladding and structural elements.

The blast pressure is inversely proportional to the cube of the distance from the blast to the point in question. Current design standoff distances for blast protection vary from 33 ft to 148 ft, depending on the building's function.

The four lowest stories of the building will be most impacted by a street-level blast and must follow accepted blast criteria. Those criteria are described in "Security Design Criteria for New Federal Office Buildings and Major Renovation Projects," issued May 28, 2001, by the Interagency Security Committee (ISC).

When designing with architectural precast concrete panels, designers should combine these criteria with the applicable blast-analysis standards. This combination ensures that the architectural precast concrete cladding system will be sufficiently sized, reinforced, detailed, and installed to resist the required blast-loading criteria.

The panels should also be tested in accordance with "Standard Test Method for Glazing and Window Systems Subject to Dynamic Overpressure Loadings (GSA-TS01-2003), released by the General Services Administration.

In addition to safely transferring the blast pressures into the supporting structure, the panels must be checked for their capacity to transfer the additional loading caused by the specified window framing and the blast-resistant glass units (see Reference 4).

Preventing Progressive Collapse

Several significant factors must be considered when designing buildings for blast resistance. These concepts include energy absorption, safety factors, limit states, load combinations, resistance functions, structural-performance, and structural redundancy to prevent progressive collapse of the building. This final one is most important, as a design satisfying all required strength and performance criteria would be unsatisfactory without redundancy.

To limit the extent of collapse of adjacent components requires five steps:

1. Highly redundant structural systems are designed.
2. The structure is analyzed to ensure it can withstand removal of one primary exterior vertical or horizontal load-carrying element, such as a column, beam, or portion of a loadbearing or shear-wall system without complete collapse of the entire structure.
3. Connections are detailed to provide continuity across joints equal to the full structural capacity of connected members.



Nimitz-MacArthur Pacific Command Center, Oahu, Hawaii; Architect: Wimberly Allison Tong & Goo Design; Photo: Gary Hofheimer Photography.

4. Floors are designed to withstand load reversals due to explosive effects.
5. Exterior walls use one-way wall components spanning vertically to minimize blast loads on columns.

Strength and ductility (energy-dissipating capacity) are necessary to achieve high energy absorption. The structural materials and details must accommodate relatively large deflections and rotation to provide redundancy in the load path. Components with low ductility are undesirable for blast-resistant design.

Margins of safety against structural failure are achieved by using allowable deformation criteria. Structures subjected to blast loads are typically allowed to undergo permanent plastic deformation to absorb the explosion energy, whereas response to conventional loads is normally required to remain in the elastic range. The component's response is determined by how much deformation it is able to undergo before failure.

The more deformation the structure or member can provide, the more blast energy it can absorb. As long as the calculated deformations do not exceed the allowable values, a margin of safety against failure exists (see Reference 5).

Rigidity versus Ductility

A balance must be found between panel stiffness and the forces that the panel connections must resist. The proper balance must be evaluated by the structural engineer. Typically, the panels should have increased section thickness or ribs and have additional reinforcement, which should be placed on both faces of the panel to resist load reversals. However, the amount of flexural reinforcing should be limited so that tensile reinforcing yields before concrete crushing can occur. Shear steel can help increase shear resistance, confine the flexural reinforcing, and prevent buckling of bars in compression. The mode of failure should be that of the panel itself in flexure and not failure of the connections or a shear failure of the panel.

A minimum panel thickness of 5 in., exclusive of reveals, should be designed. The panels also should include two-way reinforcing bars spaced not greater than the panel's thickness to increase ductility and reduce the chance of flying concrete fragments. The thinnest panel thickness acceptable for conventional loads should be used. The objective is to reduce the loads transmitted into the connection, which must resist the panel's ultimate flexural resistance (see Reference 6).

The following features typically are incorporated into precast concrete panel systems to accommodate blast loading:

- Panel sizes should be increased to two stories tall or one bay wide, at least, to increase their ductility. Panels can then absorb a larger portion of the blast energy and transfer less through connections to the main structure.
- Panels should be connected to floor diaphragms rather than to columns, to prevent applying lateral loads to the columns.



The 6-in.-thick x 22-ft-tall panels were reinforced with ribs spaced 6 ft apart.

- Panels may be designed with integrally cast and reinforced vertical pilasters or ribs on the back to provide additional support and act as beams that span floor-to-floor to take loads. This rib system makes the panels more ductile and better able to withstand an external blast, but it also forces the window fenestration into a punched-opening symmetry.

Loadbearing precast panels must be designed to span failed areas through arching action, strengthened gravity connections, secondary support systems, or other ways of providing an alternative load path (see Reference 7).

Connection Concepts

Precast concrete wall-panel connections for blast-loading conditions can be designed as strengthened versions of conventional connections, with a likely significant increase in connection hardware. They also may be designed as connection details that emulate cast-in-place concrete to provide building continuity.

For a panel to absorb blast energy and provide ductility while being structurally efficient, it must develop its full plastic-flexural capacity, which assumes the development of a collapse mechanism. The failure mode should result in yielding of the steel, not the connection splitting, spalling, or pulling out of the concrete. This means that structural steel connection material must be designed for 5% to 10% more than tensile and yield strength. The connection's shear capacity also should be at least 20% higher than the member's flexural capacity.

Steel-to-steel connections should be designed so the weld is never the weak link in the connection. Where possible, connection details should provide redundant load paths, since connections designed for blast may be stressed to near their ultimate capacity, and the possibility of single-connection failures has to be considered. The number of components in the load path and the consequences of a failure of any one of them will also be a factor.

The key concept in the development of these details is to trace the load or reaction through the connection. This is more critical in blast design than in conventionally loaded structures. Connections to the structure should have as direct a load path as practical, using as few connecting pieces as possible.

It is also important that connections for blast-loaded members have sufficient rotational capacity. A connection may have sufficient strength to resist the applied load, but when significant deformation of the member occurs, this capacity may be reduced due to rotation of the connection. Both bolted and welded connections can perform well in a blast environment if they can develop strength at least equal to that of the connected components (see Reference 8).

(For details on key connections used in precast concrete designs, see Chapter 4C "Connections.")

REFERENCES:

1. DN-14-04: *Designer's Notebook: Blast Considerations, Introduction*, p. 2.
2. DN-14-04: *Designer's Notebook: Blast Considerations: Blast Basics*, p. 3.
3. DN-14-04: *Designer's Notebook: Blast Considerations: Blast Analysis Standards*, pp. 5-6.
4. DN-14-04: *Designer's Notebook: Blast Considerations: Standoff Distance*, pp. 13-14.
5. DN-14-04: *Designer's Notebook: Blast Considerations: Design Concepts*, pp. 14-16.
6. DN-14-04: *Designer's Notebook: Blast Considerations: Architectural Precast Concrete Cladding*, pp. 19-20.
7. DN-14-04: *Designer's Notebook: Blast Considerations: Architectural Precast Concrete Cladding*, pp. 19-20.
8. DN-14-04: *Designer's Notebook: Blast Considerations: Connection Concepts and Details*, pp. 21-24.

RESOURCES:

DN-14-04: *Designer's Notebook: Blast Considerations*.



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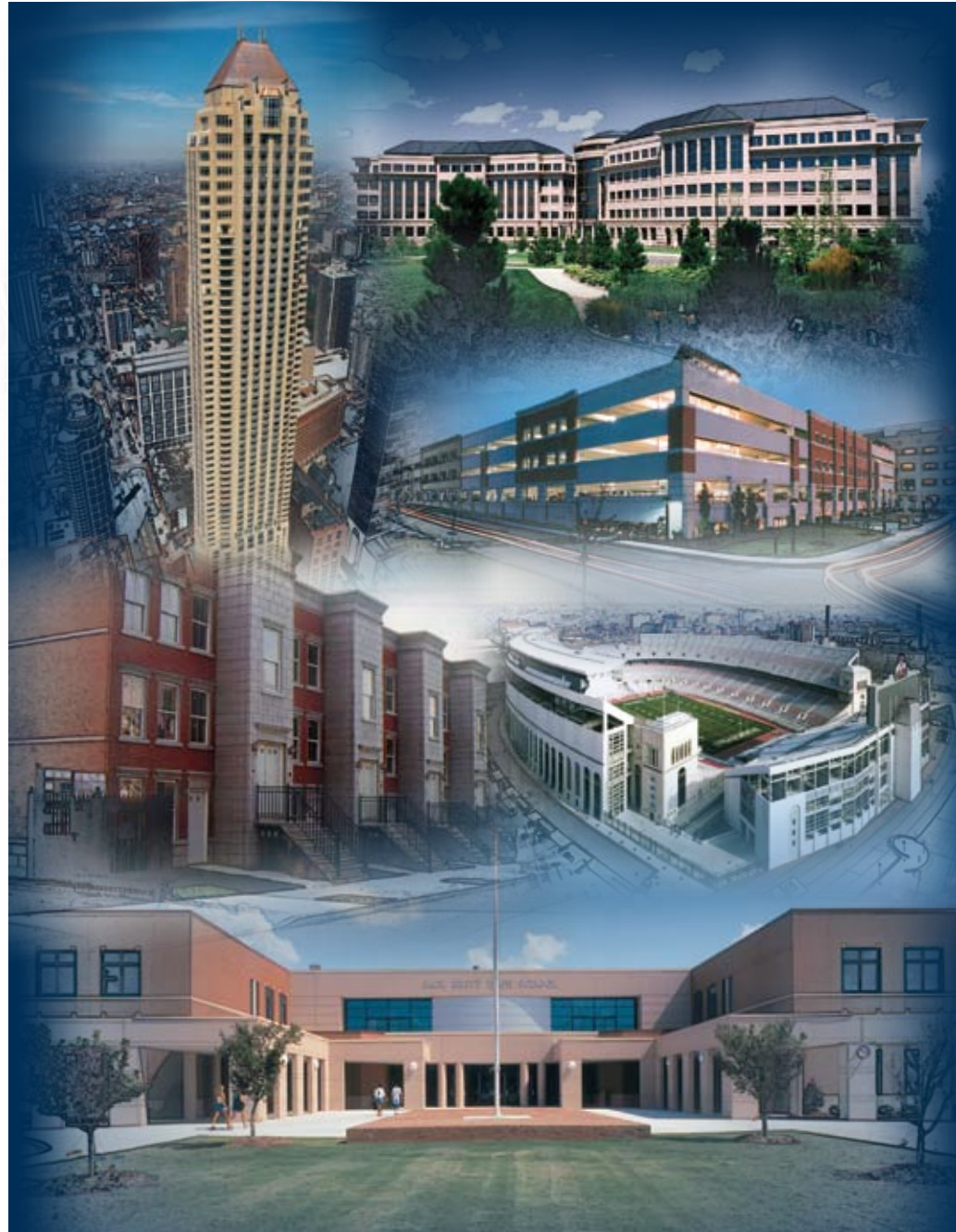
CHAPTER

COMPONENTS, SYSTEMS, & CONNECTIONS

Components _____ 4A

Precast Concrete Systems _____ 4B

Connections _____ 4C



DESIGNING WITH PRECAST & PRESTRESSED CONCRETE



A variety of components can be fabricated from precast concrete, meeting a range of project needs. Listed here are the most common components that precast concrete manufacturers produce and that designers incorporate into their projects. Customized pieces, sizes, and shapes can be created in many cases to meet specific programmatic needs.

The designer should consult with the local precaster early in the design phase to determine what components will work most efficiently and to review specific sizes, joint locations, and other details that can create cost effective options.



*University Village, Chicago, Ill.;
Architect: FitzGerald Associates
Architects; Photo: The Spancrete
Group.*

*A total of 2101 components
were used consisting
of 1550 hollow-core planks,
226 precast inverted-T beams,
100 precast columns,
144 pieces of precast shear wall,
26 pieces of precast porches,
and 45 pieces of balcony beams.*

BEAMS



Beams are typically considered structural components and are made in one of three key shapes:

- Rectangular
- Inverted Tee Beams
- L Beams

Beams are horizontal components that support deck members like double tees, hollow-core, and solid slabs, and sometimes other beams.

They can be reinforced with either prestressing strand or conventional reinforcing bars. This will depend on the spans, loading conditions, and the producer's preferred production methods.

Casting process: Prestressed beams are typically pretensioned and cast in a long-line set up similar to that used for double tees. Beams that are reinforced with conventional reinforcing bars can be cast as individual components, in shorter forms made specifically for the size of the beam. They are typically cast in the same orientation as used in the final structure.

Typical sizes: Practically any size needed to satisfy structural requirements.

Typical depths: 16 to 40 in.

Typical widths: 12 to 24 in.

Typical span-to-depth ratios: 10 to 20.

Finishes: Since beams are cast upright, the bottom, sides, and ledges are cast against a form and will typically be provided with an "as cast" finish that results in a smooth, hard finish. The top is troweled by the finishing crew and can be smooth, roughened to simulate the finish of supported double tees (as in a parking structure), or intentionally roughened to create a bond with cast-in-place concrete that may be poured on top of it.



Precast balconies alternate with porches along the building façade to create a dynamic rhythm.

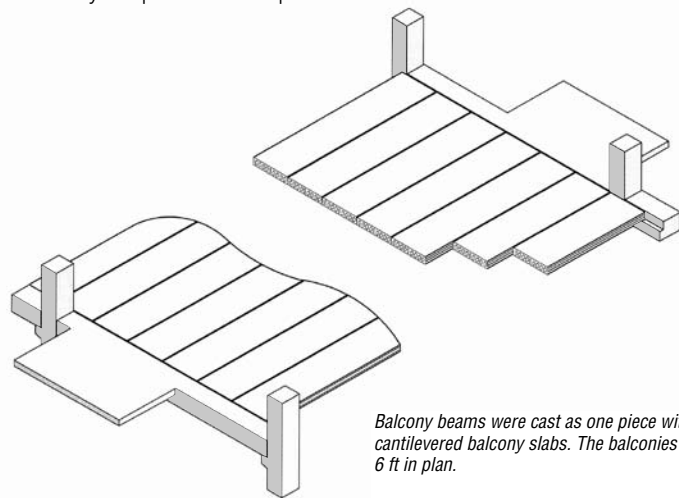
University Village, Chicago, Ill.; Architect: FitzGerald Associates Architects; Photo: The Spancrete Group.

RESOURCES:

Chapter 11.1.3, "Beam Design Equations and Diagrams," MNL-120-04: *PCI Design Handbook, Sixth Edition.*

Chapter 4.0, "Structural Design," MNL-129-98: *Precast Prestressed Concrete Parking Structures: Recommended Practice for Design and Construction.*

Chapter 4.5.3, "Beams," MNL-129-98: *Precast Prestressed Concrete Parking Structures: Recommended Practice for Design and Construction.*



Balcony beams were cast as one piece with the cantilevered balcony slabs. The balconies are 12 ft by 6 ft in plan.

COLUMN COVERS



Column covers are usually a major focal point in a structure. These units may be broad or barely wider than the column itself and run vertically up a structure. They often conceal structural columns and may completely surround them at the ground level.

They typically are supported by the structural column or the floor and are designed to transfer no vertical load other than their own weight. The vertical load of each length of column-cover section is usually supported at one elevation and tied back at the top and bottom to the floors for lateral load transfer and stability.

Casting process: Column covers typically are cast as single-story units, although units that are two or more stories in height can be cast to minimize erection costs and horizontal joints. They are cast in a horizontal position and rotated to their final position at the jobsite by the erection crew.

Typical shapes: C or U shaped (matching halves cover a structural column).

Typical sizes: One story tall.

Finishes: The exterior three sides of the column cover can be finished in any way desired similar to an architectural precast concrete panel.



RESOURCES:

Chapter 7.2.1.2, "Column Covers and Mullions," MNL-120-04: *PCI Design Handbook, Sixth Edition*.

Chapter 2, Section 2.4 "Precast Concrete Panels Used as Cladding," MNL-122-07: *PCI Architectural Precast Concrete Manual, Third Edition*.

Chapter 4.2.4, "Design Considerations for Non-Loadbearing Wall Panels," MNL-122-07: *PCI Architectural Precast Concrete Manual, Third Edition*.

COLUMNS



Columns are typically used to support beams and spandrels in applications such as parking structures and total-precast concrete structural systems of all types. They typically are designed as multilevel components ranging from a single story to six levels or more.

Casting process: They can be made in a long-line pretensioning facility and reinforced with prestressing strand or cast in individual forms with either prestressing strand or conventional reinforcing bars. They are cast in a horizontal position and rotated to their final position at the jobsite by the erection crew.

Sizes and shapes can vary to satisfy both architectural and structural requirements.

Typical shapes: Square or rectangle.

Typical sizes: From 12 by 12 in. to 24 by 48 in.

Finishes: Since columns are cast in a horizontal position, three of the four sides are created with a form. These finishes are very smooth and most often remain “as cast” in the finished construction although they may have an architectural finish and be exposed to view. The fourth side is typically troweled to match the other three sides as closely as possible.



The Berry Events Center at Northern Michigan University in Marquette, Mich., features insulated precast concrete wall panels on its exterior and precast columns, risers, and plank inside. The facility can host a variety of activities, including concerts, basketball games, and ice-hockey matches, and is only the third site in America capable of being used for U.S. Olympic speed skating. Architect: Integrated Design.



RESOURCES:

Chapter 4.9, “Compression Members,” MNL-120-04: *PCI Design Handbook, Sixth Edition*.

DOUBLE TEES



Double tees are used primarily as deck floor and roof components for any type of structure, including parking structures, office buildings, and industrial buildings. They are made either:

- Pretopped using a flange thickness of 4 in., which creates the wearing surface in parking structures; or
- Field topped with a 2-in. flange, on which a cast-in-place concrete composite topping of 2 to 4 in. is added in the field. For roof construction, there is typically no need to add topping on the 2 in. flange.

Typical widths: 8, 10, 12, and 15 ft.

Typical depths: 24, 26, 28, 30, 32, and 34 in.

Typical span-to-depth ratios: Floors: 25 to 35 / Roofs: 35 to 40

Casting process: Double tees typically are cast in 300- to 500-ft-long prestressing beds (forms) that are sub-divided into specific length tees for a particular project. The general production method consists of:

- laying out forms
- stressing the strand
- installing other embedded material and flange reinforcing
- making a pre-pour quality-control check
- pouring and finishing the concrete
- allowing about 12-16 hours of curing
- detensioning (cutting) the strands at the ends of each piece
- stripping from the form
- making a post-pour quality-control check
- moving the tee to the storage area awaiting shipment to the site.

Finishes: Form side will generally be “as cast,” resulting in a smooth, hard finish. This generally remains as is and is not painted, although it can be if desired. The top-of-flange side will be smoothed for roof construction, left rough if it will receive a field topping or broomed (either transversally or longitudinally), or circular swirl-finished if it will be used as the wearing surface in a parking structure.

RESOURCES:

Chapter 2.4, “Stemmed Deck Members,” MNL-120-04: *PCI Design Handbook, Sixth Edition*.

Chapter 4.5.1, “Stemmed Floor Members,” MNL-129-98: *Precast Prestressed Concrete Parking Structures: Recommended Practice for Design and Construction*.

Chapter 4.6, “Pretopped Double Tees,” MNL-129-98: *Precast Prestressed Concrete Parking Structures: Recommended Practice for Design and Construction*.

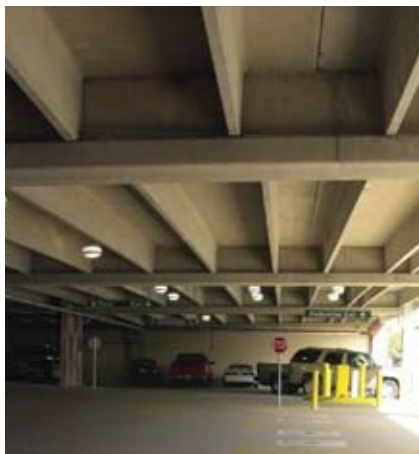
PCI JOURNAL:

“New Mega Tee Passes Load Testing,” *PCI Journal*, March-April 1997, pp. 136-139.



The Enterprise IV project features double tees as flooring, which create large, open floor plans that add flexibility for tenants.

Enterprise IV Facility, Shelton, Conn.; Architect: Kasper Group, Inc.



Columns and spandrels, as well as double tees, were part of the precast concrete building system used at Baylor University.

Dutton Avenue Office and Parking Facility, Baylor University, Waco, Tex.; Architect: Carl Walker Inc.

HOLLOW-CORE SLABS



Hollow-core slabs are used predominantly for floor and roof deck components for various structures including multifamily housing, hotel and condominiums, office buildings, schools, and prisons.

Typical widths: 2, 4, and 8 ft; some precasters offer 10 and 12 ft widths.

Typical depths: 6, 8, 10, 12, 15, and 16 in.

Typical span-to-depth ratios: Floors: 30 to 40 / Roofs: 40 to 50

Casting process: Hollow-core slabs typically are cast using a long line method with 300- to 500-ft-long prestressing beds in which a proprietary machine specific to the brand, which extrudes the concrete and creates the voids by means of either a rotating auger or by placement of aggregate filler that is later removed. One system produces the hollow-core pieces in 60-ft-long, self-stressing forms that circulate through a series of production phases ending with cutting to specific lengths.



The general production method consists of:

- preparing the form
- pulling strands from abutment to abutment
- stressing the strands to proper tension
- installing embeds and material to form openings if they occur
- making a pre-pour quality-control check
- running the casting machine from end to end
- creating a 300- to 500-ft-long slab
- curing for 12 – 16 hours
- marking the lengths of specific pieces based on requirements for a particular project
- saw-cutting the individual pieces to length
- stripping the pieces
- making a post-pour quality-control check
- moving the pieces to storage awaiting shipment to the site



Hollow-core plank. Photo: The Spancrete Group.



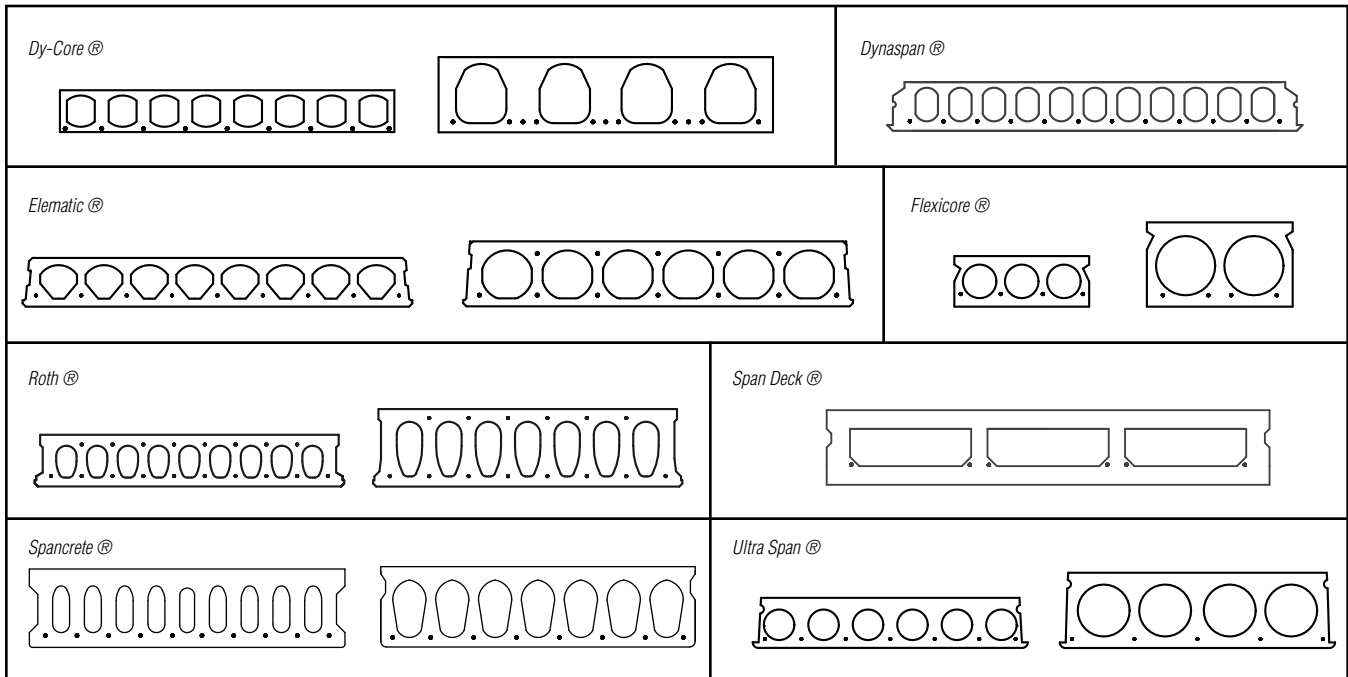


Hollow-core plank. Photo: Molin Concrete Products Co.

Finishes: Form side (bottom) is smooth as cast and typically remains that way in the finished construction. It is usually an exposed-to-view surface and is often painted. The top side is also usually smooth and can remain as such for direct carpet applications. It also can be kept slightly rough to receive a composite cast-in-place structural topping of 2 to 3 in., as with double tees or gypsum topping.

Branded processes: Each producer of hollow-core slabs uses a trademarked process that creates different shapes to form the voids within the pieces. Information on the key types of hollow-core and the signature shapes produced by each process can be found in Chapter 2 of the *PCI Design Handbook 6th Edition*. In addition, several producers have websites that can provide more detailed information.

It is also recommended that you consult a local producer near to where the proposed project is located (pci.org/find/manufacturer/).



RESOURCES:

CD/IGS-4-01: Hollow-core CD-ROM.

Chapter 2.5, "Flat Deck Members," MNL-120-04: *PCI Design Handbook, Sixth Edition*.

MK-8-87: Concrete Suggestions: Concrete Masonry Wall/Prestressed Concrete Hollow-core Floor Construction for Multi-Family, Low-Rise Housing.

PCI JOURNAL:

"Shear Strength of Hollow-Core Slabs," *PCI Journal*, January-February 2006, pp. 110-115.

INSULATED SANDWICH WALL PANELS



Insulated sandwich wall panels can be strictly architectural, strictly structural, or a combination of both. They can be placed in either a horizontal position, as in a multi-family-housing application, or in a vertical position, as on the exterior of a warehouse.

The difference between typical panels and insulated sandwich wall panels is that the latter are cast with rigid insulation “sandwiched” between two layers of concrete, called wythes. The insulation thickness can vary to create the desired thermal insulating property (“R” value) for the wall.

The structural behavior is either:

- Composite, in which the wythes are connected using ties through the insulation. The structural performance is then based on the full thickness of the panel; or
- Non-Composite, in which the wythes are connected using ties through the insulation, which limits performance to the individual capacities of each wythe.

Whether the panel is composite or non-composite depends on the configuration and material used for the ties.

Insulated sandwich wall panels can be designed to be loadbearing and support floor and roof components. They make an ideal structural element for this purpose, typically by casting a thicker interior wythe to provide the necessary support. They also can be non-loadbearing to complete a façade.

Typical widths: 4 to 15 ft.

Typical heights: 8 to 50 ft.

Typical thicknesses: 5 to 12 in., including 1 to 3 in. of insulation, more for applications in a cooling facility.

Casting process: The panels can be made in a long-line pretensioning facility and reinforced with prestressing strand or cast in individual forms with either prestressing strand or conventional reinforcing bars. They are cast in a horizontal position, with one wythe of concrete poured, the insulation placed, and the second layer poured. They are then rotated to their final position at the jobsite by the erection crew.

Finishes: As with typical wall panels, the panels are cast in a flat orientation, so the form side is typically the side that will be exposed to view in the final construction. This face can be made with virtually any type of finish, as discussed in Chapter 3A of this manual. The back face is typically troweled smooth or may have a light broom finish. Typically, the interior does not need additional furring and drywall to create the finished surface.



Madison Community Center, Dakota State University, Madison, S.D.; Architect: DLR Group.

RESOURCES:

Chapter 9.4, “Sandwich Panels,” MNL-120-04: *PCI Design Handbook, Sixth Edition*.

Chapter 5, Section 5.3.8, “Precast Concrete Sandwich Panels,” MNL-122-07: *PCI Architectural Precast Concrete Manual, Third Edition*.

MK-14-98: *Precast Concrete Wall Panels: Sandwich Wall Panels* (6 pp.).

PCI JOURNAL:

“Analytical Investigation of Thermal Performance of Precast Concrete Three-Wythe Sandwich Wall Panels,” *PCI Journal*, July-August 2004, pp. 88-101.

LITEWALLS



Light or “lite” walls are shear walls used in parking structures cast with an opening in their center to provide visual continuity and to allow daylight or artificial illumination to penetrate deeper into an interior. The components provide openness and a feeling of security. These components should not be confused with “light wells,” which are internal, open courtyards designed to provide daylight to the center of parking structures and other buildings.

As with other types of shear walls, lite walls serve as the lateral force-resisting systems in the structure. They act as cantilever beams, transferring lateral forces acting parallel to the face of the wall, from the superstructure to the foundation.

Casting process: They are cast in individual forms with either prestressing strand or conventional reinforcing bars. They are cast in a horizontal position and rotated to their final position at the jobsite by the erection crew.

Sizes and shapes can vary to satisfy both architectural and structural requirements.

Typical shapes: Rectangular with rectangular openings to create openness.

Typical sizes: 12 to 16 in. in width greater than the stem-to-stem spacing of the supported double tees.



New Street Parking Garage, Staunton, Va.; Architect: Fraizier Associates; Photo: Jason Hottel Photography.



Finishes: Lite walls are cast in a horizontal position, with three of the four sides created with a form. These finishes are very smooth and most often remain “as cast” in the finished construction. The fourth side is typically troweled to match the other three sides as closely as possible.

RESOURCES:

Chapter 1.2.2, “Parking Structures,” MNL-120-04: *PCI Design Handbook, Sixth Edition.*

Chapter 3.5, “Shear Wall Systems,” MNL-120-04: *PCI Design Handbook, Sixth Edition.*

Chapter 1.4.1.2.1, “Framing Systems,” MNL-129-98: *Precast Prestressed Concrete Parking Structures: Recommended Practice for Design and Construction.*

PCI JOURNAL:

“Recommended Practices and Procedures for the Erection of Horizontal Litewalls with Pocketed or Haunched Spandrels,” *PCI Journal*, May-June 2002, pp. 34-37.

“Recommended Practices and Procedures for the Erection of Vertical Litewalls with Pockets and Haunched Spandrels,” *PCI Journal*, May-June 2002, pp. 28-33.



Fifth & Lafayette Parking Structure, Royal Oak, Mich. The exterior façade combines 173 different shapes of brick clad lite walls. The lite walls are used to replicate the appearance of windows.

MODULAR UNITS



Precasters can produce modular precast concrete units that include a roof, floor, front and back walls, and two side walls if desired. The modules' key benefit, in addition to the speed with which these “building blocks” can be erected on site, comes from the precaster being able to outfit and finish the modules at the plant so they arrive at the site nearly complete.

These units have been used for prison cells for many years, and their use is now being expanded for school classrooms, hotel and motel rooms, and other applications where relatively small, repetitive rooms are needed on a rapid schedule.



*The Joseph Quincy Upper School, Boston, Mass.;
Architect: Equus Design Group Architects.*



Precast concrete modular classrooms lend an air of permanency not found in typical trailer-type portable units, yet they retain the feel of conventional classrooms.



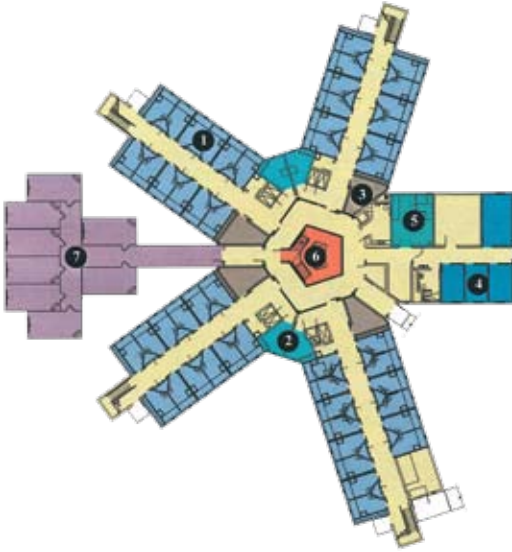
A crane hoists one of the 30-ft modules into place on the concrete foundation. The modules were delivered at night under a police escort because of daytime congestion in the area.

Prison-cell modules are the predominant method used for constructing justice facilities that include prisons and jails. These structures can be single- or multi-level structures as high as 10 to 12 stories.

The modules are cast as single- or multi-cell units with as many as four cells in one monolithic component. The configuration typically includes the inmate cell and a vertical “chase” between cells for mechanical, electrical, and plumbing accommodations.

The formwork may be proprietary and is made using steel with mechanisms for adjustment and functioning to “strip” the module from the form.

Typically, the interior exposed walls are epoxy painted, and the module is outfitted with as much of the Mechanical, Electrical, and Plumbing (MEP) accommodations as possible in the producer's plant. Final fit up is done at the jobsite. Exterior walls can be made with insulation similar to a sandwich wall panel and can receive virtually any kind of architectural treatment.



A crane lifts a 44,000 lb modular cell unit into place, forming the second level of one of the Medium Housing Buildings.

Miami Correctional Facility, Peru, Ind.; Architect: Schenkel Shults Inc.; Associate Architect: Phillips Swager Associates.



The cells arrived at the job site with furnishings, light and plumbing fixtures, windows, and door frame.



Two converging wings of Special Housing under construction expose the precast components of the building; stacked modular cells, hollow-core slab corridors, plenums, and insulated wall panels.

RESOURCES:

Chapter 1.2.3, "Justice Facilities," MNL-120-04: *PCI Design Handbook, Sixth Edition*.

Chapter 9.10.7, "Prison Cell Box Module," MNL-120-04: *PCI Design Handbook, Sixth Edition*.

Ideas By Design, Vol. 1, No. 1, March 2000: Justice Facilities (4 pp.).

MK-24-00: Concrete Cell Modules (4 pp.).

ASCENT:

"Modular Precast Design Builds Prison In One Year," *ASCENT* Winter 2002, pp. 26-28.

Casting process: Specialized steel formwork is used, with mechanisms that adjust and "strip" the module from the form. These often are proprietary to the manufacturer. The special forms allow all wall surfaces to be cast against a form. When stripped from the form, the floor or roof surface is troweled to the desired degree of smoothness, and the wall surfaces are typically prepped to fill surface voids before painting.

Finishes: Typically, the interior walls of the inmate cells are sandblasted, any surface voids are filled, and they are epoxy-painted before installation of items mentioned above.

MULLIONS



Mullions are thin, often-decorative pieces that fill open space in a building façade. They are often isolated elements forming a long vertical line, requiring them to be cast perfectly straight to avoid any visual deformities. To some degree, these variations can be handled by precast concrete connections with adjustability.

Casting process: They can be made in a long-line pretensioning facility and reinforced with prestressing strand or cast in individual forms with either prestressing strand or conventional reinforcing bars. They are cast in a horizontal position and rotated to their final position at the jobsite by the erection crew.

Sizes and shapes can vary to satisfy both architectural and structural requirements.

Typical shapes: Square or rectangle.

Typical sizes: One or more stories, subject to limitations imposed by weight or hanging.

Finishes: Three of the four sides are created with a form, as they are cast in a horizontal position. They can be finished in a variety of ways, depending on the application and the architectural purpose.



*Eagle Gate Plaza & Office Towers,
Salt Lake City, Utah; Architect:
Cooper Carlson Duy Ritchie, Inc.;
Photo: Rodriguez & Associates, LC.*

RESOURCES:

Chapter 7.2.1.2, "Column Covers and Mullions,"
MNL-120-04: *PCI Design Handbook, Sixth Edition.*

Chapter 2, Section 2.4 "Precast Concrete Panels
Used as Cladding" MNL-122-07: *PCI Architectural
Precast Concrete Manual, Third Edition.*

Chapter 4, Section 4.2.4 "Design Considerations
for Non-Loadbearing Wall Panels," MNL-122-07:
*PCI Architectural Precast Concrete Manual, Third
Edition.*

PILES



Precast, prestressed concrete pilings are often the preferred choice for permanent, durable, and economical foundations, especially in marine or bridge environments, due to their excellent adaptability and resistance to corrosion.

Piles can be spliced together to create longer piles. They are used primarily where longer piles are required but transportation needs make the longer lengths more difficult or costly to handle due to escort needs and the need for specialized rigs.



4500 precast concrete piles were driven into difficult soil conditions to create the foundation for the 1.7 million square-ft Boston Convention & Exhibition Center in South Boston, Mass. Architect: HNTB and Rafael Vinoly Architects (a joint venture).

Typical sizes: 10 to 36 in. for building projects; larger for bridges.

Typical shapes: 18-in.-square (the most common), plus octagonal and round (cylindrical) in sizes as needed. Larger sizes may have a void cast into them to save on the volume of concrete.

Casting process: They are cast in a long-line pretensioning facility and reinforced with prestressing strand. They are cast in a horizontal position and rotated to their final position at the jobsite by the erection crew.



Bath Iron Works Land Level Transfer Facility, Bath, Maine; Design-BUILDER: Clark Group.

RESOURCES:

BM-20-04: *Precast Prestressed Concrete Piles Manual*, Chapter 20.
 Chapter 2.3.10, "Piles," MNL-120-04: *PCI Design Handbook, Sixth Edition*.
 Chapter 4.9.6, "Piles," MNL-120-04: *PCI Design Handbook, Sixth Edition*.

SHEAR WALLS



Shear walls act as vertical cantilever beams, transferring lateral forces acting parallel to the face of the wall from the superstructure to the foundation. Typically, there are two shear walls oriented to resist lateral loads along each principal axis of the building. They should be designed as loadbearing panels.

Typical widths: 15 to 30 ft.

Typical heights: 10 to 30 ft depending on the width and transportation limitations.

Typical thicknesses: 8 to 16 in.



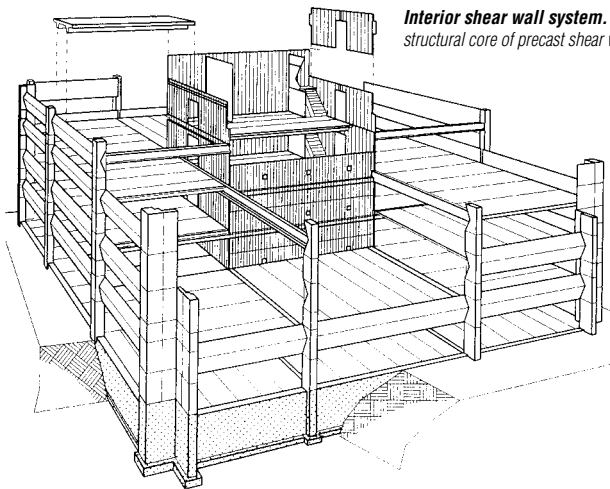
Starz Encore headquarters office and technology center for the satellite broadcast company in Englewood, Colo.; Architect: Barber Architecture.

Casting process: Shear walls typically are cast flat in an individual form and reinforced with conventional reinforcing bars. They are cast in a horizontal position and rotated to their final position at the jobsite by the erection crew.

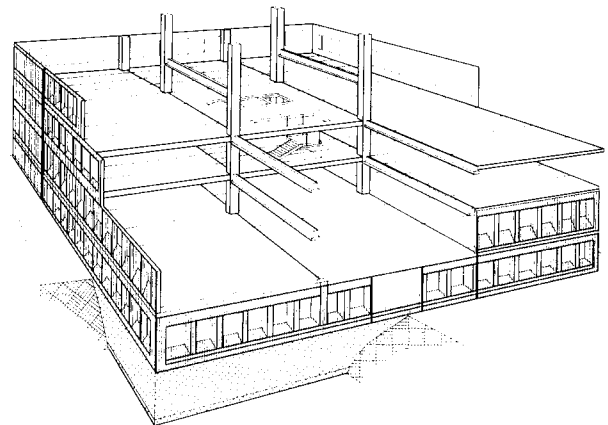
Finishes: Since shear walls are cast in a flat orientation, one side is finished in the form and the other side is manually finished. Typically, they receive the same finish and a complementary style to the surrounding structure, especially in a parking structure, where they will be visible.



Starz Encore headquarters all-precast structural system includes shear walls, loadbearing precast walls, double tees, and inverted tee beams. The system is a common approach to design in the Rocky Mountain region.



Interior shear wall system. Lateral loads are transmitted by floor diaphragms to a structural core of precast shear walls.



Exterior shear wall system permits greater design flexibility because it eliminates the need for a structural core. By combining gravity loadbearing function with lateral force resistance in general makes this system more economical.

RESOURCES:

Chapter 3.5, "Shear Wall Systems," MNL-120-04:
PCI Design Handbook, Sixth Edition.

Chapter 4.3.2.3, "Shear Walls," MNL-129-98:
*Precast Prestressed Concrete Parking Structures:
Recommended Practice for Design and Construction.*

SOLID SLABS

Solid slabs are used as structural deck components similar to hollow-core slabs.

They can be made in a long-line pretensioning facility and reinforced with prestressing strand or cast in individual forms with either prestressing strand or conventional reinforcing bars. They are typically cast in the same position as used in the structure.

Sizes can vary to satisfy the structural requirements.

Typical widths: 4 to 12 feet.

Typical spans: 8 to 30 feet.

Typical thicknesses: 4 to 12 in.

Finishes: The form side (bottom) is smooth as cast and typically will remain that way in the finished construction. When it is an exposed surface, it can remain as is or painted without additional treatment.

The top side is troweled to the desired degree of smoothness or may be intentionally roughened to receive a cast-in-place concrete topping that will act compositely and provide additional strength.



*Velocity Multifamily Residential Condos,
Hoboken, N.J.;
Architect: Equus Design Group;
Photos: Oldcastle.*



RESOURCES:

Chapter 2.5, "Solid Flat Slab Load Tables," MNL-120-04: *PCI Design Handbook, Sixth Edition*.

SPANDRELS



Spandrels are essentially perimeter beams that extend both above and below the floor and are used in a variety of applications, including structural support for deck components in parking structures and cladding on office buildings. They are typically made as:

- Loadbearing with a ledge, as in parking structures supporting double tees or in office buildings supporting double tees or hollow-core slabs.
- Loadbearing with pockets, as in support for double tees, where the stem of the double tee fits into a pocket cast into the thickness of the spandrel.
- Non-loadbearing as in cladding for any type structure, typically with curtain wall or glazing.



To achieve maximum construction cost efficiency, the spandrel beam at the exterior column line of the garage was designed as a loadbearing structure, bumper guard, and architectural façade together. Using 6 in. projecting bullnose shapes at the top and bottom of the spandrel, in concert with curving arches of 1 in. relief, the spandrel was conceived to grow almost tree-like from columns with arching haunches.



Mystic Transportation Center, Medford, Mass.; Architect: Thompson Design Associates.

Typical sizes: Any size required to satisfy structural requirements.

Typical heights: 5 to 8 ft.

Typical spans: 25 to 60 ft.

Typical thicknesses: 4 to 12 in., depending on the span and structural requirements.

Casting process: Spandrels are cast flat with the side to have the most prominent exposure being cast down to form the exposed surface. They can be reinforced either with prestressing strand or conventional reinforcing bars. They can be cast in a long-line pretensioning facility similar to double tees or in individual forms.

Finishes: The exposed face can be made with virtually any type of finish as discussed in Chapter 3A of this manual. The back face is typically troweled smooth or may have a light broom finish.

RESOURCES:

Chapter 7.2.1.1, "Spandrels," MNL-120-04: *PCI Design Handbook, Sixth Edition.*

Chapter 7.2.2.1, "Spandrels," MNL-120-04: *PCI Design Handbook, Sixth Edition.*

Chapter 4, Section 4.2.6, "Design Considerations for Non-Loadbearing Spandrels," MNL-122-07: *PCI Architectural Precast Concrete Manual, Third Edition.*

Chapter 4, Section 4.2.7, "Design Considerations for Loadbearing Spandrels," MNL-122-07: *PCI Architectural Precast Concrete Manual, Third Edition.*

Chapter 1.3, "Façade Treatments," MNL-129-98: *Precast Prestressed Concrete Parking Structures: Recommended Practice for Design and Construction.*

RAKER BEAMS

Raker beams are angled, notched beams that support stadium riser units. They are used universally in outdoor stadiums and arenas and in many indoor arenas and performing-arts theaters.

Typical sizes: Sizes can vary as required structurally and to match varying riser sections that they support.

Typical widths: 16 to 24 in.



Casting process: Raker beams are cast either upside down, on their side, or upright, depending on the manufacturer's preference. Any casting position will result in a favorable solution. Typically, three sides will have an "as cast" finish that results in a smooth, hard finish. The fourth side is troweled by the finishing crew to match the other sides as closely as possible.

RESOURCES:

Chapter 1.2.5, "Stadiums/Arenas," MNL-120-04: *PCI Design Handbook, Sixth Edition*.

CD/IGS-3-01: Stadiums CD-ROM.

Ideas By Design, Vol. 1, No. 2, December 2000: Stadium Projects (8 pp.).

STADIUM RISERS



Stadium risers are used to support seating in stadiums, arenas, theaters, and other types of grandstands.

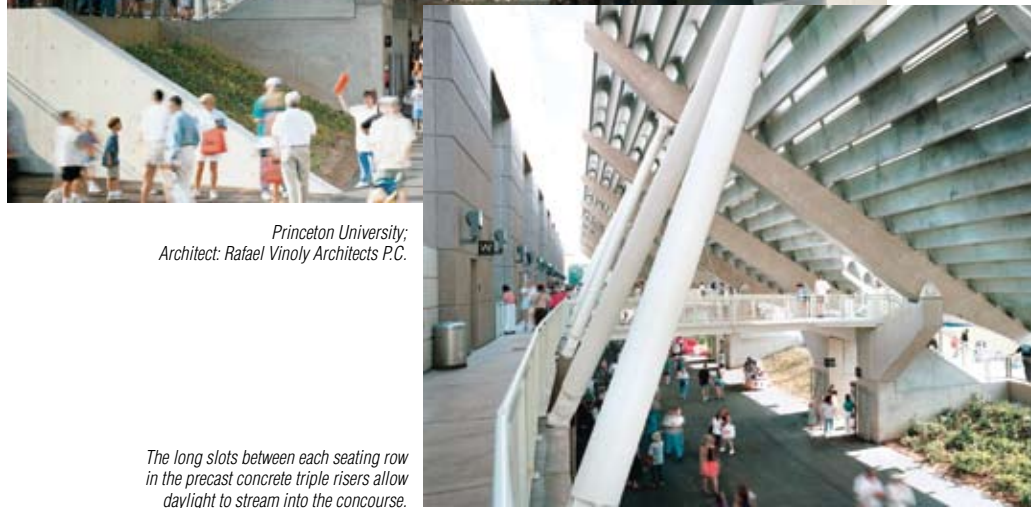
Typically, they are made as single, double, or triple risers with heights cast to satisfy site lines in the venue. Specifying single, double, or triple risers will depend on the layout and may be dictated by weights and crane access during construction.

Typical spans: 8 to 50 ft.

Casting process: Risers are typically cast in self-stressing forms made for each specific project, with up to three pieces being cast at one time, depending on the individual lengths. The bottom and vertical sections of the riser are cast against the form and typically will remain as cast in the final construction.

Finishes: The top (wearing surface) is typically troweled to the desired degree of smoothness or made slightly roughened to create a non-slip surface.

Scott Stadium at the University of Virginia, Va.; Architect: Heery International Inc.



*Princeton University;
Architect: Rafael Vinoly Architects P.C.*

The long slots between each seating row in the precast concrete triple risers allow daylight to stream into the concourse.

RESOURCES:

Chapter 4.2.5, "Bending of Asymmetrical Sections," MNL-120-04: *PCI Design Handbook, Sixth Edition*.

Figure 4.2.5.1, "Typical Stadium Riser," MNL-120-04: *PCI Design Handbook, Sixth Edition*.

Table 8.3.6, "Single, Double and Triple Stadium Riser Erection Tolerances," MNL-120-04: *PCI Design Handbook, Sixth Edition*.

Chapter 9.7.8, "Stadium Seating," MNL-120-04: *PCI Design Handbook, Sixth Edition*.

CD/IGS-3-01: Stadiums CD-ROM.

Ideas By Design, Vol. 1, No. 2, December 2000: Stadium Projects (8 pp.).

STAIRS



Precast concrete stairs are used in any application where a stair tower or individual steps are required. These modules can provide fast erection and durable access in buildings or parking structures.

Typical thicknesses: 6 to 10 in.

Casting process: They are typically made as “open-Z” stair components, in which the upper and lower landings are cast monolithically with the tread/riser section. They can also be cast as shorter components, consisting of only the tread/riser section, which is supported by separate landing components that span transversely to the stair section.

Stair components are typically cast either “on edge” or “upside down.” The format will depend on the size and the producer’s preferred production method. Abrasive nosing pieces are often cast into the treads to create a non-slip surface.

Finishes: When cast on edge, the tread and bottom remain as cast and typically will remain as such in the final construction. When they are cast upside down, the bottom will be troweled to the desired degree of smoothness and typically will remain exposed to view in the final construction.



*Velocity Multifamily Residential Condos,
Hoboken, N.J.;
Architect: Equus Design Group;
Photos: Oldcastle.*



Stair run supported by precast concrete landing.

RESOURCES:

Table 8.3.8, “Stair Unit Erection Tolerances,” MNL-120-04: *PCI Design Handbook, Sixth Edition*.

WALL PANELS

Wall panels can be strictly architectural, strictly structural, or a combination of both. They can be placed in either a horizontal position, as in a multifamily-housing application or in a vertical position, as in the exterior of a warehouse. Wall panels can be loadbearing and support floor and roof components or they can be nonloadbearing to complete a façade.

Typical widths: 4 to 15 ft.

Typical heights: 10 to 50 ft.

Typical thicknesses: 4 to 12 in.

Casting process: Wall panels can be made in a long-line pretensioning facility and reinforced with prestressing strand or cast in individual forms with either prestressing strand or conventional reinforcing bars. They are cast in a horizontal position and rotated to their final position at the jobsite by the erection crew.

Finishes: Since wall panels are cast in a flat orientation, the form side is typically the side that will be exposed to view in the final construction. This face can be made with virtually any type of finish as discussed in Chapter 3A of this manual. The back face is typically troweled smooth or may have a light broom finish.

RESOURCES:

Chapter 7.2.1.4, "Wall Panels," MNL-120-04: *PCI Design Handbook, Sixth Edition*.

MK-14-98: Precast Concrete Wall Panels: Sandwich Wall Panels (6 pp.).

MK-15-98: Precast Concrete Wall Panels: Warehouse/Distribution Centers (6 pp.).

MK-16-98: Precast Concrete Wall Panels: Manufacturing Facilities (6 pp.).

MK-17-98: Precast Concrete Wall Panels: High-Tech Facilities (6 pp.).

MK-18-98: Precast Concrete Wall Panels: Food-Processing Facilities (6 pp.).

MK-19-98: Precast Concrete Wall Panels: Retail Buildings (6 pp.).

MK-20-98: Precast Panels for Industrial Buildings (6 pp.).

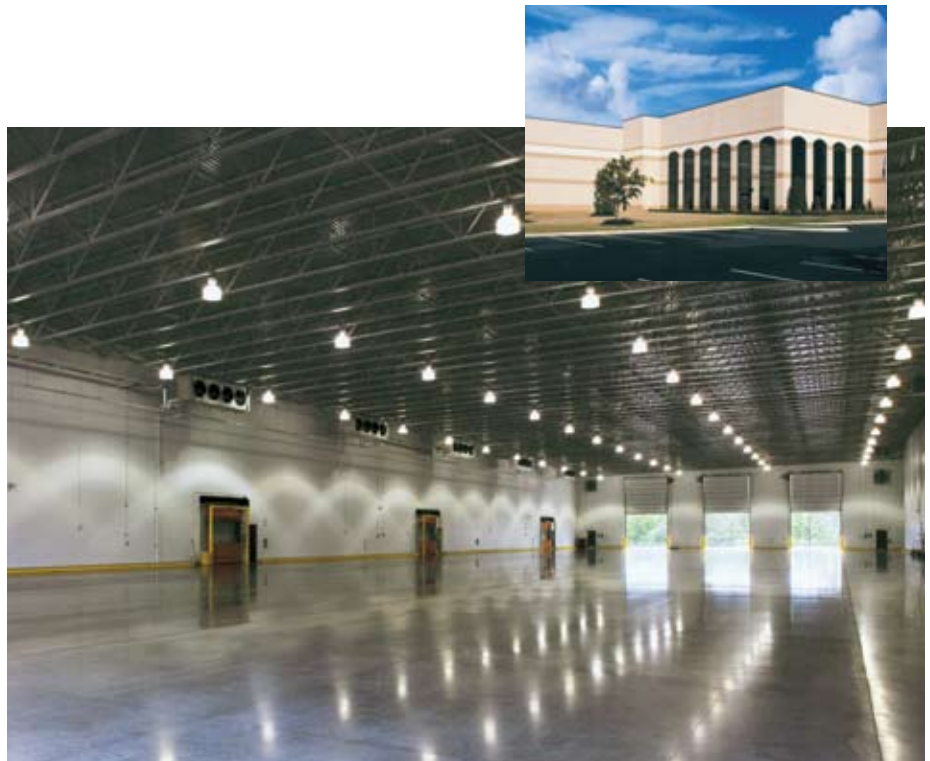
MNL-122-07: *PCI Architectural Precast Concrete Manual, Third Edition*.

PCI JOURNAL:

"Design Factors Influencing the Aesthetics of Architectural Precast Concrete," *PCI Journal*; March-April 2001, pp. 44-61.

"Design of Rectangular Openings in Precast Walls Under Combined Vertical and Lateral Loads," *PCI Journal*; March-April 2002, pp. 58-83.

"Design of Rectangular Openings in Precast Walls Under Vertical Loads," *PCI Journal*; January-February 2002, pp. 50-67.



Budweiser, Piedmont, S.C.;
Architect: Jerry W. Rives Jr. AIA; Photos: Reel Video & Stills Inc./Brian Erkens.

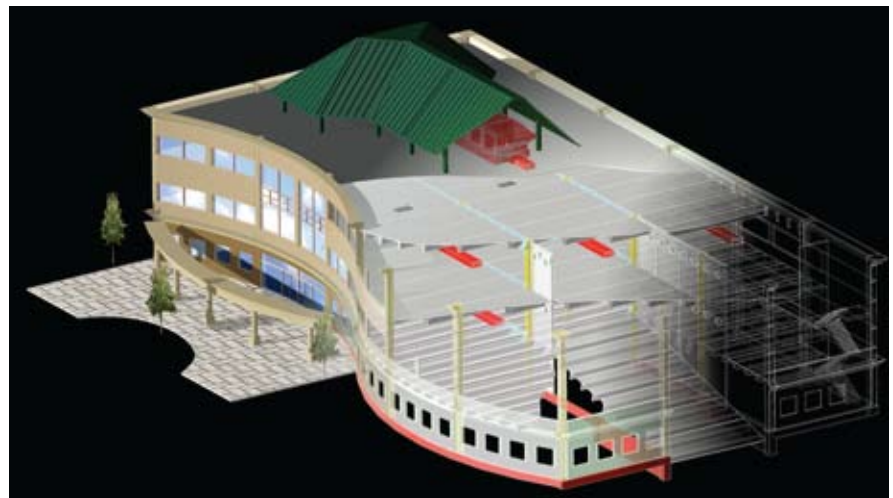
Precast Concrete Systems

The design of precast, prestressed concrete structures depends on the integration of the structural system as a whole, the connections, and the individual components. Each aspect must consider the others as well as the functional requirements imposed by the building use.

It is essential that design loads follow a load path from their point of origin to the final support or foundation. Although not always required by code, it is desirable to design the members and their connections to achieve a ductile, rather than a brittle, failure mode.

In addition to resisting gravity loads, a principal consideration in building design is the lateral force-resisting system. There are a variety of precast concrete designs that can be used to achieve these goals economically and effectively.

A qualified, registered structural engineer should be retained to provide structural engineering services for the final design.



Schematic of loadbearing precast concrete building.

SHEAR WALLS

Buildings that use shear walls as the lateral force-resisting system can be designed to provide a safe, serviceable, and economical solution for wind and earthquake resistance. Shear walls make up most common lateral force-resisting systems in the precast, prestressed concrete industry. The excellent performance of shear-wall buildings throughout the world that have been subjected to earthquakes and high winds can testify to their effectiveness.

BASIC PRINCIPLES

Shear walls act as vertical cantilever beams, transferring the lateral forces acting parallel to the face of the wall, from the superstructure to the foundation. Shear walls should be oriented to resist lateral loads applied to the building along both of the structure's principal axes.

Ideally, there should be at least two shear walls oriented to resist lateral loads along each principal axis. If only one shear wall is oriented along one principal axis, two shear walls should be provided along the orthogonal axis to resist diaphragm torsion. It also is acceptable to orient the three shear walls in any non-collinear position.

Shear walls should be designed as loadbearing panels whenever possible. The increased dead load acting on the panel is an advantage because it increases the panel's resistance to uplift and overturning.

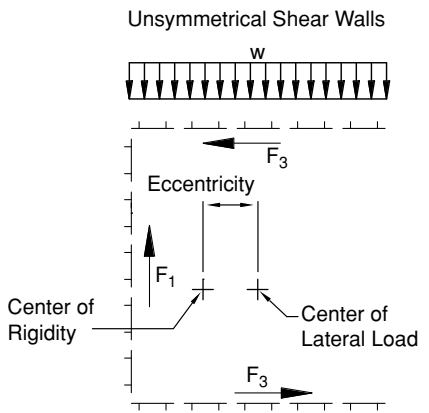
The distribution of the total lateral force acting on a building to each individual shear wall is influenced by four factors:

1. The supporting soil and footings.
2. The stiffness of the floor and roof diaphragms.
3. The relative flexural and shear stiffness of the shear walls and of connections.
4. The eccentricity of the lateral loads to the center of rigidity of the shear walls.

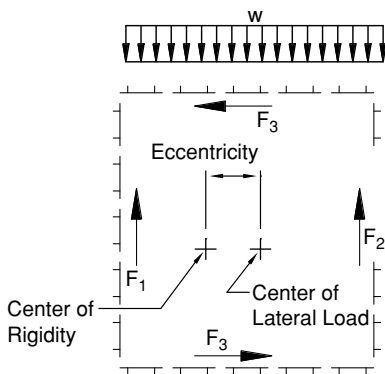
Generally, #1 can be neglected when distributing shear forces among shear walls.

With regard to #2, if the depth-to-span ratio of a diaphragm is small, it will be flexible and may deflect significantly when subjected to lateral loads. Flexible diaphragms distribute shears to each shear wall in proportion to the tributary width of diaphragm loading each shear wall.

If the diaphragm's depth-to-span ratio is large and is adequately connected, the diaphragm will be rigid and not deflect as significantly as a flexible diaphragm when subjected to lateral loads. Rigid diaphragms distribute shears to each shear wall in proportion to the shear wall's relative stiffness. In precast concrete building design, it is common to assume that floor and roof diaphragms act as rigid diaphragms (see Reference 1).



(a) Frequently Occurs in Large Buildings with Expansion Joints



(b) Frequently Occurs in Buildings with Large Door Openings

PRECAST CONCRETE DESIGNS

The design for precast concrete shear walls typically has followed principles used for cast-in-place structures, with modifications made as appropriate for the jointed nature of a precast concrete structural system. Design methods used to achieve successful performance of precast shear-wall structures have been left largely to the judgment of the structural engineer.

Observations of performance of structures in earthquakes show that where adequate strength and stiffness were provided to limit interstory drift (lateral displacement) to about 2% (relative to a point at the story below), the resulting displacements and damage were within acceptable levels.

In regions of low and moderate seismic activity, bolted or welded connections with small grout joints are generally used. In regions of high seismic activity, connections to the foundation and connections between precast concrete walls generally use details that emulate cast-in-place behavior and may include post-tensioning (see Reference 2).

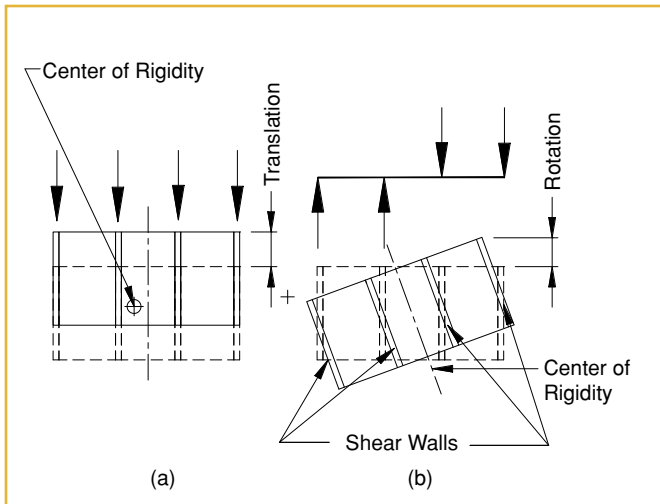
DESIGN GUIDELINES

The steps in designing structures that have shear walls as the primary lateral load-resisting elements include eight key steps that are carried out by the structural engineer of record (EOR) or the precast concrete specialty engineer subject to the EOR's approval:

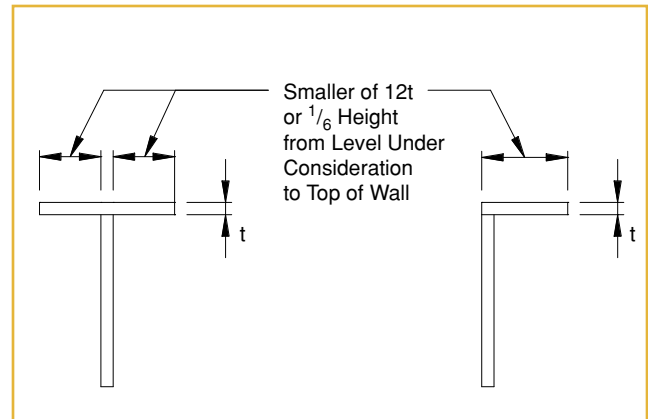
Evaluate the building function and applicable precast concrete frame. In a warehouse-type structure, for instance, it is common to include the exterior walls as part of the lateral force-resisting system. In parking structures, shear walls can be located at stair and elevator towers, at the ends of ramped bays, at selected locations on the perimeter of the structure, or at any combination of the above.

Develop a preliminary design for the shear-wall system. This requires six steps:

1. Provide at least three non-collinear walls to ensure torsional as well as direct lateral resistance.
2. Determine if shear walls can also function as bearing walls, as overturning often will be the governing criterion.
3. Arrange shear walls so they minimize restraint due to volume changes.
4. Consider whether the shear walls could be individual full-height walls (vertical joints only).
5. Consider the practicality of transportation and erection when selecting the size of wall panels.
6. Balance the design requirements of the shear walls with the design requirements of the associated diaphragms.



Translation and rotation of rigid diaphragms.



Effective width of wall perpendicular to shear walls.

Determine the vertical and lateral loads. First determine the applicable vertical gravity loads, then use the appropriate seismic-design criteria to determine the magnitude of lateral load for each floor and compare that with wind loading.

Create a preliminary load analysis. Determine the overturning moment, the lateral in-plane shear, and the axial load at the base of each of the shear walls.

Select the appropriate shear wall. Review the preliminary choice and modify the number, location, and dimensions as necessary to satisfy the requirements at the base of each. It is economically preferable that the foundations not be subjected to uplift.

Determine the final load analysis. Perform the final lateral-load and vertical-load analyses to determine the design load for each shear wall, based on its final location and dimensions.

Create the final shear-wall design. Design shear-wall reinforcement and connections for the associated diaphragms. If there is insufficient length of shear wall available to accommodate the necessary number of shear connectors, consider using an element in the plane of the diaphragm (drag strut) as an extension of the shear wall to pick up additional connectors. Also, consider the added requirements necessary to satisfy the structural-integrity provisions of the code.

Design the diaphragms. They should respond elastically to applied lateral loads to prevent formation of plastic regions in any diaphragm. They need to be designed as beams, provide the necessary tensile reinforcement for each chord, and provide shear connectors or shear reinforcement using shear-friction methods. Additional requirements needed to satisfy the structural-integrity provisions of the code also should be considered. (For more details, see “Shear Walls” in Chapter 4A “Components” and Reference 3.)

REFERENCES:

1. Chapter 3.5.2, “Shear Wall Systems: Principles of Shear Wall Buildings,” MNL-120-04: *PCI Design Handbook, Sixth Edition*.
2. Chapter 3.5.1, “Shear Wall Systems: Introduction,” MNL-120-04: *PCI Design Handbook, Sixth Edition*.
3. Chapter 3.5.4, “Design Guidelines for Shear Wall Structures,” MNL-120-04: *PCI Design Handbook, Sixth Edition*.

RESOURCES:

MNL-120-04: *PCI Design Handbook, Sixth Edition*.

LOADBEARING WALL PANELS

Often the most economical application of architectural precast concrete is as a loadbearing component, which resists and transfers loads applied from other components. These loadbearing members cannot be removed without affecting the strength or stability of the building.

Concrete components normally used for cladding applications, such as solid-wall panels, window walls, or spandrel panels, have an impressive structural capability. With few modifications, many cladding panels can function as loadbearing members. The reinforcement required to physically handle and erect a unit is often more than necessary for in-service loads.

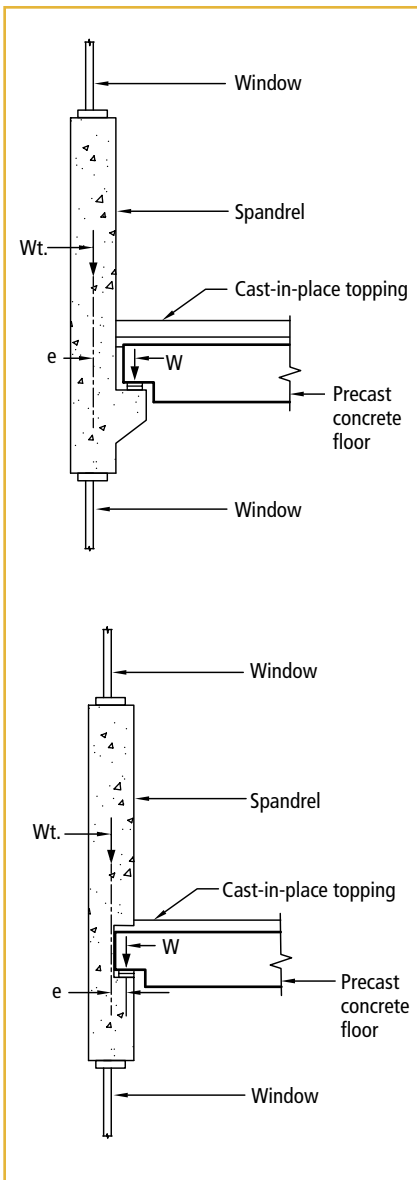
The slight increase in costs for loadbearing wall panels, due to reinforcement and connection requirements, can be offset by the elimination of separate structural frames (beams and columns) for exterior walls or by a reduction of interior shear walls. This savings is most apparent in buildings with 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, flexibility of partition layout can be improved.

To realize the full potential of these components with no sacrifice in aesthetic advantages, the structural engineer should be involved from the initial-concept stage. Considerations should include the load effects on member dimensions, coordination of temporary bracing, connections, and erection sequencing.

Loadbearing panels can be supported by continuous footings, isolated piers, grade beams, or transfer girders. The bearing-wall units can start at an upper-floor level with the lower floors framed with beams and columns.



The all-precast concrete structural system includes double tees, inverted tee beams, shear walls, and loadbearing precast walls. The system is a common approach to design in the Rocky Mountain region.



Loadbearing spandrels.

Window-wall panels also can be loadbearing if desired. Since these panels are usually custom-made for specific projects, the designer can take advantage of the self-contained columns and girders inherent in the cross section of these panels by designing haunches to provide bearing for floors. Spandrels can also be made into loadbearing components. (See Reference 1 for details on the previous section.)

DESIGN CONSIDERATIONS

Most design considerations for non-loadbearing wall panels must also be considered in the analysis of loadbearing wall panels. The design and structural behavior of exterior architectural precast concrete bearing-wall panels is dependent upon the panel shape and configuration, and they 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 the load, and manufacturing and erection tolerances.
- **Magnitude and distribution of lateral loads,** both wind and seismic, 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. For typical precast concrete structures, improved redundancy and ductility are achieved by connecting members into a load path to the lateral force-resisting system, which must be continuous to the foundation.
- **Location of joints to control volume-change movements** due to concrete creep, shrinkage, and seasonal temperature changes.
- **Connection concepts and types of connections** required to resist the various applied loads. In some cases, local practice may suggest one type of connection over another, such as the use of bolts rather than welds. All connections need to be accessible and allow for tolerances and adjustment.
- **Tolerances required for the structure** with regard to production and erection for both precast concrete units and connections, including tolerances for interfacing of different materials.
- **Specific design requirements during the construction** that may control designs, such as site accessibility.

The design of exterior walls using loadbearing architectural panels follows typical engineering procedures. However, designers must recognize the role that is played by precast concrete panel production and erection in the overall design process. Similarly, usually accepted procedures and code requirements apply to the design of an individual precast concrete panel and its connections.

In most cases, the gravity dead and live load conditions for most precast concrete exterior bearing-wall structures will control the panel's structural dimensions rather than load combinations, which include lateral loads.

Panels may be designed to span horizontally between columns or vertically between floors. The choice depends primarily on handling and erection requirements and the methods or details selected for making connections. When spanning horizontally, panels are designed as beams or, if they have frequent, regularly spaced window openings, they are designed as Vierendeel trusses. If a large

portion of the panel contains window openings, it may be necessary to analyze it as a rigid frame (see Reference 2).

SHAPES AND FINISHES

In multistory buildings, the loadbearing wall panels can be several stories in height up to the maximum transportable length, or they can be one-story high and connect at every floor level. The architectural requirements generally govern the design. The variety of shapes and surface finishes commonly associated with cladding can be provided, if the structural and other technical requirements can be satisfied.

By extending loadbearing panels vertically through several stories, complex connection details are minimized and the economic advantages of loadbearing wall panels are increased.

Architectural requirements normally dictate that building elevations have wall panels of the same appearance. As a result, the wall panels receiving the greatest gravity loads should be determined and panel units should be designed interchangeably with the same reinforcing in all panels. This allows any panel to be installed at any point on the structure's exterior, since the floor plan of a loadbearing panel building is usually the same on all stories, producing uniform loads on the building perimeter.

In most cases, there is little need to be concerned with differential foundation settlement. This is one of the most important advantages for high-rise, loadbearing panel structures where the bearing walls also serve as shear walls.

REFERENCES:

1. Chapter 2, Section 2.6, "Loadbearing Wall Panels or Spandrels," PCI MNL-122-07: *Architectural Precast Concrete, Third Edition*.
2. Chapter 4, Section 4.2.5, "Design Considerations for Loadbearing Wall Panels," PCI MNL-122-07: *Architectural Precast Concrete, Third Edition*.

RESOURCES:

- MNL-120-04: *PCI Design Handbook, Sixth Edition*.
PCI MNL-122-07: *Architectural Precast Concrete, Third Edition*.

MOMENT-RESISTING BUILDING FRAMES

Moment-resisting frames are those in which a degree of rotational restraint is provided between vertical components (usually columns) and horizontal components (usually beams and/or spandrels). This system then resists lateral loads imposed on the structure.

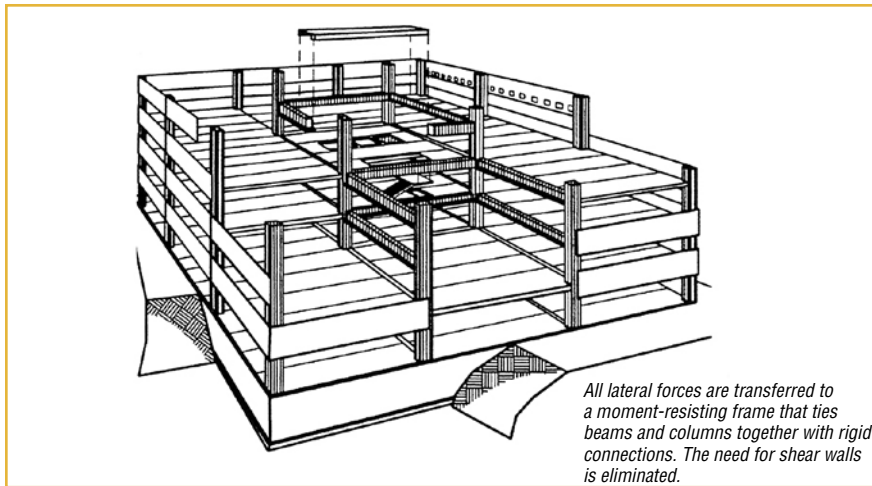
Precast, prestressed concrete beams and deck members are usually more economical when they are designed and connected into a structure as simple-span members. There are three reasons why this works most effectively:

- 1. Positive moment-resisting capacity is much easier and less expensive** to achieve with pretensioned members than negative-moment capacity at supports.
- 2. Connections that achieve continuity at the supports are usually complex.** Their cost is proportional to the complexity that makes moment-resistant frames less attractive for designers.

3. The restraint-to-volume changes that occur in rigid connections require serious consideration in the design of moment-resisting connections.

It is desirable to design precast, prestressed concrete structures with connections that 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.

When moment connections between beams and columns are required to resist lateral loads, it is desirable to make the moment connections after most of the dead loads have been applied. This requires careful detailing, specification of the construction process, and inspection. If such details are possible, the moment connections should be designed to resist only the negative moments from live loads, additional dead loads imposed after construction, lateral loads, and volume changes. They will thus be less costly (see Reference 1).



The ACI 318-05 Building Code defines three categories of moment frames: ordinary moment frames, intermediate moment frames, and special moment frames. Each type must comply with certain sections of the code. It is recommended that a qualified structural engineer with experience in designing moment frame structures be consulted early in the design stage.

Ordinary moment frames are the easiest to create and require only conventionally accepted detailing. They need only comply with Chapters 1 through 18 of the code.

Intermediate moment frames must comply with sections 21.2.2.3 and 21.12 of ACI 318-05 in addition to the requirements for ordinary moment frames. These provisions are relatively easy to satisfy using precast, prestressed concrete construction.

Special moment frames for seismic design must comply with other sections of Chapter 21 of the code. They will require more attention to detailing requirements, making the system more costly.

It is possible to emulate a monolithic, cast-in-place, intermediate moment-frame system with precast concrete components that meets all the requirements of ACI code.

Recently introduced designs use existing precast concrete components and technologies in new ways to create seismic-resistant systems that cannot be duplicated with other materials. The systems have been tested to satisfactory results in the Precast Seismic Structural Systems (PRESSSS) research program. For details on these systems, see Chapter 3H, "Safety & Security: Earthquake Resistance."

REFERENCES:

1. Chapter 3.6, "Moment-Resisting Building Frames," MNL-120-04: *PCI Design Handbook, Sixth Edition*.

RESOURCES:

IBC-1-01: Impact of the Seismic Design Provisions of the International Building Code, MNL-120-04: *PCI Design Handbook, Sixth Edition*.

PCI JOURNAL:

"Ductile Connections in Precast Concrete Moment Resisting Frames," *PCI Journal*, May-June 2006, pp. 66-77.

HYBRID SYSTEMS



DESIGNING WITH PRECAST & PRESTRESSED CONCRETE



*Mariott Pewaukee West, Pewaukee, Wis.;
Architect: FRCH Design Worldwide;
Photo: The Spancrete Group Inc.*

Precast concrete components can be combined with other construction materials, particularly steel or cast-in-place concrete, to create a “hybrid” system. Examples include architectural precast concrete cladding supported on a structural steel or cast-in-place concrete frame as well as precast, prestressed double tees or hollow-core used as the floor system on a parking garage where the main structure is steel.

Whenever two materials are combined to create one structural system, the attributes of each material must be evaluated and addressed to ensure the proper outcome. The appropriate steel and cast-in-place concrete standards should be applied in all cases, and it must be remembered that the standards for each material do not apply to buildings of composite construction, such as with concrete floor slabs supported by steel columns or with concrete-encased, structural-steel members or fireproofed frames.

STRUCTURAL-STEEL FRAMING SUPPORTING ARCHITECTURAL PRECAST CONCRETE CLADDING

Structural-steel-framing tolerances should conform to standards issued by the American Institute of Steel Construction. Precast concrete panels should follow the steel frame as erected, because the allowable tolerances for steel-frame structures make it impractical to maintain precast concrete panels in a true vertical plane in tall structures. The adjustments that would be required to make the connections practical are not economically feasible.

A practical and economical solution is to specify the more stringent AISC elevator-column erection tolerances for steel columns used in the building façade that will receive the precast concrete panels.

A structural-steel-frame building presents different erection and connection considerations from a concrete-frame building. For example, structural-steel beams, being relatively weak in torsion when compared to concrete, generally require the load to be applied directly over the web or that the connection be capable of supporting the induced torsion. This in turn places a greater structural requirement on the connection and creates difficulties during erection if any rolling behavior occurs in the steel beam.

Observations in the field have shown that where precast concrete panels are erected to a greater height on one side of a multistory, steel-framed building than on the other, the steel framing will be pulled out of alignment. Precast concrete panels should be erected at a relatively uniform rate around the perimeter of the structure. If this does not happen, the designer of the structural frame should determine the degree of imbalanced loading permitted (see Reference 1).

STRUCTURAL-STEEL FRAMING SUPPORTING A PRECAST,



Meridian, Columbia, S.C.;
Architect: SWSC; Photo: ©2003 Brian C. Robbins,
Robbins Photography Inc.

PRESTRESSED CONCRETE FLOOR SYSTEM

At times, it may be beneficial to create a structural-steel frame that supports either double tees or hollow-core plank as the floor and roof system. This has been used in parking structures, office buildings, and other applications. The objective in all cases should be to utilize the positive attributes of each material to its best advantage such as the resistance to corrosion of double tees used in a parking garage.

As noted above, consideration must be given to the different standards governing the materials to be used.

CAST-IN-PLACE CONCRETE FRAMES

Cast-in-place concrete frame tolerances are given in *ACI 117, Standard Tolerances for Concrete Construction and Materials*, unless otherwise stated in the specifications.

These tolerances are not realistic for tall buildings. In addition, greater variation in heights between floors is more prevalent in cast-in-place concrete structures than in other structural frames. This can affect the location or matching of the inserts in the precast concrete units with the cast-in connection devices. Tolerances for cast-in-place concrete structures may have to be increased to reflect local trade practices, the complexity of the structure, and climatic conditions.

It is recommended that precast concrete walls should follow concrete frames in the same manner as for steel frames, if the details allow it and appearance is not affected.

Unless the cast-in-place structure is executed to above normal tolerances, the width of joints must be designed to allow for a large tolerance. The actual joint width may differ in each bay and will certainly require sealants with corresponding flexibility. Joint widths may be adjusted to allow them to be equal at either end of a panel, but equalizing the joints on either side of a column should not be done unless panels can be adjusted horizontally after erection. The problems this can cause are avoided where the cladding passes in front of the columns and the jointing is between the panel edges (see Reference 2).

REFERENCES:

1. Chapter 4, Section 4.6.3, "Erection Tolerances: Structural Steel Framing," PCI MNL-122-07: *Architectural Precast Concrete, Third Edition*.
2. Chapter 4, Section 4.6.3, "Erection Tolerances: Cast-In-Place Concrete Frame," PCI MNL-122-07: *Architectural Precast Concrete, Third Edition*.

RESOURCES:

- MNL-120-04: *PCI Design Handbook, Sixth Edition*.
PCI MNL-122-07: *Architectural Precast Concrete, Third Edition*.

TOTAL-PRECAST CONCRETE SYSTEMS

Total-precast concrete structures (TPS) provide all the benefits of precast construction, with added value as a result of integrating structural, architectural, and other building systems. Architecture is combined with structure by integrating the exterior façade into a loadbearing system. Vertical shaft construction combines personnel and Mechanical, Electrical, and Plumbing (MEP) delivery systems with structural systems and advances construction access vertically through the project. MEP integration allows for the most efficient mechanical, electrical, and plumbing systems to be utilized, while structural and architectural systems are coordinated to accommodate necessary physical space requirements. Other peripheral systems such as windows, interior finishes, and embedded hardware are readily integrated into what was previously raw, core-shell construction.

Designing and constructing a total-precast concrete system requires familiarity with precast concrete design, fabrication, and delivery methods, so that maximum value can be realized. For owners, TPS may require financial decisions earlier than traditional program scheduling. Designers will be required to coordinate many of the integrated systems at earlier stages than normal program scheduling. Precast concrete manufacturers may be chosen at earlier stages of this process, many times at or prior to contractor selection. Working through these challenges effectively allows the owner to fully capture maximum value.

There are operational challenges that require advance planning. Size and weight constraints play a significant role in the design and cost profile of the precast concrete system components, making accurate and thorough operational knowledge an important part of early project discussions.



*NBSC Headquarters building, Greenville, S.C.;
Architect: Neal + Prince & Partners;
Photos: Metromont Corporation.*

Scheduling

Owners should be encouraged to expedite procurement of the required precast concrete knowledge and expertise, usually through a qualified producer who can supply the project needs. This can be accomplished either through design-build procurement or direct negotiation with a precast concrete supplier.

Traditionally, a design team might move through the schematic design (SD)/ design development (DD) phase of a project and into construction documents (CD), without intensive consideration of system integration. With TPS, this integration begins shortly after the SD phase, if not immediately at the onset of design schematics. With proper planning and the inclusion of experienced design professionals, this process flows smoothly. Effort normally allotted to the CD and construction administration (CA) phases of a project are significantly shifted to the SD and DD phases, as functional systems and finishes are integrated into the basic core/shell design. This allows both the contracting group and design team to operate more effectively once construction commences, as the major core/shell coordination is substantially complete and emanating from a sole source, the precast concrete manufacturer/erector. Contractors and designers spend less effort coordinating conflicts and more time with forward planning of site and interior finishes.

Architectural Design

To obtain the maximum benefit for the owners as finishes and systems are integrated into TPS, the architect must understand simple challenges such as size and weight of precast concrete components planned for the structure. Many elements of the architect's design palette are affected by these simple parameters and therefore they should be understood early in the design process.

Exterior finishes, reveal patterns and panel shapes all require attention to panel thickness and concrete cover. The structural support wall panels provide often require minimum panel thickness for proper detailing of floor or roof elements such as hollow-core or double tees. These details must be combined to ensure the final finish quality is of appropriate quality and acceptable appearance.

Window tolerances and detailing requires careful consideration of how openings are sized, located, and coordinated with the reveal or rustication design required on exterior surfaces. With careful detailing, site tolerances can be made more liberal without negatively impacting the aesthetic design.

Panelization of the exterior façade defines joinery that can be manipulated within these detailing constraints, to accomplish required aesthetics. Strangely enough, mundane issues such as shipping and handling may become the challenges that will require the most attention. For every project location, there are weight and size constraints required for shipping that the local precaster can identify and help coordinate. In addition, specific operational limitations that are both plant- and site-driven, can sometimes influence panel weight and size limitations.

Various patterns integrated into formwork. Nimitz-MacArthur Pacific Command Center, Oahu, Hawaii; Architect: Wimberly Allison Tong & Goo Design; Photos: Gary Hofheimer Photography.



Structural Design

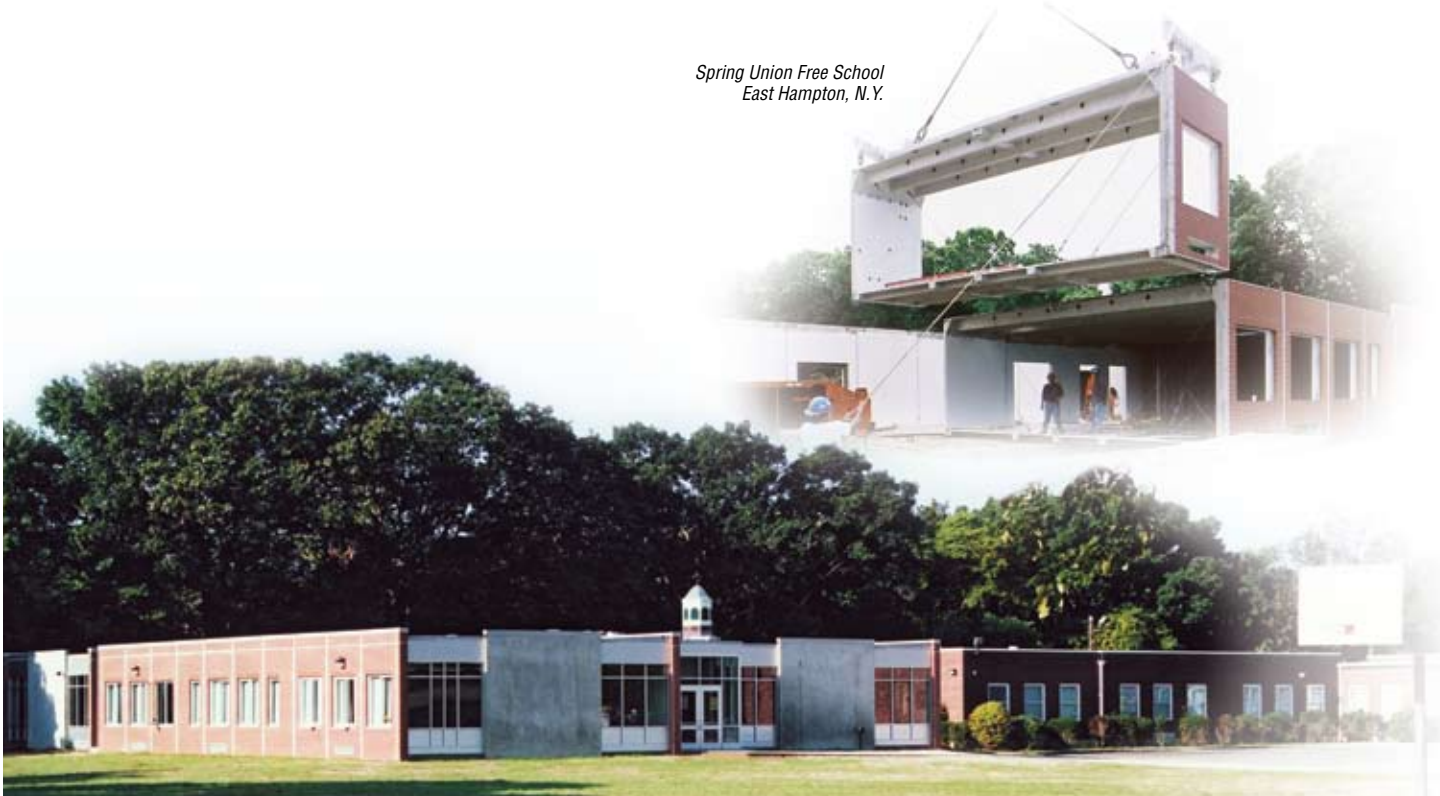
As architecture and building systems are integrated into the structural system, the precast concrete design engineer is presented with new and varied challenges. With proper team coordination and knowledgeable resources, the engineer can create the necessary structural system while accounting for this integration.

Notches and setbacks are particularly challenging in any structural system. TPS must carry the weight of the loadbearing façade when these design features are required. Utilizing transfer beams, prestressing capabilities, and other panelization techniques, these types of features can be effectively crafted into the final structural design.

Floor-to-floor height requirements for MEP systems are coordinated through design modification to the main girders, dapping of double-tee floor components, or by providing pre-coordinated openings in the precast framing. While many openings can be readily field cut, it is advantageous and cost effective to incorporate as much of this in the manufacturing process as possible.

Early coordination provides a good opportunity to combine foundation systems into total-precast concrete systems, particularly when using grade beam/pier foundations. Below-grade foundation wall systems and other foundation-related systems can be readily integrated into the TPS, providing the contractor/owner with added scheduling flexibility (see Reference 1).

*Spring Union Free School
East Hampton, N.Y.*



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- "Team Perspective On Total-Precast Structures," *ASCENT*, Fall 2003, pp. 10-14.
- "Total Precast Concrete Offers Multiple Benefits," *ASCENT*, Spring 2005, pp. 24-26.
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- "Total Precast Systems' Basic Building Blocks," *ASCENT*, Summer 2005, pp. 22-25.
- "Universities Exploit Precast For Mixed-Use Projects," *ASCENT*, Summer 2004, pp. 24-27.
- "University of Georgia Carlton Street Parking Structure, Special Awards," *ASCENT*, Fall 2002, p. 10.

PCI JOURNAL:

- "All-Precast Concrete Design Delivers On-Time Opening for Florida's LECOM Medical Students," *PCI Journal*, January-February 2006, pp. 82-97.
- "All-Precast Concrete Design for the Saratoga Street Parking & Office Structure for the University of Maryland," *PCI Journal*, March-April 2004, pp. 34-47.
- "All-Precast Concrete School of Architecture Creates Striking Identity for Florida International University," *PCI Journal*, July-August 2004, pp. 58-71.
- "Aurora Municipal Center's Stunning Design Showcases the Possibilities of Precast Concrete Solutions," *PCI Journal*, November-December 2004, pp. 80-93.
- "Deerwood North Building 300, Jacksonville, Fla.," *PCI Journal*, September-October 2004, pp. 136-139.
- "Energy Park Corporate Center, St. Paul, Minnesota," *PCI Journal*, March-April 2005, pp. 136-141.
- "Hopi Health Center—An All-Precast Concrete Hospital in the Desert," *PCI Journal*, July-August 2001, pp. 44-55.
- "Precast Parking Structures Enhance the Shops at Willow Bend," *PCI Journal*, September-October 2001, pp. 36-45.
- "UGA's Carlton Street Parking Facility Meets University Demands for Construction Speed and Aesthetics," *PCI Journal*, November-December 2002, pp. 26-47.



Connections

Connections are fundamental to all buildings and construction no matter what material is used. The purpose of a connection is to transfer loads, restrain movement, and/or to provide stability to a component or an entire structure. As such, the design of connections is one of the most important aspects in the design and engineering of precast/prestressed concrete structures.

Many different connection details will result from the combination of the multitude of sizes and shapes of precast concrete components and the variety of possible support conditions. Individual precasters have developed connection details over the years that suit their particular production and erection preferences and they should be considered for a specific project early in the design stage. All connections should comply with applicable building codes and the final structural design should be done by an engineer licensed in the location of the project. It is common for the architect and engineer of record to show connection loads and locations on the contract documents and allow the successful manufacturer's engineering department to provide the final design and details of the connections.

This section is intended to provide basic information that is important to understand when designing a total-precast concrete structure or architectural cladding panels supported by building frames of other materials such as steel or cast-in-place concrete.



Photo: ©PhotoDisc.

DESIGN CONSIDERATION

Precast concrete connections must meet a variety of design and performance criteria and not all connections are required to meet the same criteria. The basic criteria include:

Strength A connection must have the strength to avoid failure during its lifetime.

Ductility This is the ability of a connection to undergo relatively large deformations without failure. Ductility is achieved by designing the connection so that steel devices used yield before a weld or the concrete around the connection.

Volume Change Accommodation Restraint of movement due to creep, shrinkage, and temperature change can cause large stresses in precast concrete components and their connections. It is better to design the connection to allow some movement, which will relieve the build-up of these stresses.

Durability When the connection is exposed to weather or used in a corrosive environment, steel elements should be adequately covered by concrete, painted, epoxy-coated, or galvanized. Stainless steel may also be used, however, the added cost should be considered carefully.

Fire Resistance Connections, which could jeopardize the structure's stability if weakened by high temperatures from a fire, should be protected to the same degree as the components that they connect.

Constructability The following reflects only some of the items that should be considered when designing connections:

- Standardize connection types
- Avoid reinforcement and hardware congestion
- Avoid penetration of forms
- Reduce post-stripping work
- Consider clearances and tolerances of connection materials
- Avoid non-standard product and erection tolerances
- Plan for the shortest-possible crane hook-up time
- Provide for field adjustments
- Provide accessibility
- Determine if special inspection is required per the applicable code for the material and the welding process
- Provide as direct a load path as possible for the transfer of the load

Aesthetics For connections that are exposed to view in the final structure, the designer should incorporate a visually pleasing final product.

Seismic Requirements Structures and/or components that must be designed for seismic loads may require special consideration. Consultation with a structural engineer with experience in seismic design is recommended.

Tolerances The designer must realize that normal allowable fabrication, erection, and interfacing tolerances preclude the possibility of a perfect fit in the field.

CONNECTION MATERIALS

A wide variety of connection hardware and devices is used in the precast concrete industry including:

Headed Concrete Anchors (studs) are round bars with an integral head. These are typically welded to plates to provide anchorage to the plate.

Steel Shapes including wide flanges, structural tubes, channels, plates, and angles.

Reinforcing Bars are typically welded to steel sections to provide anchorage to the steel.

Reinforcing Bar Couplers are typically proprietary devices for connecting reinforcing bars at a joint. Manufacturers of these devices can provide technical information.

Deformed Bar Anchors are similar in configuration to deformed reinforcing bars and are welded to steel shapes to provide anchorage similar to headed concrete anchors.

Bolts and Threaded Connectors are used in many precast concrete connections. Use of ASTM A36 or A307 bolts is typical. Use of high-strength ASTM A325 and A490 is usually not required.

Specialty Inserts are available from many manufacturers of these devices. They include standard threaded inserts, coil threaded inserts, and slotted inserts that provide for tolerances and field adjustment.

Bearing Pads are used predominantly for structural applications to support beams, double tees, and similar components. Use of random fiber oriented bearing pads (ROF) is recommended.

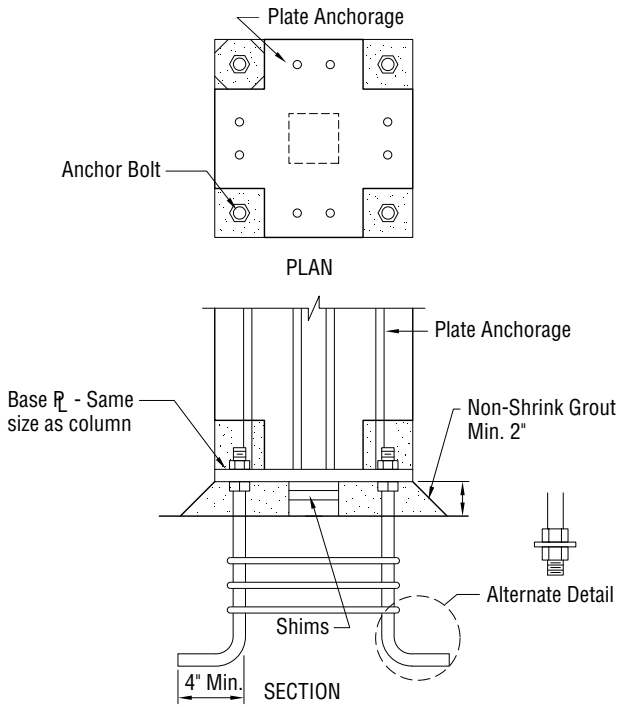
Shims can be hard plastic or steel and are often used to provide adjustment to align a precast concrete component for elevation or horizontal alignment.

For the proper use and design of these and other materials reference the *PCI Design Handbook 6th Edition* (MNL 120-04) or the *PCI Connections Manual* (MNL 138-08).

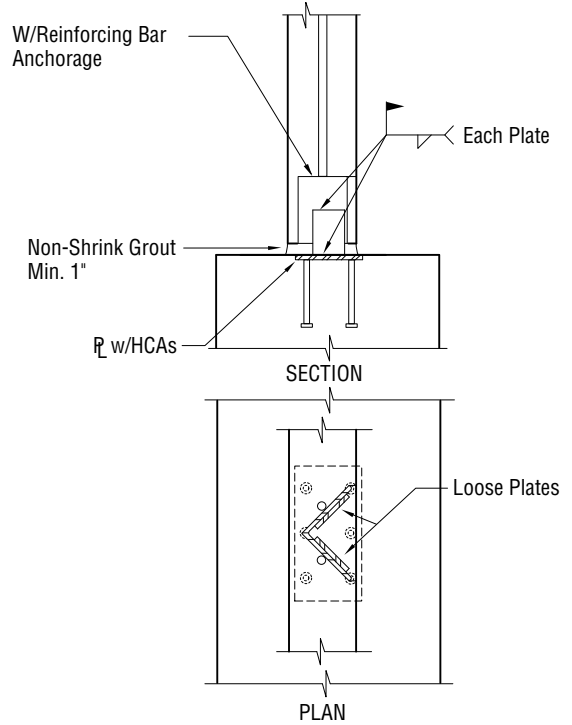
connection types

STRUCTURAL

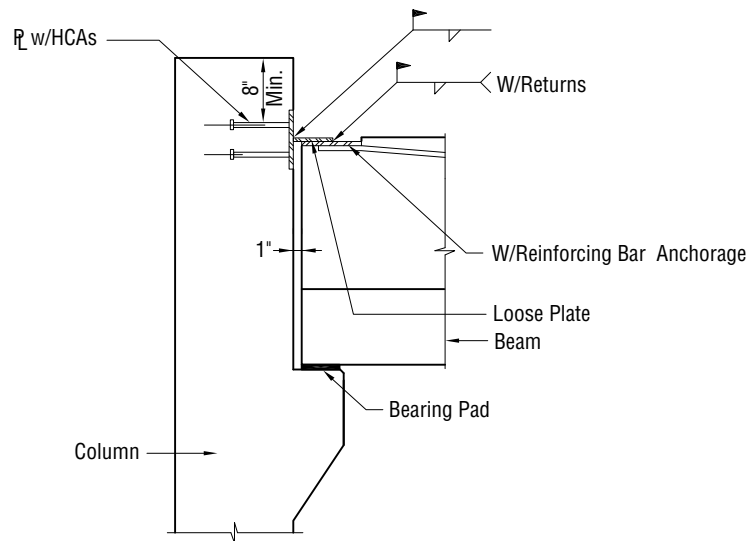
COLUMN BASE PLATE



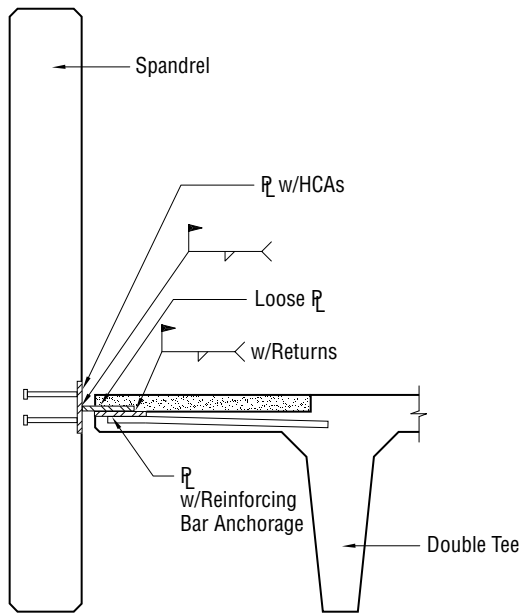
PANEL TO FOOTING



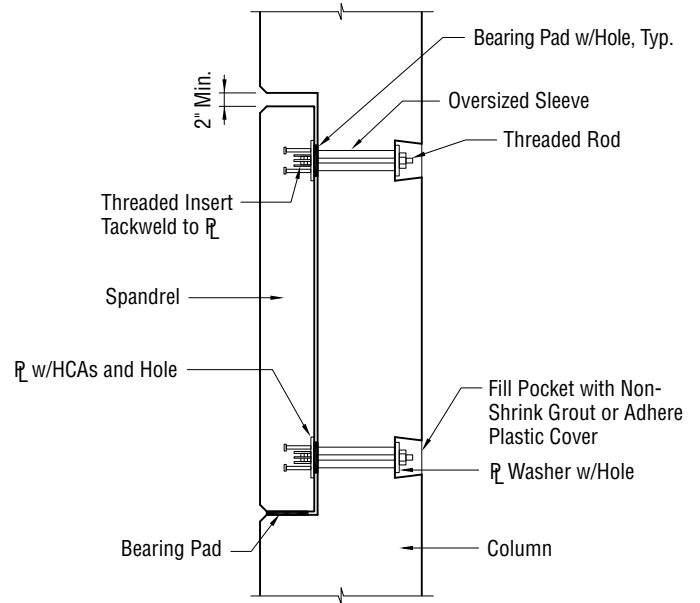
BEAM TO COLUMN WITH CORBEL



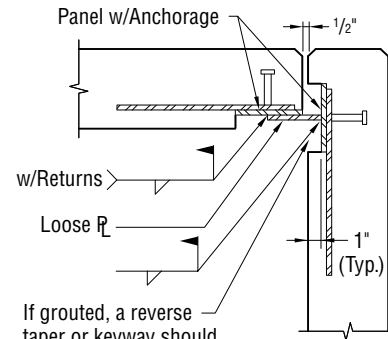
SPANDREL TO DOUBLE TEE



SPANDREL TO COLUMN



PANEL TO PANEL CORNER

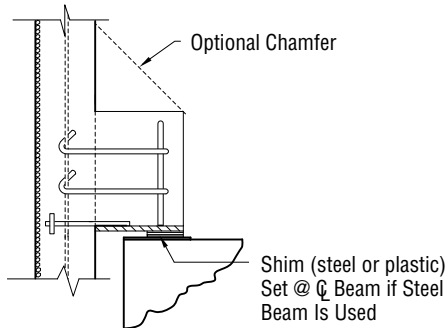
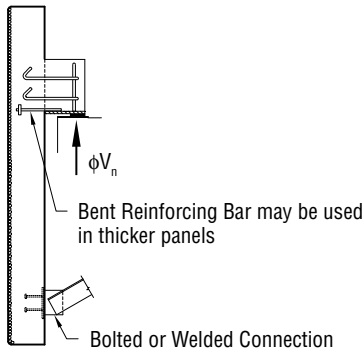


If grouted, a reverse taper or keyway should be placed around the blockout to lock the patch into the recess

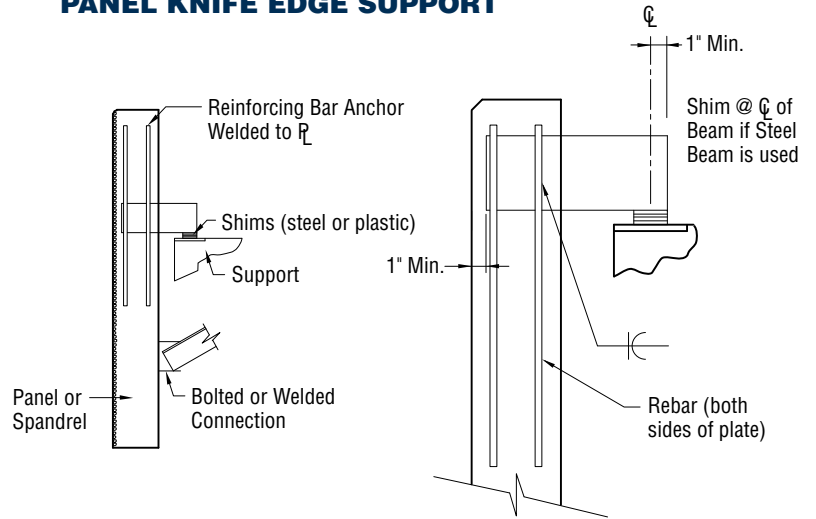
connection types

CLADDING

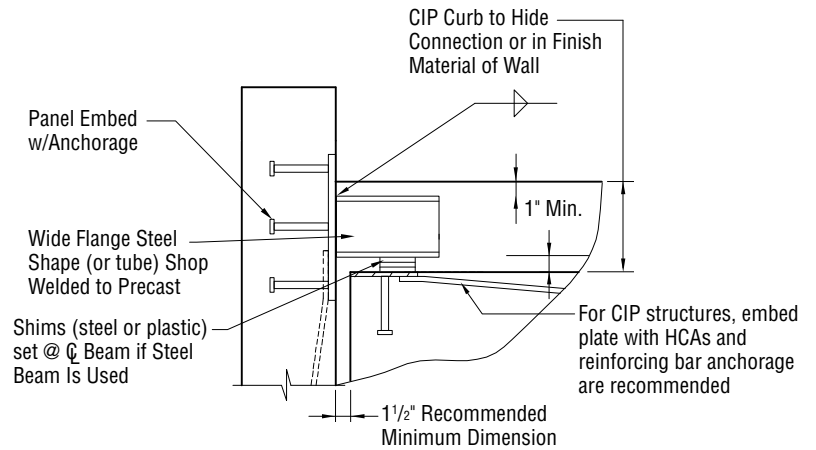
PANEL CONCRETE CORBEL SUPPORT



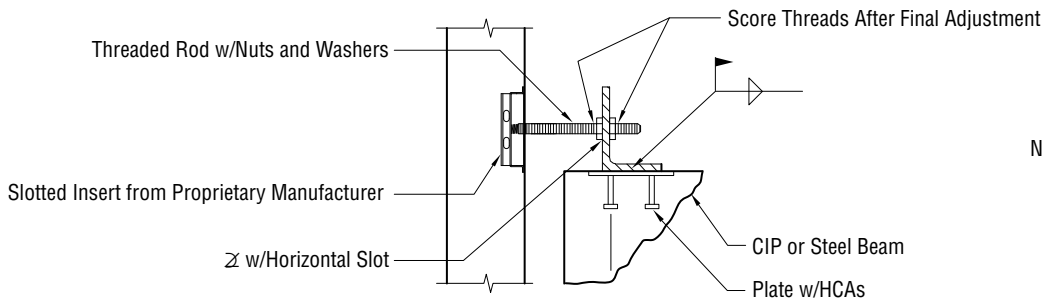
PANEL KNIFE EDGE SUPPORT



PANEL STEEL CORBEL SUPPORT

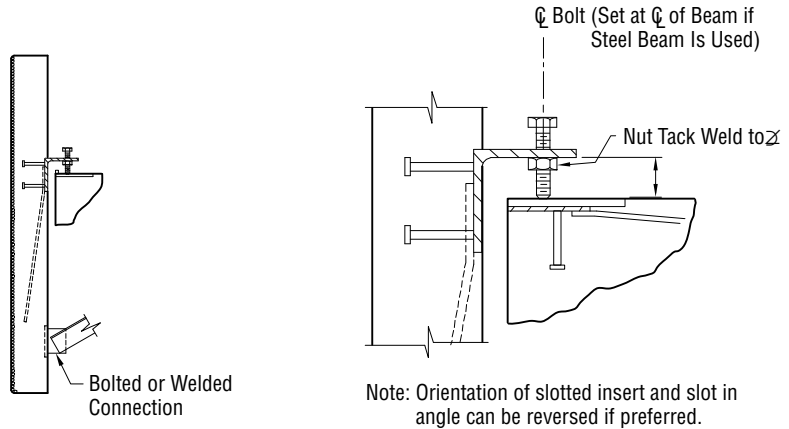


PANEL TIE BACK



Note: Orientation of slotted insert and slot in angle can be reversed if preferred.

PANEL ADJUSTABLE SUPPORT



Tips For Successful Connection Design:

- Do** use bearing pads for support of beams, spandrels, double tees, and other structural components.
- Do** consider deflection behavior of a member that is supporting a precast component.
- Do** design for support using only 2 points.
- Do** provide at least four tie back connections for a cladding panel.
- Do**, if designing a cladding panel for seismic loads, use an in-plane seismic connection close to the panel's center of gravity.
- Do** account for eccentric loading and the effect it may have on the rotation of supporting members, particularly if they are steel beams.
- Do** consider the horizontal forces resulting from an eccentrically loaded component and the effect this has on the support.
- Do** provide points of support only at one level for multilevel cladding panels.
- Do** design connections so that the component can “move” as a result of temperature variations and volume changes.
- Do Not** design connections with the **bearing locations** welded at both (top and bottom) ends of a prestressed concrete component. Making welded connections at the **tops** of prestressed concrete components at both **ends** is typical.
- Do** consider the allowable tolerances of the precast concrete component and the supporting structure.
- Do** consider intermediate connections of long spandrel panels to avoid bowing due to temperature variations.

RESOURCES:

PCI Design Handbook, 6th Edition
(MNL 120-04).

PCI Architectural Precast Manual, 3rd Edition
(MNL 122-07).

PCI Connections Manual, 2nd Edition
(MNL 123-88).

*PCI Connections Manual for Precast and
Prestressed Concrete Construction, 1st Edition*
(MNL 138-08).



CHAPTER
PRECAST CONCRETE
GUIDE SPECIFICATIONS

five

Architectural & Structural



For more information on the guide specifications and on general practices, see Chapter 10, "Specifications and Standard Practices" in PCI's MNL-120-04: *PCI Design Handbook, Sixth Edition*.

The precast, prestressed concrete industry has grown rapidly, and certain practices relating to the design, manufacture, and erection of precast concrete have become standards in many areas of North America. As a result, the *Code of Standard Practice for Precast Concrete* has been compiled and presented in the form of recommendations for the guidance of those involved with the use of structural and architectural precast concrete.

The goal of the code is to build a better understanding of precast concrete by suggesting standards and practices that more clearly define procedures and responsibilities, thus resulting in fewer problems for everyone involved in the planning and execution of projects.

As the precast, prestressed concrete industry continues to evolve, additional practices will become standard and current standards will require modification. PCI will continue to revise the code and update this binder to ensure that designers remain current with standards and approaches to maximizing the benefits of precast concrete components.

ARCHITECTURAL GUIDE SPECIFICATIONS

Architectural precast concrete is characterized by a higher standard of uniformity of appearance with respect to surface details, color, and texture than that of structural precast concrete. Typical architectural precast concrete elements fall into two groups:

1. Major primary elements, including wall panels, window-wall panels, and column covers; and
2. Other components, such as decorative pieces and trim units, including copings, mullions, sills, and appurtenances such as benches and bollards.

To avoid misunderstandings, it is important that the contract documents for each project list all the components that are considered to be architectural precast concrete. Quality assurance for architectural precast concrete is defined in PCI's MNL-117-96: *Manual for Quality Control for Plants and Production of Architectural Precast Concrete Products, Third Edition*.

Guide specifications for architectural precast concrete that designers can use to create their specifications are available from PCI in electronic form. These specifications must be edited to fit the conditions of use for each specific project. Particular attention must be given to the deletion of inapplicable provisions. Necessary items related to a particular project should be included, and appropriate requirements should be added where blank spaces are provided.

For more information on the guide specifications and on general practices, see Chapter 10, "Specifications and Standard Practices" in PCI's MNL-120-04: *PCI Design Handbook, Sixth Edition*.

STRUCTURAL GUIDE SPECIFICATIONS

Structural precast concrete usually includes a variety of components. These include:

beams	column covers	columns
double tees	hollow-core slabs	insulated sandwich wall panels
litewalls	modular units	mullions
piles	raker beams	shearwalls
sheet piles	solid slabs	spandrels
stadium risers	stairs	wall panels

To avoid misunderstandings, it is important that the contract documents for each project list all of the elements that are considered to be structural precast concrete components.

Some structural members may be left exposed in the structure for desired aesthetic purposes. High-quality, attractive architectural treatments may be provided on the surface of these structural elements, and these should be specially listed in the contract documents. Quality assurance for structural precast concrete and structural precast concrete with an architectural finish is defined in PCI's MNL-116-99: *Manual for Quality Control for Plants and Production of Structural Precast Concrete Products*.

Guide specifications for structural precast concrete that designers can use to create their specifications are available for designer from PCI in electronic form. These specifications must be edited to fit the conditions of use for each specific project. Particular attention must be given to the deletion of inapplicable provisions. Necessary items related to a particular project should be included, and appropriate requirements should be added where blank spaces are provided.



CHAPTER

SIX

PCI RESOURCES

Design Tools

APC-1-98: *Collection of Ideas on the Production of Architectural Precast Concrete*

This 84-page book discusses some of the key considerations when fabricating architectural precast concrete components. Included are production practices, raw materials and accessories, concrete requirements, reinforcement and pre-stressing, quality control, and product tolerances.

APC-2-02: *Successful Planning With Architectural Samples*

This six-page article reprint from PCI's *ASCENT* magazine, written by Architectural Director Sidney Freedman, discusses the benefits provided by mockup samples prior to beginning fabrication. Key topics include development of samples, budgeting for samples, comparing samples to production runs, mockups for production approval, and assessment of samples.

BM-20-04: *Precast, Prestressed Concrete Piles Manual, Chapter 20*

First printed as a chapter in PCI's *Bridge Design Manual* (MNL-133), it is reprinted in this form to aid designers and others with an interest in precast, prestressed concrete piles. It includes sections on pile characteristics and materials, geotechnical and structural design, pile-to-cap connections, manufacturing, transportation, and installation. Design examples are also presented.



CD-IGS-1-00: Housing CD-ROM

This business card-sized CD-ROM for PCs provides an overview of how precast concrete components can be used in the housing industry. It includes explanations of applications and case histories for single-family homes, multifamily buildings, hotels and motels, retirement centers, and assisted-living facilities.

CD-IGS-3-01: Stadiums CD-ROM

This business card-sized CD-ROM for PCs provides an overview of how precast concrete components can be used to design stadiums, arenas, and theaters. It includes explanations of design applications and case histories for a variety of community, university, and professional sports stadiums around the country.

CD-IGS-4-01: Hollow-core CD-ROM



This business card-sized CD-ROM for PCs provides an overview of how precast concrete hollow-core planks are fabricated and the advantages they offer to a variety of building projects. Connection details, field requirements, and a variety of case histories are offered.

CD-IGS-5-01: Industrial CD-ROM

This business card-sized CD-ROM for PCs provides an overview of how precast concrete components aid in the design and construction of industrial facilities. Short- and long-term advantages, along with case histories, are presented to show how the components are used with warehouse/distribution centers, manufacturing plants/assembly facilities, retail stores, food-processing plants, and high-tech lab/manufacturing operations.

CD-IGS-6-02: Parking CD-ROM

This business card-sized CD-ROM for PCs provides an overview of how precast concrete components can be used to design parking structures. Included are advantages offered by these systems, as well as how various components work together, connection details, aesthetic options, lighting and security considerations, maintenance issues, and a range of case histories.

CD-IGS-8-02: Commercial Building CD-ROM

This business card-sized CD-ROM for PCs provides an overview of how precast concrete components can be used to design commercial buildings of all types. A range of applications is presented, including office buildings, corporate campuses, financial centers, institutional and public facilities, mixed-use structures, and retail stores. Sections discussing the inherent value of architectural precast concrete wall panels and the benefits of using structural precast concrete components in these facilities is also provided. A section also covers the applications for GFRC.

DN: Designer's Notebook Series

This series of seven-page articles, originally presented in PCI's quarterly *ASCENT* magazine, provides detailed techniques for handling different aspects of architectural precast concrete components to enhance design attributes. The series includes diagrams, charts and standard applications along with the how-to text. Many of the articles also include a first-person account from an architect who reviews his firm's use of precast concrete in this context. The series includes:

DN-01-98: Designer's Notebook: Bullnoses.

DN-02-98: Designer's Notebook: Cornices.

DN-03-98: Designer's Notebook: Reveals.

DN-04-98: Designer's Notebook: Multiple Mixes/Textures.

DN-05-99: Designer's Notebook: Window Panels.

DN-06-99: Designer's Notebook: Corners & Returns.

DN-07-00: Designer's Notebook: Stone Veneer.

DN-08-00: Designer's Notebook: Clay Products.

DN-09-01: Designer's Notebook: Radiused Precast Concrete.

DN-10-01: Designer's Notebook: Sculptural Forms.

DN-11-02: Designer's Notebook: Design Economy.

DN-12-02: Designer's Notebook: Benefits & Advantages.

DN-13-03: Designer's Notebook: Specification Guidance (28 pp.).

DN-14-04: Designer's Notebook: Blast Considerations (28 pp.).

DN-15-06: Designer's Notebook: Energy Conservation (64 pp.).



GFRC-3-02: Innovation By Design: Glass Fiber Reinforced Concrete Cladding (16 pp.)

IBC-1-01: Impact of the Seismic Design Provisions of the International Building Code

This 48-page study was written by S.K. Ghosh of S.K. Ghosh Associates Inc., commissioned by the Alliance for Concrete Codes and Standards, and published by the Structures and Code Institute. It discusses the potential impact of the seismic-design provisions of the 2000 IBC that addresses concerns of design professionals, building and code officials, academics, and others.

Manuals and Books

MNL-115-68: Fundamentals of Prestressed Concrete Design

This 134-page book addresses some of the key provisions of precast concrete design, focusing on calculations, equations, and charts to acquaint engineers with the fundamental principles of designing prestressed concrete structural elements. Five key areas are covered: the properties of concrete and steel, design considerations involving flexure and shear, typical design examples, key features of guiding documents and codes, and general design considerations.

MNL-119-90: PCI Drafting Handbook, Second Edition

This manual presents a comprehensive overview of the techniques needed to effectively generate precast concrete shop drawings. It includes administration considerations, standards for drafting-room equipment and layout, drafting techniques and procedures, drawing preparation, the submittal/approval process, and other key aspects. The use of computer-aided drawing (CAD) is outlined in a separate, equal-sized section covering similar requirements. Appendixes cover terms, checklists, tolerances, and other aspects of both manual and CAD drafting.



MNL-120-04: PCI Design Handbook, Sixth Edition

This edition of the essential precast concrete manual was totally revamped and includes a CD-ROM with all guide specifications as well as a digital version of the handbook itself. The manual includes sections on applications and materials, design considerations, structural analysis, connection designs, tolerances, thermal and acoustical attributes, specifications, and other key topics. Its primary purpose is to aid in the structural design of precast concrete structures and components.

MNL-122-07: PCI Architectural Precast Concrete Manual, Third Edition

Tips and techniques for working with architectural precast concrete are outlined in this manual, which includes sections related to designing for economics, surface aesthetics, reinforcements, connections, tolerances, joints, and design considerations such as windows, energy conservation, acoustical properties, and fire resistance. Sections on designing precast concrete panels for use as cladding, loadbearing wall units, shearwalls, and formwork for cast-in-place concrete are also presented. Its primary purpose is to aid in designing architectural precast concrete structures and components.

MNL-123-88: Design and Typical Details of Connections for Precast and Prestressed Concrete (Second Edition)

This manual provides details on the variety of connections that can be used with precast concrete components to achieve an effective structural system. It presents information that will ensure proper consideration of compatibility of connection behavior with other materials and the overall structural system. Discussions include general considerations, design concepts, connection materials, design procedures and examples, typical connection details, and design aids.

MNL-124-08: *Design for Fire Resistance of Precast, Prestressed Concrete, Third Edition*

This manual provides an analytical method of evaluating the fire endurance of structures made of precast, prestressed concrete. It gathers information from many sources and presents it with example problems that illustrate the use of design aids and principles. Included are sections on the properties of steel and concrete at high temperatures, fire endurance of slabs and beams, heat-transmission requirements of ASTM E119, considerations with architectural precast concrete, and other topics.

MNL-126-98: *Manual for the Design of Hollow-Core Slabs, Second Edition*

This manual covers the primary design requirements for hollow-core floor and roof systems. It serves as a guideline for architects and engineers for the use and application of the products. Included are sections on hollow-core slab systems, designing slabs, diaphragm designs, connections, creating fire-resistant assemblies, and enhancing acoustical properties.

MNL-127-99: *Erectors' Manual: Standards and Guidelines for the Erection of Precast Concrete Products*

This manual provides standards that help ensure proper erection of precast, prestressed concrete products. The manual's goal is to establish a level of quality that will be recognized and respected by the construction industry. The book includes sections on preconstruction planning, practices and procedures, equipment, safety, tolerances, and quality control. Appendixes provide supplemental detail on drawings, welding, repairs, and other considerations.

MNL-128-01: *Recommended Practices for Glass Fiber Reinforced Concrete Panels, Fourth Edition*

This manual presents key considerations for designing, manufacturing, and installing GFRC panels and other components. It lays out project responsibilities and details materials, physical properties, design, tolerances, manufacturing requirements, quality control, delivery needs, and installation aspects.

MNL-129-98: *Precast, Prestressed Concrete Parking Structures: Recommended Practice for Design and Construction*

All aspects of designing parking structures using a variety of precast concrete components are outlined in this manual. It includes discussions of façade treatments, functionality, cost considerations, durability aspects, drainage, structural design, connections, production needs, and erection considerations. An appendix details maintenance needs (a more extensive version of this is available as MNL-136-04: *Maintenance Manual for Precast Concrete Parking Structures*).



MNL-130-91: *Manual for Quality Control for Plants and Production of Glass Fiber-Reinforced Concrete Products*

This manual serves as a guideline for manufacturing GFRC, which requires a greater degree of craftsmanship than other precast concrete construction products. The book focuses on quality-control requirements and discusses overall philosophy, product control, plant facilities, and materials.

MNL-135-00: *Tolerance Manual for Precast and Prestressed Concrete Construction*

This manual provides a working reference for the dimensional control of precast concrete products and construction, covering both plant-cast or site-cast as well as precast and precast, prestressed concrete. It covers all aspects of tolerances for production, erection, and interfacing, as well as feasibility, visual, economics, legal, and contractual considerations.

MNL-136-04: *Maintenance Manual for Precast Concrete Parking Structures*

This manual outlines key considerations for maintaining precast concrete parking structures to maximize their use while minimizing their care requirements. The book features photos of key areas for concern and provides timelines and checklists for inspecting and maintaining each aspect on a recommended schedule.

MNL-138-08: *PCI Connections Manual for Precast and Prestressed Concrete Construction*

This manual provides detailed diagrams and explanations of the various types of connections necessary to create interfaces among precast concrete components as well as with other materials. Included are sections on various types of connection materials and discussions of foundation designs, connections for beams, columns, double tees, spandrels, and other components. Calculations and examples of each are shown.



Architectural Precast Concrete Color and Texture Selection Guide, Second Edition, PCI, 2003

This loose-leaf binder provides large, four-color photos of a large variety of precast concrete finish textures and colors. Numbered color plates, two per page, provide architects with a detailed look at nearly 500 options for aggregates and finishes. Included are examples of acid etching, retarders, and various levels of sandblasting.

Visions Taking Shape: Celebrating 50 Years of the Precast/Prestressed Concrete Industry

This hardcover book provides a history of the precast concrete industry in America as well as an overview of how PCI came to be formed. It also includes a review of the 50 Best Precast Concrete Structures in America, as picked by an industry panel of judges, as well as a look at what future decades hold for the precast concrete industry.

Continuing Education



CD-IGS-2-01: Career Opportunities CD-ROM

This business card-sized CD-ROM for PCs outlines the range of job opportunities in the precast concrete industry that exist for those with engineering backgrounds. Designed primarily for use in university classes, it provides an overview of the industry and how engineering students can use their capabilities.

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