Designing
with Precast and Prestressed Concrete

PCI

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 one

INTRODUCTION

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CHAPTER ONE

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 (PRESSS) 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.

CHAPTER ONE

b.

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.

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.

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.

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 (GFRC) 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 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.

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.

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.
CD/IGS-8-02: Commercial Building CD-ROM.
"Certified Quality For People, Products and Performance," PCI brochure; 10 pp. 2003.
DN-15-06: Designer's Notebook: Energy Conservation; 64 pp.
Ideas By Design, Vol. 1 No. 1, March 2000: Justice Facilities; 4 pp.
Ideas By Design, Vol. 1 No. 2, December 2000: Stadium Projects; 8 pp.
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Ideas By Design, Vol. 2, No. 1, June 2002: Commercial Buildings; 12 pp.
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.
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.
MK-36-03: Total Precast Concrete Structures; 12 pp.
MNL-122-07: *PCI Architectural Precast Concrete Manual, Third Edition.*

References:

1. Chapter 1.3, "Benefits and Advantages of Architectural Precast Concrete," MNL-122-07: *PCI Architectural Precast Concrete Manual, Third Edition.*
2. MK-34-03: Precast Concrete Makes The Grade For K-12 School Facilities; 12 pp., 2004.
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.

CHAPTER ONE

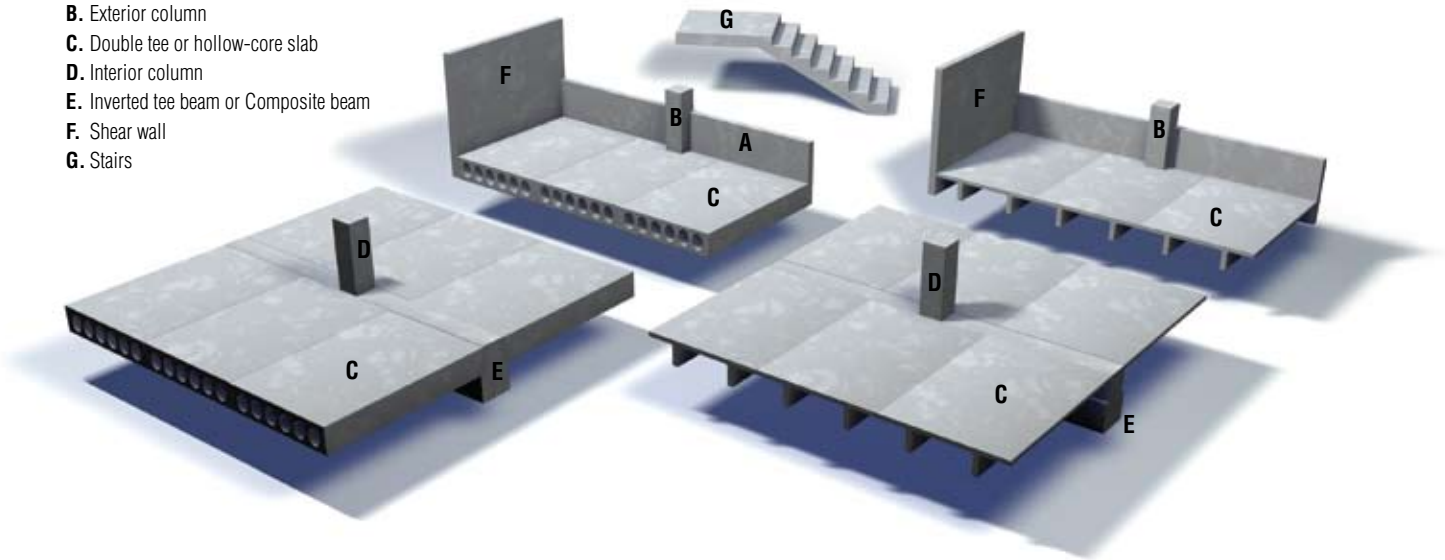
C.

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.*

CHAPTER ONE

d.

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.

CHAPTER ONE e.

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.

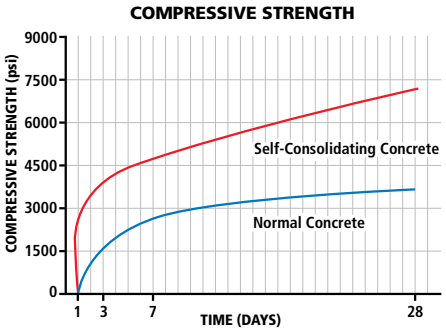
The two key attributes of self-compacting concrete are its high degree of workability and its stability during and after placement. SCC's workability is typically characterized by using a modification of the traditional ASTM C 143 slump test method, called the slump flow test.

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 turnaround 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 Bouyges 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.

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.

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).

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 (UHPFRC). 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:

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

- **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.")

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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2. "Ultra-High Performance Concrete Extends Precast Strength," *Ascent*, Winter 2002; pp. 34-35.
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CHAPTER ONE

f.

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.

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

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

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.

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.

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.

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