Concrete

New Technology, New Approaches

PHOTO: MARTIN TAYLOR

A concrete building at San Francisco State University campus reflects the weight of the concrete and its flexibility, which allows this cantilever.

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Learning Objectives

After reading this article, you should be able to:

- ✔ Understand new materials and construction approaches affecting the specification, design, and erection of concrete structures.
- ✔ Describe the various attributes of concrete that impact the sustainability of commercial and institutional building.
- ✔ Compare the benefits and drawbacks of various approaches to concrete mixes, reinforcement methods, structures, and decorative finishes.

Durable, versatile, dependable, and easily available, concrete is among the world's time-honored structural and finish materials. Even more compelling than its long-standing benefits are new advantages conferred by recent improvements to concrete technology. In fact, several new formulations and application methods offer benefits in both design and construction for Building Teams, especially with regard to new building materials, construction techniques, reinforcement approaches, and decorative finishes.

While many of these advances are for site-cast concrete, others are appearing in precast and unit construction, says Bob Thomas, VP of engineering and research for the National Concrete Masonry Association, Herndon, Va. "Concrete masonry is a time-proven building system that is just as valid and economical as it ever was, with a greater versatility in appearance and design functionality than ever before," says Thomas.

As for cast-in-place concrete, "Architectural concrete elements can be

PHOTO: COURTESY LAFARGE

The "Hypergreen tower," a project by architect Jacques Ferrier, explores the limits of sustainable design using high-tech concrete structures.

produced to compete with granite and marble, but combine both aesthetics and structural capability, all for a fraction of the cost of straight natural materials," adds Jay Shilstone, a concrete consultant and principal of Shilstone Companies, Plano, Texas. "No matter whether it is used to form the billowing curves of the Sydney Opera House or the massive utility of the J. Edgar Hoover Building, concrete can assume almost any shape."

And because sand, water, and aggregate make up more than 80% of a typical concrete mix, the materials can be produced virtually anywhere, whether in low-technology developing countries or in high-technology industrial areas. "Concrete is the most widely used building material in the world, and is used in nearly every type of construction," adds Lionel Lemay, SVP of Technical Resources at the National Ready Mixed Concrete Association (NRMCA), Silver Spring, Md.

Advantages for Sustainable Design

For green building, the best-known advantages of concrete include its thermal mass and durability, both of which can contribute to an attractive life cycle cost. Other specific sustainability benefits, according to the Skokie, Ill.-based Portland Cement Association (PCA), include "reduced undesirable sound transmission, increased energy performance, urban heat-island reduction, locally available materials sourcing, improved indoor air quality, lighting efficiency gains, and storm water management."

When considering concrete's reduced environmental footprint as compared to other building materials, Building Teams should take into account attributes that impact a life cycle analysis (LCA) for each given project. With that in mind, NRMCA's Lemay highlights the following key LCA performance criteria:

- Concrete is resource efficient, and the ingredients require little processing.
- Most concrete materials are acquired and manufactured locally, which minimizes transportation energy.
- Concrete building systems combine insulation with high thermal mass and low air infiltration, to make buildings more energy efficient.
- Concrete has a long service life for buildings and other infrastructure uses, increasing the time between reconstruction, repair, and maintenance efforts—and the associated environmental impact of those activities.
- Concrete, when used as pavement or exterior cladding, helps minimize the urban heat-island effect, thus reducing the energy required to heat and cool buildings. Urban heat-island effect refers to the increase in ambient outdoor temperatures due to paved and dark building surfaces.
- Concrete incorporates recycled industrial by-products such as fly ash, slag, and silica fume which help reduce embodied energy, carbon footprint, and quantity of land-filled materials.
- Concrete absorbs CO_2 throughout its lifetime through a process called carbonation, helping to further reduce its carbon footprint.

On the other hand, one of the ingredients required for concrete production is cement, a material with considerable embodied energy that generates high levels of CO_2 emissions. In fact, cement production accounts for 5% of global CO_2 emissions, although in the United States, that figure is lower, at less than 1.5%, thanks to efforts on the part of U.S. manufacturers, says PCA. In addition, PCA points out that "while cement does have a high embodied energy, it is only a fraction of concrete, and its embodied energy is a fraction of the energy used to heat and cool buildings."

The main argument put forth by proponents of using concrete for green building is the importance of evaluating structural and finish material choices based upon the big picture of its LCA and life cycle benefits, as delineated above. "Concrete is far and away the longest-lasting building material—if it is properly used. The longevity it provides helps to offset the energy it embodies," says Dave Root, an associate with the concrete design firm Atlas Archimedes, Lawrence, Kan.

Other advocates encourage Building Teams to consider materials in terms of raw materials. "Concrete is a sustainable construction material because its overall impact on the future is positive in terms of resource depletion," says William D. Palmer, Jr., Complete Construction Consultants, Lyons, Colo., and a former director of educational programs for the American Concrete Institute and executive director of the Masonry Society. He points out that concrete construction can qualify for credits toward certification in the U.S. Green Building Council's LEED programs as well as in Canada's Green Globes. Among the areas where credits are available, Palmer lists:

- Stormwater management.

• Minimizing and optimizing energy use.
• Reducing construction waste.
• Utilizing recycled content in both the concrete and reinforcing steel.
• Use of regionally produced materials.
• Improving indoor air quality and indoor environmental quality.

Concrete Construction Methods

There are a host of new advantages being driven by the application of concrete. These new methods and systems are of special interest to construction firms and their subcontractors.
Some of the more innovative approaches to concrete construction are occurring with 1) reusable formwork, 2) precast and pre-stressed open-space truss (POST) systems, 3) hybrid cast-in-place/precast structures, and 4) tunnel-form construction.

Reusable construction elements. Driven by a desire for easier, faster, and more cost-effective construction, many concrete contractors have been adopting reusable frames and formwork. For example, some manufacturers of reusable concrete column formers, which are made from recycled plastic, claim that the products can be used and cleaned for reuse up to 100 times. Due to the lightweight, modular nature of these systems, in many instances the forms can be erected by one or two workers, saving on construction time and labor.

Although some of the formwork approaches are ideal for highly repetitive, low-rise applications such as multifamily housing, its use is hardly limited to more simple structures.

Precast/prestressed open-space truss. For applications where Building Teams desire structures with alternating column-free interiors, the precast, pre-stressed open-space truss,

The Decorative Side of Concrete

In the development of new concrete materials, its the decorative concrete sector that's seeing the most change—change that's clearly visible to building occupants. "The use of concrete as an aesthetic element has exploded in the past 10 years," says Jay Shilstone, a concrete consultant and principal of Shilstone Companies, Plano, Texas.

"The decorative concrete industry has developed into a multifaceted range of techniques that not only encompass the well-known imprinting with texture molds, but also the use of paper stencils, exposed aggregate, sandblast stencils, colored stains, vertical wall imprinting, acid etching with spray-on finish and textures, and more," adds Glyn Thomas, managing director of Creative Impressions, a decorative concrete firm based in Preston, Lancashire, U.K.

"Concrete is literally being worked in every way imaginable: it is polished, etched, sandblasted, and cast against every type of form facing," says Jamie Farny, PCA's program manager for masonry and special products. "It is imprinted with a grid to give the appearance of hand-laid mosaic tiles. It is sprinkled with specialty materials for color and texture or overlaid with an artistic imprint. It is tinted, dyed, and stained in every way possible, and it is carved on both horizontal and vertical surfaces."

One area in particular, precision cast color control, has come a long way, in part due to the use of self-consolidating concrete. "SCC, in combination with the capability for concrete producers to precisely control integral color through color batching systems, offers outstanding control of surface finish," says Lionel Lemay, SVP of technical resources at the National Ready Mixed Concrete Association (NRMCA), Silver Spring, Md.

Moreover, says Shilstone, "Most concrete pigment manufacturers now provide liquid color control systems that can produce a wide variety of colors."

Although coloring options are appealing, staining is frequently utilized to lend a classic and natural look to the concrete surface. Stained concrete also provides a permanent, flake-proof color, and can be employed for renovation projects to revive older concrete. Acid stains are typically available in a limited number of hues—mostly subtle earth tones—while water-based acrylic stains offer greater variety, including black, white, and metallic tints.

Yet another approach is to apply one or more stains on top of colored concrete to create diffuse and varied natural tones, says Farny. "Stains react with each concrete surface to create one-of-a-kind effects." He says. To create more intense hues, he suggests applying dry-shake color hardeners to the surface of wet concrete to create an opaque color layer. "This technique lends itself to creating eye-catching designs while increasing the durability of the finished surface," he says.

PHOTO: DETLEF SCHOBERT

Colored concrete has become an increasingly trendy specification. This blue, mottled effect was selected by the architects Herzog & deMeuron for the Edificio Forum in Barcelona, completed in 2004.

Or course, there's more to decorative concrete than just coloring and staining. For instance, stamped and patterned concrete is becoming more popular. By stamping the surface of freshly poured concrete, the look of cobbles, brick, or stone can easily be simulated. In addition, dry shake color hardener, with either liquid or powder release, can be added for an even more enhanced appearance.

known by the acronym POST, can be a useful solution. In this system, a precast, pre-stressed concrete truss is manufactured to simultaneously support two levels of the structure. The result is that alternative levels may contain no interior structural elements, giving designers (and owners) full flexibility in their layout of walls and partitions.

For parking garages in buildings with POST structures, the absence of columns has been shown to increase parking capacity by as much as 15%, without compromising fire ratings or acoustic performance. In addition, the trusses—which are ideal for long spans with a shallow floor depth—help ensure an open and column-free ground floor space, which is increasingly desirable for mixed-use and retail facilities, hotels, and senior living properties.

Hybrid cast-in-place/precast structures. What's attractive about hybrid cast-in-place/precast structures is that the resulting systems combine the benefits of both forms of construction. The benefits can include better seismic performance and improvements to project costs and schedules.

Because the structures are precast by a manufacturer and then brought to the job site, the time and labor involved in forming, casting, curing, dismantling, and site clean-up is significantly reduced. "The use of precast panels rather than metal panel cladding reduces site work costs by allowing the panels to act as retaining walls, where excavation would otherwise have required expensive rock removal," says Joseph Iano, AIA, founder of Amphion Communications, Seattle, and co-author of *Fundamentals of Building Construction: Materials and Methods*.

Tunnel-form construction. Yet another construction method gaining popularity is a load-bearing wall system in which the walls and slab are poured simultaneously by way of "tunnel forming." According to the PCA, "Because the forms are stripped in 24 hours, the daily cycle meets the demand of fast-track construction projects with repetitive cell layouts"—a description that is virtually synonymous with current trends in hotel and condominium construction. In addition, says Joe Nasvik, senior editor of *Concrete Construction*, "The more that forming operations can be reduced to repetitive steps, the greater the benefits of the system. Tunnel-form construction can be ideal for high-rise buildings, hotels, military housing, prisons, and some warehouse applications."

Also, due to the repetitive nature of the much concrete work, tunnel-forming has been credited with reducing mistakes on the jobsite, say contractors familiar with the technique.

Yet even though tunnel-form construction and other novel methods are of "paramount importance in the construction of concrete structures," according to Jack Gibbons, central region manager for the Schaumburg, Ill.-based Construction Reinforcing Steel Institute (CRSI), Building Teams will find even more efficiency and value in the basic tools of the trade. Says Mike Mota, CRSI's Atlantic region manager, "An even more significant trend is the development of new technologies such as concrete pumps, placing booms, formwork, formwork lining systems, and high-strength and high-early-strength concrete—in other words, technologies that help get the concrete where it needs to be as quickly as possible and at minimal cost."

They suggest further that one of the most significant developments in concrete construction has been "the introduction of chemical admixtures that allows concrete to be placed at extremely low water/cementitious ratios at every level of workability required."

New Concrete Building Materials

Innovations in concrete materials and reinforcing are available in a plethora of new offerings in the last few years, each presenting different improvements and advantages over conventional products. Of particular interest have been concrete mixes that provide specific performance improvements, whether in construction or building operations, or both. Within this class of advances are 1) "particle-packing" concrete, 2) reactive powder concrete, and 3) self-consolidating concrete.

Particle-packing concrete. Another new product, "particle-packing concrete," has recently found its way into projects in New York City, including the Freedom Tower on the former World Trade Center site, and other metropolitan areas. According to one manufacturer, iCrete, the product offers a reduced carbon footprint because it optimizes the void space between aggregates and consequently reduces the amount of required cement paste by as much as 40%.

PHOTO: JOE WOOLHEAD, COURTESY ICRETE

"Particle-packing concrete," which provides several benefits in constructability, strength, and sustainability, is being used in high-rise developments like the Freedom Tower project on the former World Trade Center site in New York city.

"With its technology, [particle-packing concrete] produces a stronger, more cost-effective concrete that is environmentally sensitive. In fact, this is the highest-strength concrete ever poured in New York," says Daniel R. Tishman, chair and CEO of New York-based Tishman Construction Corp., which serves as construction manager for the Freedom Tower. Another aspect of particle-packing concrete is that, prior to mixing, the proportions of materials used in each batch are customized by a software program.

After visiting a plant where particle-packing concrete is produced, Hamlin Jennings, a professor of materials science at Northwestern University, Evanston, Ill., said, "Although many of the technical components of the … system are not new, their combination into a system that optimizes concrete to reduce material cost while maintaining specified strength and slump is new."

Reactive powder concrete. With the addition of steel and synthetic fibers in the mix, reactive powder concrete—also referred to as ultra-high-performance concrete—can achieve compressive strengths of 30,000 pounds per square inch (psi), says the PCA. More significant, perhaps, is that the cast material can support loads in tension, too.

"The ductile behavior of this material is a first for concrete, with the capacity to deform and support flexural and tensile loads, even after initial cracking. The use of this material for construction is simplified by the elimination of reinforcing steel and the ability of the material to be virtually self-placing, or dry cast," says the PCA.

Purdue University's Division of Construction Engineering and Management has reported on studies of the materials, noting that reactive powder concrete "uses extensively the pozzolanic properties of highly refined silica fume and optimization of the portland cement chemistry to produce the highest strength hydrates." (The reports are available at the school's Emerging Construction Technologies website, www.ect-purdue.org.) In short, this means that the new formulations are super-concretes that in a few years may be competing with steel on a structural basis. With regard to seismic performance, say the Purdue University researchers, "inertia loads are reduced with lighter members, allowing larger deflections with reduced cross sections, and providing higher energy absorption."

Self-consolidating (self-leveling) concrete. The Purdue researchers also tout the advantages of self-consolidating concrete (SCC) mixes, which have the primary advantage of eliminating the need for conventional placing and vibration techniques in the field.

"Self-consolidating concrete is a specially engineered concrete that typically is very flowable and remains stable and nonsegregating, during and after placement," explains the NRMCA's Lemay. "Because it flows to fill voids around reinforcement without internal or external vibration, self-consolidating concrete can result in a reduction of labor cost by as much as 50-80%. It also provides a reduction of energy costs and noise levels, since there is little or no vibration required."

Nasvik classifies self-consolidating concrete as one of the new state-of-the-art products in the marketplace. "It has enjoyed wide acceptance in the precast concrete industry and is beginning to be used by cast-in-place contractors, especially wall contractors," says the editor of Concrete Construction. "Most decorative contractors have had little experience with SCC, but it can greatly improve the look of decorative work. And because SCC produces high early strength, molds can be stripped more quickly."

The PCA also notes that because SCC material flows well and consolidates into small voids, it's particularly useful for more detailed, decorative work, such as for ornate, neoclassical columns and moldings.

PHOTO: COURTESY THE CONCRETE CENTRE

Insulating concrete forms, also known as ICFs, provide high levels of insulation as well as unexpected benefits, such as good blast resistance.

In addition to particle-packing mixes, reactive powder, and SCC, a number of other concrete innovations are being used in the field. *Mortarless concrete block* is gaining popularity thanks to advances in built-in interlocking systems, as well as the use of recycled materials to enhance the sustainability and aesthetics of unit masonry, such as post-consumer glass.

Another advance in cast concrete is high-ductility concrete. Similar to reactive powder mixes, these concrete formulations offer high strength and greater flexibility once cast. These products also incorporate metallic or organic fibers to achieve these properties. "Compressive strengths as high as 33,000 psi and flexural strengths as high as 7200 psi are claimed, and under extreme loading, the material exhibits ductile behavior more similar to steel than conventional reinforced concrete," states Amphion's Iano. "Ductile concrete also exhibits low porosity, reduced creep under sustained loading, and reduced drying shrinkage."

Translucent concrete, made by adding carefully oriented optical fibers to the concrete mix, has been turning some heads. In fact, one of these products was deemed one of the "coolest inventions" a few years ago by Time magazine, and it was featured in an exhibit at the National Building Museum. Since then, the application has been seen in architectural applications for walls and floors and in many concrete sculptures.

"It's most common application is for interior non-load bearing applications," relates John Hrovat, OAA, LEED AP, senior associate and manager of architectural design for Albert Kahn Family of Companies, Detroit. "However, companies are continuing development of this product and a structural variation could hold incredible opportunities as a future building system."

Emerging Ideas in Reinforcing

The parallel emergence of advances in strategies for reinforcing—including new materials and designs—is hardly surprising,

PHOTO: COURTESY STRUCTURAL SYSTEMS

A post-tensioning process underway: New techniques in post-tensioning include the use of intumescent materials in the post-tensioning process to increase the fire resistance of concrete structures.

notes Neil Watson, editor of the United Kingdom-based Concrete Society's Concrete magazine: "Reinforcement is fundamental to structural concrete. From straightforward reinforcing bar to prefabricated components, manufacturers and fabricators are continually extending the options available to solve problems, reduce costs, and increase durability."

According to the Concrete Reinforcing Steel Institute (CRSI), "High-strength, low-cost, long-lasting reinforced concrete has proven itself as the material of choice for ensuring the greatest return and best value for building owners and their tenants well into future decades."

Among the latest trends in steel reinforcing, CRSI's Gibbons lists:

- The use of reinforcing bars with higher yield strengths.
- Computer programs for fabrication bar lists.
- Computer generation of placing drawings.
- Automated bar fabrication machines that speed production and lower on-site labor costs.
- Coiled steel reinforcing bars.
- Welding of shop-fabricated steel reinforcing-bar assemblies

Gibbons also points to advances in structural engineering and design, such as improved shear connectors for concrete slabs at concrete columns, steel reinforcing-bar couplers, increased use of epoxy-coated bars in both mats of bridge decks, and two-coat epoxy-coated bars.

Many of these techniques have become common practice for leading commercial and institutional Building Teams. A few others are just emerging, such as: 1) carbon-fiber reinforcing mesh; 2) reinforcing mats, sometimes called "reinforcement carpet"; 3) stainless-steel-clad rebar; and 4) MMFX, the acronym for microcomposite steel reinforcing. All of these technologies make construction easier and improve the durability and performance of the installed concrete.

Carbon-fiber reinforcing mesh. A novel carbon mesh product, branded as CarbonCast, uses a noncorrosive, high-strength carbon fiber grid as a replacement for conventional reinforcement. In addition, the system is lightweight, relatively easy to work with, and allows similar designs to use less concrete material.

According to Dave Cook, VP with the Clyde Companies, a large construction firm based in Orem, Utah, the product "eliminates wire mesh reinforcement, reduces shrinkage and cracking, doubles impact resistance, and triples fatigue resistance."

"Carbon fibers have an elongation of 1.5%, while steel has an elongation of 6%," says Todd Jackson's, a foundation repair expert and associate member of American Concrete Institute's Committee 440 on Fiber Reinforced Polymers. Because of the advantage in tensile strength, he feels the technology can be a good substitute for steel. "If you repair a wall with steel reinforcing, the wall could move in an additional 6% before the steel would come into play. If the wall is reinforced with carbon fiber mesh, it won't move as the fiber material is much stiffer."

Reinforcement carpet. Another relatively lightweight reinforcing material is known as "reinforcement carpet," a method that the PCA has pointed out can help reduce shipping and erection costs and improve the speed and precision of concrete mat construction.

Quickly and simply manufactured, these reinforcement rolls are precisely spaced and sized, welded to flexible metal banding, and rolled around reinforcement hoops that are later discarded. "As well as saving labor, the system requires less steel than conventional reinforcement systems and the mesh is easy to lay," according to the U.K. Concrete Society's Watson. "The fivefold increase in fixing speed can lower construction time, leading to a significant reduction of total costs."

Galvanized and stainless clad rebar. Another issue with conventional steel rebar is corrosion due to naturally occurring environmental conditions. Billions of dollars are spent annually "to reconstruct or repair structures whose design life has been either shortened or eliminated as a result of corrosion, or through loss of aesthetic value or functional obsolescence," say the Purdue researchers.

One solution is the use of galvanized and stainless-clad rebar. These rebar materials penetrate hardened concrete to dramatically reduce corrosion by 65%, extending the service life of the facility. In addition, it provides a protective layer on both the anode and cathode parts of the steel, according to the Purdue team: "This protective layer further acts to displace chlorides from the steel. The product can be used as an admixture in the placement of new concrete or topically applied to existing structures."

Microcomposite steel reinforcing. Another corrosion-resistant alternative is MMFX, or microcomposite steel reinforcing. These materials are engineered at the atomic level to improve installed strength, energy absorption, toughness, brittleness, ductility, and formability, as compared to conventional carbon-steel reinforcing. The favorable strength characteristics of these materials can reduce construction costs and the quantity of materials needed. In some cases, MMFX will also simplify the placement of concrete, as a result of greater bar spacing, in heavily reinforced concrete structures, according to the Purdue researchers.

In addition, MMFX is not a coated material, so its monolithic composition is unaffected by field handling, as compared to coated products that frequently suffer damage on the construction site, or require touch-up recoating. MMFX can also be used by crews trained in standard field rebar fabrication procedures, whereas some coated products call for offsite cutting and bending, as well as special end-caps or other protections. Lastly, MMFX is safe: There are no unusual safety hazards for field erection, which has been one complaint about epoxy-coated bar.

Another "nano" innovation on the horizon is "self cleaning" concrete. By applying a "nano technology additive to the concrete, it reacts with sunlight to repel stains commonly associated with pollution and grime. This technology also has a compelling side benefit in that it improves air quality in the immediate area around the installation," explains AKA's Hrovat. "The possibilities are intriguing in that this technology can be used as part of new construction, part of a paving system and even can be applied as a retrofit coating to an existing façade."

Reliable, Novel Concrete Structural Techniques

When it comes down to the structural design of concrete buildings, designers benefit from a number of systems and approaches for walls. For example, ever since its introduction to the United States a few years ago, *aerated autoclaved concrete* (AAC) block has become popular for its green qualities and light weight. At the same time, *insulating concrete forms* (ICF) offer a quick, easy option for building highly insulated, strong walls. Another approach, tilt-up construction, is pushing the limit of heights and sizes of the wall sections that can now be erected—as high as 100 feet, enabling greater efficiencies.

One of the most appealing features of lightweight aerated autoclaved concrete is that it utilizes less material and energy to produce as compared to other concrete materials, as approximately 80% of its volume is made of residual air voids and pockets. In fact, about 12 cubic feet of finished AAC material can be produced from three cubic feet of raw material slurry, according to the International Masonry Institute. Other advantages include longevity and energy efficiency of properly erected walls, as well as conventional, cost-effective installation methods. Units made of AAC can be large and precisely dimensioned, meaning that less on-site adjustment is needed for a given project, thus adding to jobsite productivity. In terms of sustainability, AAC offers the unique combination of high R-value, thermal mass, and air tightness, all built into the durable structural elements.

For simplifying construction, however, the PCA maintains that it's "hard to find an easier system than ICFs." ICFs are wall systems produced from hollow foam blocks or panels stacked into the desired enclosure shape. "The forms are filled with steel-reinforced concrete to form a solid structure, sandwiching a heavy, high-strength material between two layers of light, high-insulation foam," notes the PCA. "The resulting walls are air-tight, strong, quiet, highly insulated, pest and fire resistant, and durable in the face of even the harshest weather." Because the industry produces a wide variety of ICF shapes and sizes, it is a commonly used system for industrial buildings, hotels, government facilities, schools, shopping centers, and religious facilities.

ICF construction provides high R-values, low air infiltration, and high thermal mass, which helps account for the 25-50% energy savings that ICF-constructed facilities boast as compared to similar wood-framed or steel-framed facilities, according to the Glenview, Ill.-based Insulating Concrete Form Association.

"It's not just about energy efficiency any more," says ICFA director Joe Lyman. He says that the U.S. Department of Defense has been investigating ICF technology for its resistance to blasts. "We've found through blast demonstrations that ICFs lessen the impact of air pressure placed on the lateral face of a wall," says Lyman. "When an air blast hits the wall, it compresses the EPS foam against the concrete." Amphion's Iano adds that other benefits claimed by ICF system manufacturers include design flexibility, acoustic and thermal control, jobsite safety, cost efficiency, and ease of installation.

As for tilt-up construction, perhaps most compelling is the ability to erect large-sized panels, which accounts for its popularity in the construction of big walls for industrial buildings. CRSI estimates that about 20% of all U.S. industrial structures have been constructed using the tilt-up method, in addition to a large share of warehousing and distribution facilities.

In recent years, tilt-up construction has become popular for more vibrant building types, too: schools, office complexes, and retail centers. "New finishes and forming techniques have allowed designers to incorporate texture, color, openings, articulation, and curves into a building system that was once thought of as the mainstay of big-box buildings," says Lemay. "Now tilt-up is even making big box buildings more attractive than ever."

While not generally considered a decorative concrete application (see accompanying box, "The Decorative Side of Concrete"), tilt-up panels can be treated with ornament, color, and other enhancements. According to the Tilt-Up Construction Association, these options include:

- Colorings added to the concrete mix.
- Textured paints.
- Applied textures produced by form-liner cast surfaces.
- Exposed aggregate.
- Mechanical tooling surface treatments.
- Surface forming, sometimes in combination with trompe l'oeil painting, to suggest three-dimensional forms.

Another recent enhancement to tilt-up, according to the TCA, is the use of intumescent materials in the post-tensioning process to increase the fire resistance of concrete structures. By incorporating a layer of reinforced intumescent coating between an inner and outer layer of high-density polyethylene sheathing, the coating swells during fires to effectively insulate and protect the substrate layer.

Yet another novel technique is external post-tensioning, known as EPT, for added strength. With EPT, tendons are attached to the outside of the concrete structure and then tensioned, applying a vertical, upward force to the bottom of the floor. "This method allows for the application of large upward forces at practically any location in a sagging floor and also increases shear strength and helps eliminate further deflection," says John Criger, P.E., VP and technical manager for VSL, a Hanover, Md.-based company that designs, manufactures, and installs post-tensioning and structural strengthening systems. "They can be applied to many types of structures and, in particular, provide effective strengthening reinforcement for retrofits."

Whether it's decorated, precast, post-tensioned, reinforced, cast in place, or tilted up, concrete is not only a building material of choice, but it is changing with the times. From sustainability to versatility to durability, concrete has much to offer. Perhaps that's why the PCA calls it "the most widely used construction material on earth," with the "longest lifespan of any traditional building material." BD+C