PCI & PARKING: PAST, PRESENT AND FUTURE

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ABSTRACT

The precast/prestressed concrete industry led the structural innovations of the mid-20th century; innovating parking garage design with the single and double tee by Harry Edwards and T.Y.Lin, pioneered in bridge building by Gustave Magnel. However, a long history of the "unit structural concrete method" has been explored in the United States since the beginning of the century.

Parking garages are again at the forefront of design. The precast/prestressed industry has the opportunity to shape/re-shape its future by creating new shapes and forms to meet the complex challenges of today that allow for new sustainable solutions, – such as a precast double-tee that also redirects light for greater light at less cost. This is one example that will be discussed in the paper. New mobility devices, all of different scales and speeds seek a place to park, how to efficiently integrate them along with pedestrian movement provides new challenges in design and layout. Along with aesthetics and multi- functionality, – parking that is more than parking –value will be the key word going forward. This presentation will show how the precast/prestressed parking industry is poised to provide " better value" by remaining flexible, innovative, and working collaboratively with other professionals.

Keywords: Double-tee, Unit systems, T.Y. Lin, Harry Edwards, Collaboration, Sustainability

INTRODUCTION

The parking garage has been at the forefront of structural exploration since its beginning when the emerging typology was referred to as the “static machine”. It was first understood to require longer spans, elevators, and fireproof construction. The parking garages’ challenge was to use available technology along with the new warehouse and factory design concepts. Initially parking garages were built similar to warehouses and other inhabitable structures; however they have now evolved into open decks or ramps more closely aligned to lightweight bridges. These conditions expose the modern parking facility to extreme temperature fluctuations and weather issues while still being inhabited by humans.

The modern parking garage has also been aesthetically challenged by the post-modern movement and other architectural design theories. Cesar Pelli has stated “For me the solid ground...is given by the basic relationship between the art of our buildings and their system of construction”. This has been one of the many challenges for the parking garage structure - creating the art within the system of construction.

The precast/prestressed concrete industry led in structural innovations during the mid- 20th century producing parking garage designs with the single and double tee by Harry Edwards and T.Y.Lin, pioneered in bridge building with Gustave Magnel. However, a long history of the “unit structural concrete method” (a single unit of concrete repeated to construct) had been explored in the United States since the beginning of the 20^{th} century. The unit as a method of construction has a unique history within the precast/prestressed concrete industry. Creating repetitive units of a material to duplicate for construction purposes has a long history in the profession. However, in the early 20^{th} century the challenge was to create longer and longer spans with greater structural support and using a repetitive structural unit was the most efficient way to do it.

When reinforced concrete was in its infancy, in the United States at the beginning of the 20^{th} century, a process known as prestressing emerged. In the United States, prestressed concrete in its earliest meaning covered both pre and post tensioned concrete. Many different concepts of these innovative ideas, that have clearly defined meanings today, were part of the struggle to create longer and stronger spans for the new technological machine age. Longer spans and other structural material improvements allowed the parking garage and other building typologies to evolve and flourish in the course of the 20th century. These innovations could not have occurred without the give-and-take between structural advances and changes in construction methods, materials, and codes. Concrete was valued for its fireproof qualities, but the unit structural methods did not become widely used until research and experimentation yielded new ways to employ it.

Poured concrete—a mixture of gravel, sand, and Portland cement—was used in construction in New England as early as 1824; in 1835, it was recorded as having been used to erect an “interesting little structure” in New York City. By the turn of the century, cast-in-place concrete (which was poured on the construction site, in its final structural position) was being reinforced with steel rods, matrixes, and cables, which acted together to increase the tensile strength of the concrete. This new construction technology, known as reinforced concrete, was developed to meet new needs, was well suited to the parking garage, and is still in use today. Integral concrete was another type of reinforced concrete used in the first half of the 20th century (in the construction of the Fisher Building parking garage, for example). In this method, structural steel is surrounded by poured-in-place concrete, in a process that takes place entirely in the field.

Almost simultaneously with the introduction of reinforced concrete, a new development emerged—a process known as prestressing. In this process, the steel rods and cables within the concrete are placed in tension, which enables them to act as an invisible column, stabilizing the beam. If the tensile forces are introduced while the concrete is setting or is still liquid, the result is known as prestressed or pretensioned concrete; if the forces are introduced after the concrete has hardened, the result is known as post-stressed or post-tensioned concrete. Concrete can be pre- or poststressed either in the field or elsewhere, such as in a factory. Post-tensioning, however, is typically undertaken in the field.

Concrete that is poured elsewhere (even on the site, but not in its final position) and then assembled is called precast concrete. There are two main categories of precast concrete: structural precast, which is used for structural purposes, and architectural precast, which is used for aesthetic purposes. Either form can be pre-tensioned or post-tensioned; however, precast concrete is not necessarily prestressed in any way.

Until the late 1970s, the term *prestressed was* sometimes used to refer either to prestressed or to cast-in-place post-tensioned concrete. Today, *prestressed* refers to pre-tensioned concrete only—and, because most structural precast concrete is also prestressed, the terms *prestressed concrete* and *precast concrete* have become virtually interchangeable—and are in fact sometimes used in combination: “prestressed precast concrete.”

In the United States, experimentation with prestressed concrete (in its early meaning, which referred to either pre- or post-tensioned concrete) began before the turn of the 20th century. In 1886, P.H. Jackson, of San Francisco, patented a method of tightening steel rods in stone and in concrete architectural sections. As early as 1893, precast reinforced concrete was used to create bulkheads in New York City. In Europe, meanwhile, Eugene Freyssinet, a Frenchman who is considered the father of prestressed concrete, developed successful methods for both prestressing and post-tensioning concrete and advocated the use of these techniques.

By 1904, the Joint Committee on Reinforced Concrete had been established to identify, regulate, and disseminate information on concrete research and concrete processes. The American Concrete Institute (ACI) was founded the following year. In 1906, after three major building failures, serious discussion about the new construction technologies occurred at the meetings of both the International Congress of Architects and the Joint Committee on Reinforced Concrete.

The ACI regards C.A.P. Turner as one of the pioneers of reinforced concrete: in the early 1900s, Turner used his own system of fire protection in the construction of a concrete parking garage. Others experimenting with reinforced concrete included Albert and Julius Kahn—who, also in the early 1900s, developed the Kahn trussed bar. As noted earlier, the Park Square Garage—designed by Gaetano Lanza and constructed in Boston in 1905—incorporated discoveries from Lanza's experiments with reinforced concrete.

By 1907, the Edison Portland Cement Company was manufacturing primary components for buildings; this was the beginning of precast construction. Systematic production of precast reinforced concrete was not patented, however, until 1909, by Ernest L. Ransome, who referred to the process as "unit construction."

In 1912, John E. Conzelman patented what he called the "unit structural concrete method" of precast concrete construction, a technique that was used in 1914 to create 50 pedestrian shelters for the Pacific Electric Railway, in Los Angeles; the structures were still in use in the 1950s. (Figure 1) By 1912, tilt-up reinforced concrete (a technique in which a concrete slab is precast on site, then tilted up into position) was being used in Des Moines, Iowa. In 1925, R.E. Dill, of Alexandria, Nebraska, patented a method for manufacturing prestressed concrete posts and slabs by post-tensioning the steel.

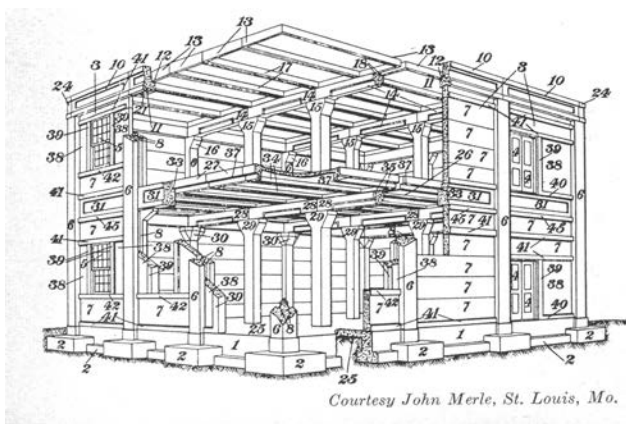

Fig 1: Conzelman Unit Construction (PetersonJ.L., "History and Development of Precast Concrete in the United States", Journal of the American Concrete Institute, February 1954, 483.)

Experimentation with various methods of using and reinforcing concrete was accompanied by experimentation with the ingredients. By 1916, the concrete industry had developed standards for Portland cement, the primary ingredient in concrete. Published an a 1918 article, D.A. Abrams developed the water-cement ratio that yielded high-early-strength concrete—concrete that hardens to its final strength quickly, usually within 72 hours.

In the 1950s, after Gustave Magnel's techniques for prestressing concrete had been brought from Belgium to the United States, Lakeland Engineering and Prestress, Inc., held the first conference on prestressed concrete, in Lakeland, Florida. The Prestressed Concrete Institute was legally chartered in 1954 in Tampa, Florida, by six Florida prestressed-concrete companies, with T.Y. Lin and Harry Edwards as its key researchers. In 1963, prestressed concrete was introduced into the ACI building code. In 1976, the Post-Tensioning Institute formed to advocate post-tensioning. By this time, *prestressed* technically referred only to pretensioned precast structural and architectural concrete.

FROM PRECAST TO CAST-IN-PLACE CONCRETE

The development of precast prestressed concrete changed the parking industry. Once the design and construction issues had been resolved, the standardization offered by these new structural forms allowed parking garage construction to be more systematic and cost-efficient. More importantly, however, the parking deck became a totally abstract space: a pure Cartesian grid that had little or no relationship to defined internal spaces. Because of this new structural system, garage designers were free to develop the “purely” functional, highly efficient, self-park garage.

EXPERIMENTATION WITH PRECAST CONCRETE.

One of the earliest recorded precast structures was a stable built in Brooklyn, New York, in 1900. In this structure, the roof slabs were four feet (1.2 meters) wide, 17 feet (five meters) long, and two inches (five centimeters) thick, and were reinforced with rods and wires. A car barn and repair shop constructed in Harrisburg, Pennsylvania, in 1909, had precast concrete columns, beams, walls, and roof slabs—over 1,400 pieces in all—and was built in only 33 days. A small storage garage for machinery, built in Cambria, Wisconsin, in 1940, had an arched frame of precast concrete that was divided into three pieces for easy delivery. The arches were field-spliced at the points where the curvature of the arch changed (that is, where the bending moment is zero). Concrete-block walls and hollow, six-inch (15-centimeter) roof slabs were used to enclose the structure.

By the 1940s, several factors had combined to create one of the biggest breakthroughs in the technology of the parking structure: longer floor slabs. These factors were new cement mixtures and processes, new precast shapes, and new reinforcement techniques. Whereas earlier flat floor slabs had been two feet (0.6 meters) wide, 3.5 inches (nine centimeters) deep, and eight feet four inches (2.5 meters) long, the Formigli Corporation, of New Jersey, began manufacturing slabs that were two feet (0.6 meters) wide, six to 12 inches (15 to 30 centimeters) deep, and from 16 to 32 feet (five to ten meters) long. In 1944, the first technical committee on prestressed concrete was organized by the ACI and the American Society of Civil Engineers. By the early 1950s, Arsham Amerikian had designed a five-foot by 18.5-foot (1.5-meter by 5.5-meter) flat concrete reinforced slab with a thickened edge, and by the mid-1950s, Charles C. Zollman had taken this achievement even farther—to a length of 33 feet, three inches (ten meters). In 1952, the Roebling Company designed a new, seven-wire strand for prestressing steel, further adding to the functionality of prestressed and post-tensioned concrete. At the same time that construction and material technology allowed the manufacture of longer and longer slabs, new equipment made it possible to transport and place heavier and longer precast pieces: jacks had been developed, for example, that could lift 75 tons (68 metric tons) of precast concrete.

In the 1950s, as the precast reinforced concrete floor slab was becoming standard, Perlmutter, Altenberg, and Sachter patented the twin tee, the first precast double tee. The precast prestressed double tee developed by Harry Edwards in 1952--1953 was four feet (1.2 meters) wide, 14 inches (36 centimeters) thick, and 15 feet (4.5 meters) long. At approximately the same time, a six-foot- (1.8-meter-) wide double tee was developed in Colorado, and T.Y. Lin invented the single tee (which was initially known as the Lin tee). Eventually, precast prestressed double tees—the industry standard—had increased in size to a maximum width of 15 feet (4.5 meters) and a maximum length of 80 feet (24 meters); the depth varied according to the relationship between width and length. This size, which first appeared in 1997, is known as a mega-tee.

Precast prestressed floor tees required cast-in-place toppings to seal the joints between the tees and to provide some structural continuity. Today, both pretopped tees, and tees with no topping at all, are found in parking garages.

PRECAST PRESTRESSED CONCRETE IN THE PARKING GARAGE.

By the 1950s, garages were typically constructed from a combination of precast and poured-in-place concrete. In 1953, the first roof parking deck ever constructed of precast prestressed concrete members was installed by Prestressed Concrete of Colorado at the Spitzer Electric Company. The beams, which were either rectangular or I-shaped in cross section, had spans ranging from 17 to 80 feet (five to 24 meters). The garage of the ZCMI Department Store, in Salt Lake City, combined slab construction (cast from the top of the garage down) with precast prestressed concrete columns. This very simple structure, which opened in 1954, had minimal ornamentation except for the concrete floors, which were poured with a sawtooth edge that echoed the new, angled parking pattern. The sawtooth edge was an example of a purely functional design that served an aesthetic purpose. In 1955, Carport, Inc., of Oklahoma City, built a garage of precast reinforced columns and slabs for $800 a space.

In the 1950s, the benefits of precast prestressed concrete were just beginning to be apparent: it was not until the 1960s that the new, long-span construction and erection techniques allowed the modern garage to come into its own. The longer spans not only allowed more design flexibility, but also provided cost savings. The Beverly Hills Garage, for example, completed in 1961, used 75-foot- (23-meter-) long single tees and realized a savings of 24 percent over the typical garage of the period. Most of the savings were derived from the 17 percent reduction in floor area made possible by the construction method. At about the same time, in Asbury Park, New Jersey, a four-story, 350-car Park & Shop was erected in just 11 days. This project, designed by Gage & Martinson, Engineers, cost $1,400 per space: it may not have been the least expensive garage to construct, but it was certainly erected the most quickly—a characteristic that translates into savings, because the structure can begin collecting revenue sooner.

Precast prestressed concrete structures also lowered insurance rates: in 1965, precast prestressed concrete subjected to the Underwriters Laboratories' fire tests for four hours and 50 minutes earned the two-hour fire rating. (Fire tests are run until the product or material fails, or meets standards beyond all expectations.) Precast prestressed concrete was also believed to be inherently watertight, when used in combination with expansive or high-strength cements, eliminating the seepage that typically occurred in concrete garages. At the University of California at Berkeley, in 1961, a turf-covered athletic field was constructed on top of a parking deck; clearly, the designers assumed that the construction would be waterproof.

THE PRECAST CONCRETE REVOLUTION: T.Y. LIN AND HARRY EDWARDS

T.Y. Lin was a visionary in the world of modern structural engineering. A professor at the University of California at Berkeley, Lin began his research career by working on the Arroyo Seco Pedestrian Bridge, which was built near Los Angeles in 1951. Lin also owned a consulting structural engineering firm called T.Y. Lin & Associates, and was chairman of the Division of Structural Engineering and Structural Mechanics at the University of California at Berkeley. Many of the key garage designers of the past 30 years had their start in his firm.

In 1953, Lin studied under Gustave Magnel, at the University of Ghent, in Belgium. (Magnel had designed the Walnut Lane Bridge, in Philadelphia, the first prestressed concrete structure in the United States, and had developed new methods for prestressing concrete that came into use in the United States during the 1950s). In 1955, Lin published *Design of Prestressed Concrete Structures*, which had tremendous influence in North America.

In the early 1960s, Lin created the single tee, which was one of the most efficient shapes for spanning the width of a bay. In addition to allowing a completely open span that would accommodate two cars on each side of the driving aisle, the single tee permitted better distribution of light from the fixtures mounted on its underside. The single tee was initially eight feet (2.4 meters) wide and could be manufactured in lengths of up to 110 feet 34 meters); although it was used extensively in early precast pretensioned construction, its shape made it difficult to transport and to install. The "B" parking structure, a ten-story garage in Beverly Hills designed by Lin and built in 1953, was entirely constructed of precast pretensioned single-tee concrete. By 1961, more than 20 buildings of similar construction had gone up; the Beverly Hills structure was the most famous of this group.

In 1954, in Tampa, Florida, the first prestressed-concrete companies joined forces to create the Prestressed Concrete Institute (PCI), which undertook research to expand the shapes, sizes, and capabilities of precast and precast prestressed concrete. This form of concrete was championed not only by Lin, but by Harry Edwards, the founder of Lakeland Engineering and Prestress, Inc. As a result of the work of Lin, Edwards, and others, precast prestressed concrete currently has approximately 45 percent of the market for freestanding parking garages.

During the second half of the 1950s, Edwards created the four-foot by 50-foot by 14-inch

(1.2-meter by 15-meter by 36-centimeter) double tee—which, because of its greater width and structural stability, became the industry standard. The double tee was eventually produced in widths from four to ten feet (1.2 to three meters) and in lengths from 30 to 120 feet (nine to 37 meters). The first double tees were topped with concrete; later designs did not require topping or were pre-topped at the factory. Among the many examples of garages constructed out of double tees are the Maryland Concert Center Parking Garage, in Baltimore; and the parking garage at Eppley Airfield, in Omaha.

PRECAST PRESTRESSED CONCRETE IN THE PARKING GARAGE.

At an office complex constructed in the 1960s for the Humble Oil and Refinery Company, in Houston, Texas, the precast prestressed tees used in the garage had a span of 63 feet (19 meters). The Phoenix Sky Harbor Airport Parking Structure and Terminal, built in 1965, was, at the time, the largest parking facility to rely entirely on precast prestressed concrete for both structural and architectural purposes. Atlanta’s First National Bank Garage, constructed in 1968, was a 700-car facility that spanned railroad tracks; it was built with precast prestressed, post-tensioned, and poured-in-place members. The precast Lin tees (single tees) used in the structure had a clear span of up to 52 feet (16 meters).

Even with the advent of the fully precast prestressed garage, many parking facilities continued to combine all the available methods of working with concrete. For example, the parking garage at Honolulu’s Ala Moana Center, built in 1964, combined precast prestressed concrete and composite cast-in-place concrete. Similarly, the Alcopark, constructed in Oakland, California, in 1963—an oval garage with inner and outer ramps and a 100-foot by 136-foot (30-meter by 41-meter) heliport pad on the roof—combined a double-tee beam structure and cast-in-place concrete.

The parking facility at the Michigan Bank National Association, built in Detroit in 1968, combined precast prestressed and cast-in-place post-tensioned concrete to create a rigid frame structure. The garage featured 94-foot- (29-meter-) long precast prestressed concrete columns and single tees. In an approach known as the Prescon system, the columns and the tees were post-tensioned together by means of tendons that had been precast into the single tees. The columns were post-tensioned after the slabs were in place, creating the rigid frame. (A rigid frame is one way of resisting structural loads, once grouting is complete.)

The Tridak Parking Structure, in New York, another example of the innovative use of concrete, included an architectural precast facade that enclosed the drainage and electrical systems for the structure. In the early 1970s, this construction technique was used on facades in a number of locations.

Garages constructed in the early 1970s at Boston’s Logan Airport and at Hancock Place, also in Boston, used a precast prestressed “pi” system, along with cast-in-place framing. (The pi system was so named because in cross section, the system resembled the Greek letter.) The pi system, which was invented by Othar Zaldastani of Nichols, Norton and Zaldastani, Inc., was created to address the fact that in single- or double-tee structures, cracks often developed because of insufficient thickness in the required concrete topping, allowing moisture to penetrate. The pi system eliminated the cracks by producing a new kind of joint.

At the Gary National Bank Parking Garage, a 317-car facility built in Gary, Indiana, in 1970, the columns and tee girders were precast prestressed concrete, and the six-inch- (15-centimeter-) thick elevated ramps were poured in place and post-tensioned. The tee girders were then tensioned to the vertical columns as well as to the spandrel walls. Movable form work was also used at the Gary garage, which increased efficiency by allowing the concrete to be poured in large sections.

A three-story precast prestressed garage built in 1972 in Quincy, Massachusetts, set a record: 569 precast prestressed concrete pieces were furnished in 43 working days, and the entire structure was built in eight months. In 1974, a new approach was used at the Baylor Hospital parking structure, in Dallas, Texas: precast concrete walls that included haunches to support the floor. Using this method, it is possible to construct solid walls or “lite walls” (walls with punched openings), either of which can act as shear walls.

By the mid-1960s, the modern parking structure was completely exposed to the weather—and, as a result, was closer, as a structural entity, to a bridge than to a building. However, it took some time for this transition to be fully reflected in both construction materials and design details. At approximately the same time, breakthroughs in precast prestressed concrete made it possible for parking garages to span functioning railroad tracks—and, eventually, highways. In other words, parking facilities began to literally function as bridges. In 1967, there was a proposal for a garage that would have spanned the Los Angeles freeway; such a structure was actually built over the streets of San Mateo, California. A portion of Boston’s Hancock Place Garage, built in 1972, straddles the Massachusetts Turnpike. In 1978, an air-rights garage was built over Tulsa’s loop highway. (As it became more and more difficult to find land for parking in many cities, air rights played an increasing role in parking.) Omaha has a downtown garage, built in 1961 and still in use today, that spans 100 feet (30 meters) over 17th Street.

In 1989, the Sarasota County Parking Garage, a 1,000-space, 300,000-square-foot (27,870-square-meter) parking garage was designed and erected in 16 months (with an unexpected two-month delay) entirely with precast construction. The unique elevator tower was a free-standing structure designed to withstand lateral forces, such as wind or earthquake loads, and functioned independently from the large shear walls. In 2001, the 11,500-car, $125 million Northwest Airlines Midfield Terminal parking structure, in Detroit, became the largest all-precast concrete parking structure ever built at one time. At the Denver International Airport, which was completed in 1991, K-frames (precast open space frames with steel cross-members) were used instead of solid shear walls, allowing the interior of the garage to remain open, for pedestrian safety.

In combination with double tees, precast frame systems are also used to resist lateral loads, in an approach that allows the integration of structure and facade. Because different framing systems are appropriate for various conditions, and the choice of framing system will, in turn, affect the appearance of the facade, parking structures built entirely of precast prestressed concrete offer new design strategies for the facade. The advantages—and increasing popularity—of precast prestressed parking structures were reflected in the fact that during a one-year period beginning in 2006 and ending in 2007, approximately 43 percent of garage construction starts used prestressed concrete exclusively; 11 percent were conventional cast-in-place structures; 34 percent were cast-in-place post-tensioned structures; 8 percent were steel; and 4 percent were hybrid structures (typically precast and post-tensioned). (Most freestanding garages are constructed of either precast prestressed concrete, post-tensioned concrete, or a combination of the two.)

Precast concrete allowed for greater quality control throughout the production process, yielding a product that was more resilient and less likely to degenerate in response to typical use. In the recent years, new research in connections for seismic risk, improve the precast diaphragms. New procedures as in the “Draft Seismic Design Methodology for Precast Concrete Diaphragms” guidelines are being studied and evaluated and are nearing completion to be updated in the International Building Code.[1]A recent innovation in precast pre-topped concrete, is a resin-bonded, carbon-fiber grid material that increases the resistance of precast concrete to corrosion, spalling, and cracking; the product allows double tees to be thinner and lighter, while providing better long-term performance. In structures that use carbon-fiber reinforced, conventional steel provides the primary reinforcement, while the new technology provides secondary reinforcement and shear transfer.

Today’s precast prestressed concrete is a factory-produced form that is designed to accommodate heavier loads and longer spans. Garages constructed entirely of precast prestressed concrete have many advantages: short construction time, reduced construction costs, and good quality control. Precast pieces may be columns, beams, shear walls, double tees, or spandrels: the elements are erected at the job site, in Tinkertoy fashion. (Small local companies, such as Iowa Prestressed Concrete, still provide their own systems for parking structures, which are based on simpler precast beams, columns, and slabs.) Because precast prestressed construction is exposed to wide variations in temperature and moisture level, as well as to vibration, the connections are crucial. Stainless steel or epoxy-coated hot-dipped galvanized steel is often used to mitigate corrosion. To ensure the greatest longevity for the structure, any field-applied coatings require complete surface penetration. Typically, the parking garage consists of a prestressed double-tee floor member bearing on a precast frame. The double tee can be pre-topped or field-topped, and sometimes no topping is used. The University of Iowa, in Iowa City, was the first to experiment with “untopped” concrete. In 1977, as part of a request from the university to reduce the cost of the hospital garage, a precast deck designed by Carl Walker, Inc., was constructed without a topping, which saved 39 percent on construction costs. The untopped approach is still in use today.

OTHER ISSUES IN CONCRETE CONSTRUCTION

Unusual requirements, such as sites that were extremely constrained, led to experimentation with new construction methods. For example, because the site of the Olympic Hotel parking garage, constructed in Seattle in 1964, was too small for the mobile cranes used to erect precast prestressed concrete, the 17-ton (15-metric-ton), 59-foot- (18-meter-) long pieces were erected by means of a portable bridge crane.

Lift-slab construction was also used at small sites. The height record for lift slabs was set in 1953, by the Tower Parking Garage, in Columbus, Ohio, a 14-level mechanized facility with lift slabs 88 feet (27 meters) above street level; construction required a temporary bracing tower. In the early 1960s, lift-slab construction was being explored at a number of locations around the country. The Park & Lock Garage, a six-level facility constructed in 1961 in Newark, New Jersey, for the Edison Parking Company, consisted of two continuous, overlapping spirals. It was the first parking garage in which lift-slab construction was used to create warped slabs (slabs that slope in two directions).

In many parts of the country—particularly in the San Francisco area—earthquake-resistant design is an important issue. At San Francisco's Downtown Center Garage, built in 1955, a prestressed concrete shear pylon was used in conjunction with reinforced poured-in-place rigid flat-slab construction. In this garage, the fact that the shear wall was placed within the large spiral corner ramp was crucial both to the stability and the usability of the structure.

Even in non-earthquake zones, shear walls are an important part of parking garage design. Although they contribute to structural stability, shear walls can interfere with sight lines and visual safety in self-park facilities. To address this issue, grout-filled steel sleeves have been used in precast moment-frame structures. (This approach was first used in the 1960s, in the Ala Moana project.) In 1972, precast prestressed concrete members were used in the San Bernardino Civic Center Garage, which is in a zone 3 earthquake area. In this structure, cast-in-place techniques were used to create a three-dimensional nonductile space frame with special joinery designed by Victor Gruen and Associates; these special joints provided the necessary stability for the shear walls to be eliminated. T.Y. Lin & Associates were the structural consultants for the facility, and Plumb, Tuckett and Hubbard were the consulting engineers and architects.

UNIT, PREFAB, AND DEMOUNTABLE PARKING GARAGE CONSTRUCTION

Unit, prefab, and demountable garages are all constructed from a kit of parts. In unit construction, multiples of one or two units are used to create the entire structure. In prefab construction, all the pieces are delivered to the site, ready to assemble. Demountable garages may be erected in various ways, but they are distinguished by the fact that they can be easily disassembled and moved to another site.

The first mention of a demountable garage—which happened to be constructed entirely of steel—was in a 1910 article entitled "Knock Down Garages." Such structures were occasionally referred to in publications of this era, and it is known that in 1915, a barrel-shaped demountable garage was constructed in Spokane, Washington. It was not until the 1950s, however, that efforts to save time and money, and to create longer spans, led to extensive research into nontraditional approaches to garage construction. In 1950, the Blaise Company opened a New Orleans parking garage, built by means of unit construction, that looked very much like a series of tables resting one on top of the other. In 1951, the Miami firm of L.G. Farrant and W.C. Harry, working as consulting engineers, developed a unit building design that reduced construction costs to $400 per space; the approach, which relied on a slab that was reinforced in such a way that it could be 1.5 inches (four centimeters) thick, instead of the typical 12 inches (30 centimeters), widened the possibilities for garage construction. Tierpark, a prototype constructed in 1960 by Tishman Research Corporation, of New York City, was created from precast prestressed concrete units—an approach that made it possible to limit per-space costs to between $1,200 and $1,500.

Unit, prefab, and demountable parking garage construction generally relied on “Tinkertoy” assembly or on a “box” approach (in this approach, the garage is constructed from the largest preassembled members that can be delivered by truck transport). The architect Paul Rudolph summed up these approaches by noting that “the 20th century brick measures 10 feet x 12 inches x 60 feet [three meters by 30 centimeters by 18 meters]”—which, in 1970, was the maximum dimension that most states would allow to be transported on state highways. To minimize the number of pieces that had to be moved, designers of unit, prefab, and demountable garages favor units that are as large as possible, and build decks to this maximum dimension.

THE STRUCTURAL AESTHETIC

One expression of 20th-century modernism was known as the structural aesthetic: this approach, which allowed structure to serve both a functional and an aesthetic role, was a perfect fit for the parking garage. Although the structural aesthetic yielded some parking garages that seemed to go on forever, such large and imposing structures often worked well within the spacious, automobile-generated suburban landscape. The structural aesthetic was less compatible, however, with older urban settings.

An appealing example of the structural aesthetic can be found in the parking structure at Cleveland’s Mt. Sinai Hospital: a column shape, repeated with its mirror image, was used to create a pleasing rhythm on the facade. At the seven-level Crown Street Garage, in New Haven, Connecticut, tree columns—single pieces that were 93 feet (28 meters) long and weighed 41 tons (37 metric tons) each—created both structural integrity and a distinctive pattern on the facade. This facility was constructed of single-tee beams and had a cast-in-place spiral ramp. Both the tree columns and the floor tees were exposed, creating a rhythm on the facade.

The hospital parking ramp constructed in 1968 at the University of Iowa, in Iowa City, offers another example of the merger of structure and aesthetics. On the facade of this facility, the precast reinforced columns support the precast spandrels by means of a limblike hook. The combination of exterior columns and exposed supports yield a clean yet compelling facade.

At a parking structure built in 1977 for the city of Rock Island, Illinois, the goal was to use the structural elements—in this case, precast prestressed Vierendeel trusses—to provide the facade with architectural character and a pleasing visual rhythm. As one contemporary observer noted, in the case of the garage, unlike that of other commercial buildings, "use of ornamental skin in general makes the design of a parking structure heavy, expensive and unjustifiable."

A more recent successful effort to use precast concrete as both skin and structure garnered the Prestressed Concrete Institute's 1994 Harry H. Edwards award for advancing the use of this approach. At the United Services Automobile Association building, in Tampa, Florida, both the office structure and the parking facility were based on the same five-foot (1.5-meter) grid, creating a handsome combination. A load-bearing ladder-wall system on the facade provided the structure for the pre-topped concrete double-tee floor. Inside, standard pretopped double tees were supported by a second ladder-wall system. Spillis, Candela & Partners were the project architects, Walter P. Moore was the engineer, and Coreslab was the precaster. [2] (All text up to this point excerpted from the book *The Parking Garage: Design and Evolution of a Modern Urban Form*, Chapter Six: Exploring Structure and Material)

FUTURE

Parking garages are again at the forefront of design and the precast/prestressed industry has the opportunity to shape/re-shape its future. Creating new shapes and forms to meet the complex challenges of today will allow for new sustainable solutions. A simple curved form of lightweight material added to the underside of a precast double tee would redirect light downward and outward. A student at the University of Nebraska envisioned this simple concept to lower lighting costs inside of the garage while providing greater light for the users

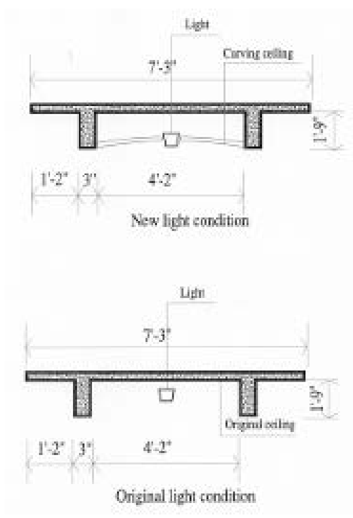

Fig. 2 Added shape to double-tee to improve lighting

of the parking facility. Another advantage of this simple idea would allow an up-lighting source to be mounted tighter to the underside of the double–tee allowing for greater height clearances. This is one step toward the future. (Figure 2)

New mobility devices, all of different scales and speeds, will soon need a place to park. The basic parking space can now transform in size and shape. The structural grid that has given it form can find a new way to engage. One of the current trends is mixing habitable spaces with parking spaces and this can produce new shapes and forms such as in the Herzog and DeMueron Miami Beach parking facility, 1111 Lincoln Rd, just recently completed. Efficiently integrating these new mobility devices along with pedestrian movement provides new challenges in design and layout.

CONCLUSIONS

The unit is a key design element in architecture and construction. The Precast/Prestressed concrete industry has the most design flexibility in meeting the challenges of new unit design to take advantage of the emerging architectural and planning strategies of integration of uses. Along with aesthetics and multi- functionality – parking that is more than parking – value will be the key word going forward. The Precast/Prestressed parking industry is poised to be the " better value" by remaining flexible, innovative and working collaboratively with other professionals by going back to its roots in unit design creating modern unit systems.

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